# Hector’s and Māui dolphin Toxoplasmosis Science Plan 2021

## Contents

## Summary

The Hector's and Māui dolphin Toxoplasmosis Science Plan provides a framework for all researchers and government agencies to understand, guide investment, and give effect to the priority needs for research for the management of *T. gondii* and the disease toxoplasmosis, particularly to address the urgent need to reduce the risk from the parasite to Māui dolphins.

*T. gondii* is an exceptionally widespread parasite, with multiple pathways for infection, and an associated highly complex disease to manage.

This plan demonstrates the need to coordinate research activities amongst government agencies and other research providers to address knowledge gaps to inform management of the parasite in terrestrial, freshwater, and marine systems due to the origin, distribution, and transmission pathways of the parasite through the environment.

With such a range and complexity of disciplines, authorities and stakeholders, coordination is the priority. To coordinate the primary research to take action it is recommended to:

- Run workshops bringing together the different domains to determine how different agencies, partners, and stakeholders can contribute to priority research, and identify and prioritise social science research questions to aid in the direction and further guidance of research and the implementation of solutions.
- As part of the workshops determine how best to coordinate research and priority actions.

The priority research needed to take action are:

- *Improve understanding of the parasite in the dolphins through recovery of dead bodies for necropsy.*
- *Develop tools for the detection and quantification of oocysts in the environment, particularly in aquatic systems, and conduct spatial analyses to identify spatial and temporal 'hot spots'.*
- *Improve knowledge of feral and domestic cat populations – abundances, distribution, their relative oocyst shedding rates, and genotypes of T. gondii they carry.*
- *Develop appropriate tools to manage the different cat category populations at different scales.*
- *Improve understanding of feral and domestic cats and their pest prey to improve management for controlling the T. gondii parasite*
- *Develop an understanding of the total economic burden of Toxoplasmosis to New Zealand*

## Purpose

The Toxoplasmosis Science Plan 2021 has been developed to:

- Support the Government's vision that New Zealand's Hector's and Māui dolphin populations are resilient and thriving throughout their natural range;
- Support the long-term goal of ensuring Hector's and Māui subpopulations are thriving or increasing, supported by an enduring, cohesive, and effective threat management programme across New Zealand;
- Improve knowledge of the threat to Hector's and Māui dolphins, and other New Zealand wildlife from the parasite *Toxoplasma gondii* and what is required to reduce the risk to the dolphins to near zero; and
- Identify and prioritise new research and management measures, to inform management responses to the threat to the dolphins of infection with the parasite *Toxoplasma gondii*.

# Context

## Hector's and Māui dolphins

Hector's and Māui dolphins are small coastal dolphins found only in New Zealand waters. Hector's dolphins were gazetted in 1999 as a threatened species under the Marine Mammals Protection Act 1978 (MMP Act). Since 2002, Hector's dolphin (*Cephalorhynchus hectori hectori)* and Māui dolphin (*C. h. maui*) have been designated as separate sub-species in recognition of the genetic and morphometric differences between the populations. Hector's dolphins live almost exclusively around the South Island and Māui dolphins are only found on the west coast of the North Island.

## Status of Hector's and Māui dolphins

Hector's dolphin is ranked as *Nationally Vulnerable* under the New Zealand Threat Classification System[1] with an overall population estimated to consist of around 15,000 individual dolphins[23]. Māui dolphin is ranked *Nationally Critical* under the NZTCS[1]. The latest population estimate is similar to previous estimates with 54 individuals above 1 year of age (95% confidence interval = 48-66 dolphins) within the survey area[4]. Current population trends are uncertain for both the small Māui dolphin population and populations of Hector's dolphins, but both may be significantly reduced by human induced impacts. Due to their very low population size Māui dolphins remain particularly vulnerable to any human-induced deaths.

## Toxoplasmosis

The potentially fatal disease toxoplasmosis is caused by the unicellular protozoan parasite *Toxoplasma gondii*. *Toxoplasma gondii* is a globally widespread protozoan parasite that can infect all bird and mammal species. Cat species (Felidae) are the only known definitive host for *T. gondii* and therefore this parasite would have been absent from Aotearoa/New Zealand prior to the introduction of the domestic cat (*Felis catus*) in the 18th century[5]. The parasite reproduces sexually in the gut of the cat and is spread through the cat's faeces as oocysts ('eggs'). These oocysts remain infective in soil and freshwater for at least 2 years, and in seawater for at least 6 months. Birds and mammals can become infected with *T. gondii* by ingesting contaminated soil, water, plant material or infected prey species. The environmentally robust nature of toxoplasma oocysts, the potential for infection across a wide range of species (including humans, domestic and wild animals), and widespread distribution of the definitive hosts (companion (pet) and unowned (stray and feral) cats), means that *T. gondii* is an exceptionally widespread parasite, with multiple pathways for infection, and an associated highly complex disease to manage.

Toxoplasmosis can be fatal in many species including humans, sheep, and dolphins. There are two main ways that dolphins can become infected. The first is by ingesting oocysts (the 'egg' stage of the parasite), most likely in filter-feeding prey. The oocysts rupture in the gut of the dolphin, releasing unicellular sporozoites (the mobile form of the parasite) that enter the lymphatics and bloodstream of the dolphin. From there they spread to many tissues where they either multiply rapidly and destroy

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[1] https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs29entire.pdf
[2] MacKenzie, D.I.; Clement, D.M. (2014). Abundance and distribution of ECSI Hector's dolphin. New Zealand Aquatic Environment and Biodiversity Report No. 123. 79 p
[3] MacKenzie, D.I.; Clement, D.M. (2016). Abundance and distribution of WCSI Hector's dolphin. New Zealand Aquatic Environment and Biodiversity Report No. 168. 67 p + supplemental material
[4] https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/maui-hectors-dolphins/maui-abundance/maui-dolphin-abundance-2021.pdf
[5] Roberts, J. O., Jones, H. F. E., & Roe, W. D. (2020). The effects of Toxoplasma gondii on New Zealand wildlife: implications for conservation and management. Pacific Conservation Biology. https://doi.org/10.1071/PC20051.

vital tissues such as the liver and lung, resulting in death, or they invade individual cells in the brain, nervous tissue and muscles and form dormant tissue cysts (latent infections). The second mechanism of infection is known as vertical transmission, where the parasite moves from the bloodstream of a pregnant female, across the placenta and into the foetus, where they can cause foetal death (abortion or stillbirth), congenital defects, or latent infection of the calf. Latent infections may cause behavioural changes that may increase the risk of mortality from other means. Infection with *T. gondii* has been linked to changes in risk taking behaviour in intermediate hosts (including humans), it is speculated that this may lead to increased vulnerability to predation and possibly entanglement in fishing gear from behavioural changes in the dolphins. Dormant tissue cysts can also become reactivated when an animal is under stress or is immunocompromised, releasing large numbers of rapidly multiplying parasites into the bloodstream and causing severe or fatal disease.

As described above, for small cetaceans like Hector's and Māui dolphins the disease can potentially cause both direct death of the infected animal, loss of the next generation through vertical transmission (passing the parasite from mother to baby before birth), and various potential sub-lethal affects.

In New Zealand, the effects of toxoplasmosis on livestock have long been well understood and are typically managed for sheep in New Zealand by vaccination (Toxovax[tm]). Information on the human health implications of the disease, at least with regards to pregnant or immunosuppressed individuals, is widely available, but it has only recently been identified as a threat to New Zealand native wildlife; in particular, Hector's and Māui dolphins[6].

DOC sends every dead Hector's or Māui dolphin that is recoverable and in a suitable state for necropsy to be examined by veterinary pathologists to identify cause(s) of death. It is because of this necropsy programme that toxoplasmosis was first identified as a cause of death in the dolphins. Of the deaths that were not fishing related, toxoplasmosis was identified as the primary cause of death in 29% of the non-calf dolphins examined between 2007 and 2018 (9 of 31 dolphins; 7 of these were female, of which 6 were mature females). To date, all of the dolphins determined to have died from toxoplasmosis were found in spring months, when there is a highly significant bias in carcasses washing up on beaches[7].

Although the sample size is small, these toxoplasmosis related mortalities were not clustered in time (with deaths from toxoplasmosis recorded in 7 out of 12 years with reliable data) or space, as the parasite has been detected in Hector's and Māui dolphins from multiple locations around New Zealand. Two toxoplasmosis-related deaths were from the west coast of the North Island (Māui dolphin habitat), five from the east coast of the South Island and two from the west coast of the South Island. About 60% (17 of 28) of Hector's and Māui dolphins tested were found to have evidence of infection with *T. gondii* through detection of the parasite's DNA using polymerase chain reaction (PCR) in dolphin tissues. While the level of *prevalence for T. gondii* found in examined dead dolphins may not be representative of the whole population, it represents latent or chronic infection, and gives an indication of the likely magnitude of exposure to *T. gondii*.

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[6] Roe WD, Howe L, Baker EJ, Burrows L, Hunter SA (2013) An atypical genotype of *Toxoplasma gondii* as a cause of mortality in Hector's dolphins (*Cephalorhynchus hectori*). Vet Parasitol 192:67–74

[7] https://www.mpi.govt.nz/dmsdocument/42431-AEBR-248-Characterisation-of-Hectors-and-Maui-dolphin-Cephalorhynchus-hectori-incident-data-focusing-on-temporal-patterns

Beyond the impacts identified for Māui and Hector's dolphins, toxoplasmosis has also caused the deaths of other native species [8], including kākā (*Nestor meridionalis*), red-crowned kākāriki (*Cyanoramphus novaezelandiae*), kererū (*Hemiphaga novaeseelandiae*) and several kiwi species (*Apteryx spp.*)[8].

There are multiple genotype strains of the *T. gondii* parasite worldwide, however, currently all fatal New Zealand wildlife cases (including Hector's and Māui dolphins) that have been successfully genotyped were the variant Type II 'ToxoDB#3'representative strain[8]. The predominance of the ToxoDB#3 strain implies either that this is the dominant genotype present in New Zealand, or that this genotype is particularly virulent in native species. Research at Massey University has demonstrated that genotypes other than ToxoDB#3 are present in New Zealand, but the relative prevalence and host distribution of these genotypes is unknown.

## The Threat Management Plan

The overall strategic direction for biodiversity in Aotearoa New Zealand for the next 30 years is provided in Te Mana o Te Taiao - The New Zealand Biodiversity Strategy. This provides the overarching direction and guidance to related strategies and work programmes, of which the Hector's and Māui Dolphin Threat Management Plan (TMP)[9] is one.

Anthropogenic threats to Hector's and Māui dolphins are managed under the Hector's and Māui Dolphin TMP, jointly administered by the Department of Conservation (DOC) and Fisheries New Zealand (part of the Ministry for Primary Industries). Of the anthropogenic threats that we have information about mortality rate, the main threats to the dolphins are likely to be commercial fishery captures and the parasitic disease toxoplasmosis, as the parasite *T. gondii* is only present in New Zealand because of the human introduction of cats.

Following the most recent review of the TMP, in 2020 Ministers agreed a set of population outcomes to allow the dolphins to recover from historical impacts and thrive in the future. Ministers also agreed to a set of objectives and management actions to reduce threats to the dolphins from fishing, toxoplasmosis, seismic surveying, and seabed mining, in order to meet the population outcomes of the TMP.

Fishing-related threats have generally been sufficiently addressed to meet the fisheries objectives set within the TMP and help meet the populations outcomes agreed by Ministers in 2020, with some further fisheries management measures for the South Island Hector's dolphins currently being publicly consulted on (at time of writing). For Māui dolphins, set-net closure areas increased from 6,850 $km^2$ to 15,025 $km^2$, and trawl closure areas (including harbours) increased from approximately 4,409 $km^2$ to 5,837 $km^2$. This effectively reduces the estimated level of risk to Māui dolphins from fishing-related deaths to close to zero.

Seismic surveying and seabed mining were largely prohibited in the marine mammal sanctuaries created to protect the dolphins.

During the TMP review it became clear that, although there remain divergent views on impact and best mitigation options, the greatest remaining unmanaged anthropogenic threat to Hector's and

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[8] Roberts, J. O., Jones, H. F. E., & Roe, W. D. (2020). The effects of *Toxoplasma gondii* on New Zealand wildlife: implications for conservation and management. *Pacific Conservation Biology*. https://doi.org/10.1071/PC20051.

[9] https://www.doc.govt.nz/our-work/protecting-species/protecting-marine-species/our-work-with-maui-dolphin/hectors-and-maui-dolphin-threat-management-plan/

Māui dolphins is the parasitic disease toxoplasmosis. It is a confirmed primary cause of death[10][11] for both dolphin subspecies, and a particular problem for Māui dolphin, because of their small population size and the impact this disease can have on reproductive success.

In response to this threat, a Toxoplasmosis Action Plan[12] was developed with the long-term goal:

*By 2035, reduce toxoplasma loading to the marine environment so that the number of dolphin deaths attributable to toxoplasmosis is near zero*.

### Guiding policies and legislative framework

The TMP is guided by the responsibilities and legislative frameworks of DOC and Fisheries New Zealand. DOC is the leading central government agency responsible for the conservation of New Zealand's natural and historic heritage, which includes Hector's and Māui dolphins. Fisheries New Zealand is responsible for managing fisheries and their effects on protected species. Regional councils provide for the protection of the habitats of indigenous fauna and flora under the Resource Management Act 1991. There are several policies and pieces of legislation that guide agencies' responsibilities, which are outlined in Appendix 1.

## Science plan development

Research on Hector's and Māui dolphins and the threats impacting them is crucial to ensuring the actions implemented under the TMP and associated plans are appropriate and lead to subpopulations thriving and recovering.

This Hector's and Māui dolphin Toxoplasmosis Science Plan has been developed to coordinate research activities amongst government agencies and other research providers to enable the achievement of the goals and objectives of the TMP for Hector's and Māui dolphins. While the TMP is focused on the dolphins, many of the research needs presented in this Toxoplasmosis Science Plan fall within other strategies and governance structures that manage terrestrial threats and freshwater systems due to the origin, distribution, and transmission pathways of the parasite through the environment, and yet are fundamental to fulfilling the goals and objectives of the TMP.

### Collaborative science planning

To ensure that an effective management process for toxoplasmosis is based on robust information and evidence-based decision-making, three science planning research workshops were held with experts invited from New Zealand and overseas. The workshops focused on understanding the disease in the dolphins and the factors that influence their exposure to this parasite.

The objectives of the workshops were to engage across disciplines to:

- determine the key knowledge gaps;
- identify realistic tools and methods to fill these gaps; and
- prioritise research to best inform management of toxoplasmosis for the dolphins.

[10] Roberts, J.O.; Webber, D.N.; Roe, W.D.; Edwards, C.T.T.; Doonan, I.J. (2019). Spatial risk assessment of threats to Hector's and Māui dolphins (Cephalorhynchus hectori). New Zealand Aquatic Environment and Biodiversity Report No. 214. 168 p.

[11] Roe, W.D.; Howe, L.; Baker, E.J.; Burrows, L.; Hunter, S.A. (2013). An atypical genotype of Toxoplasma gondii as a cause of mortality in Hector's dolphins (Cephalorhynchus hectori). Veterinary Parasitology 192: 67–74.

[12] https://www.doc.govt.nz/globalassets/documents/conservation/threats-and-impacts/toxoplasmosis/toxoplasmosis-action-plan.pdf

As the parasite has terrestrial origins with cats as the definitive host, many of the themes, questions and subsequent priority actions involve the environmental transmission pathways for the parasite to the marine environment (e.g., river catchments, stormwater, and wastewater) and understanding the characteristics and distribution of the parasite in cats, pest prey species and the environment within a New Zealand context.

## Research themes

The workshop established the following themes to capture and prioritize research questions:

1. Magnitude of the risk from toxoplasmosis in Hector's and Māui dolphins.
2. Risk factors for *T. gondii* infection in Hector's and Māui dolphins (i.e., what increases the risk?).
3. Understanding the *T. gondii* genotypes: presence, distribution, and prevalence in New Zealand and the genotype(s) fatal to dolphins.
4. Understanding cats and their role in the spread of *T. gondii* and the opportunities for management.
5. Characterising and monitoring potential control/mitigation methods and broader questions to support management of the parasite *T. gondii* .

## Prioritisation

Each theme was worked through to deliver a list of research questions, and these were prioritised by workshop participants (Table 2. Appendix 2). To help with prioritisation consideration was given to whether data and methods already exist to tackle the questions.

It was recognised, however, that management efforts to reduce *T. gondii* loading to the marine environment will require broader socialisation of some management ideas, particularly with respect to issues around cat management. Many social aspects could be at play, including social norms around cat ownership, and views around what is responsible for the decline of Māui and Hector's dolphins. These human dimensions and the issues of psychological distance, social license, and behaviour change, means that many of these questions will require further review through a social science lens. This is a complex issue and leaping straight into management may be detrimental to the objectives of protecting the dolphins.

## Priority research

The priority research needed to take action are listed by theme in Table 1. The priority research was determined by workshop participants through the ranking of questions within each theme, considering the factors above.

Table 1.

| Theme | Priority research |
|---|---|
| **1. Magnitude of the risk of toxoplasmosis in Hector's and Māui dolphins?** | *Improve understanding of the parasite in the dolphins through recovery of dead bodies for necropsy.* |
| **2. Risk factors for *T. gondii* infection in Hector's and Māui dolphins. What increases the risk?** | *Develop tools for the detection and quantification of oocysts in the environment, particularly in aquatic systems, and conduct spatial analyses to identify spatial and temporal 'hot spots'.* |
| **3. Understanding the *T. gondii* genotypes: presence, distribution, and prevalence in NZ and the genotype(s) fatal to dolphins** | *Increase knowledge of T. gondii genotypes in the New Zealand context – particularly within the Waikato and Manukau catchments, and coastal environment (including infective prey).* |
| **4. Understanding cats and their role in the spread of *T. gondii* and the opportunities for management** | *Improve knowledge of feral and domestic cat populations – abundances, distribution, their relative oocyst shedding rates, and genotypes of T. gondii they carry.* |
| | *Develop appropriate tools to manage the different cat category populations at different scales.* |
| | *Improve understanding of feral and domestic cats and their pest prey to improve management for controlling the T. gondii parasite* |
| **5. Characterising and monitoring potential control/mitigation methods and broader questions** | *Develop an understanding of the total economic burden of Toxoplasmosis to New Zealand* |

## Rationale for priority research

***Improve understanding of the parasite in the dolphins through recovery of dead bodies for necropsy.***

The questions of highest priority directly related to the disease in the dolphins are reliant on the necropsy programme that DOC funds. Expanded protocols for the examination of other marine mammal species are being progressed to consider the viability of using proxy species to increase sample size to better understand distribution, genotypes, and hotspots for the parasite.

Other research on Hector's and Māui dolphins has been developed through a separate science process[13]. Some of the results of this other science will also be applicable to understanding the risk to the dolphins from exposure to infection with the *T. gondii* parasite through understanding the distribution of the dolphins and their prey within their environment and how these distributions overlap with hotspots for the oocysts.

[13] https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/maui-hectors-dolphins/2021-hectors-and-maui-5-year-research-plan.pdf

***Develop tools for the detection and quantification of oocysts in the environment, particularly in aquatic systems, and conduct spatial analyses to identify spatial and temporal 'hot spots'.***

To be able to identify "hotspots" of *T. gondii* contamination in marine and freshwater environments from priority catchment areas, and to better understand the required scale and where to target management. This would also crucially allow the testing of the efficacy of management interventions to reduce the loading of the *T. gondii* parasite to these systems, e.g., through planting of riparian margins in key areas.

***Increase knowledge of T. gondii genotypes in the New Zealand context – particularly within Waikato River and Manukau Harbour catchments, and coastal environments (including in infective prey).***

Genotyping of *T. gondii* strains of different cat populations (i.e., by location or ownership status) to identify cat populations shedding *T. gondii* strains that are known to be lethal to the dolphins. This is fundamental to be able to target management interventions at local scales, and to trial targeted management in areas that will contribute most to reducing threats to the critically endangered Māui dolphin population.

Genotyping of *T. gondii* strains within sentinel species within transport pathways, may also enable better localisation for management interventions, without directly sampling cats.

***Improve knowledge of cat populations – densities, distribution, their relative oocyst shedding rates, and genotypes of T. gondii they carry.***

The National Cat Management Strategy Group recommends that the following cat population categories provide the basis for a management framework:

- Feral cats; and
- Domestic cats;
    - Companion (owned) cats; and
    - Stray cats;
        - Socialised stray cats (managed and unmanaged); and
        - Unsocialised stray cats (managed and unmanaged).

Cat densities have been used as a predictor of oocyst loading to the environment, with higher densities reflecting higher loadings. However, not all populations of cats contribute equally to oocyst loading into the environment. Understanding the distribution, abundances, and densities, of the different cat populations (feral, companion, unsocialised and socialised stray cats), and the rate of shedding of oocysts for each of those groupings will help inform models to predict areas to target management responses, and the types of response that may be required.

***Develop appropriate tools to manage the different cat category populations at different scales.***

Different strategies, approaches and tools will be required to manage the different categories of cat, relevant to each category and at different scales.

Currently available tools for the management of feral cats are limited and resource intensive, restricting actions in both time and space, with different agencies having responsibility depending on the land tenure. New tools are being tested, however some of these may not be suitable for landscape scale application on the New Zealand mainland. Additional tools, therefore, will be required to be developed which are environmentally safe, humane, socially acceptable and fit-for-purpose for managing feral cats at different scales.

Efforts to reduce *T. gondii* loading at the source through management of oocyst shedding to the environment, transfer to waterways, and ultimately to the marine environment will require socialisation of ideas, particularly with respect to issues around cat management. Different sets of tools and approaches will be required for the management of each of the cat categories, with responsibilities lying with various agencies. There will be a need for consideration for the development of social license and communication strategies to support needed actions.

***Improve understanding of feral and domestic cats and their pest prey, and other food sources, to improve management for controlling the T. gondii parasite***

While cats are the only definitive host for the parasite, and therefore are the only animals that can shed oocysts, any warm-blooded animal can be an intermediate host. Rabbits, invertebrates, birds, and to a lesser extent mice and lizards are the most common prey of feral cats, whereas birds, rats, and mice, are the most common prey of domestic cats in New Zealand[14]. Some of these prey populations, particularly rodents and rabbits, may cause the parasite to persist in areas, allowing new cats to that area to become infected through eating infected prey.

Companion cats or strays may also become infected by being fed raw meat infected with the parasite. Building awareness, and shifting the behaviour of cat carers, will be important to address this issue

Current research at Manaaki Whenua – Landcare is investigating a possible mechanism to reduce *T. gondii* parasite loadings in an area by simultaneously reducing pest prey species and cats. The elimination of the parasite may be achieved in an area with increased reduction in levels of pest prey species at lower levels of cat depopulation.

***Develop an understanding of the total economic burden of toxoplasmosis to New Zealand***

An economic study of this nature would identify the broader issues caused by *T. gondii* across sectors and the cost burden to New Zealand as a whole. This would likely include costs associated with human health impacts from toxoplasmosis, alongside impacts on livestock and associated industry.

A study of this type would increase awareness of the impacts of the parasite and may identify further collective need to act to reduce or eliminate *T. gondii* loading to the environment and influence broader support for greater coordination of actions that could in turn benefit the dolphins.

## Next Steps

The urgent need is to reduce the risk to Māui dolphins from the disease toxoplasmosis. Targeted research is currently being undertaken and planned for the dolphins, however much of the research and many of the possible management strategies cross multiple domains (i.e., terrestrial, freshwater, and marine), multiple specialities (e.g., genetics, epidemiology, pest management, behavioural change) and multiple formal jurisdictions/responsibilities. Management efforts to reduce *T. gondii* loading to the marine environment will require contributions from across all these different domains

[14] Craig Gillies – Presentation to Toxoplasmosis workshop Oct 2020

to different degrees. With such a range and complexity of disciplines, authorities and stakeholders, coordination is the priority.

Actions taken to reduce the loading of *T. gondii* to the environment are likely to confer wider benefits to conservation beyond the protection of the dolphins.

The recommended next steps:

- Run workshops bringing together the different domains to determine how different agencies, partners, and stakeholders can contribute to priority research, and identify and prioritise social science research questions to aid in the direction and further guidance of research and the implementation of solutions.
- As part of the workshops determine how best to coordinate research and priority actions.

The Toxoplasmosis Science Plan should be a guide to research priorities that will be most valuable to gain the knowledge required to inform management. The Science Plan aims to ensure that the research undertaken is coordinated, focused on agreed research needs, and accounts for the multitude of disciplines.

## Mechanisms for delivery of research priorities

The Hector's and Māui dolphin Toxoplasmosis Science Plan provides a framework for all researchers and government agencies to understand research priorities required that will contribute to the strategic goal of the Threat Management Plan: "*By 2035, reduce toxoplasma loading to the marine environment so that the number of dolphin deaths attributable to toxoplasmosis is near zero.*"

Scientists, research teams and government organisations should use this plan to guide investment into research based on the plan priorities. The research required spans from fundamental to applied research and experimental development of tools and approaches for management.

Funders should use this plan to understand and give effect to the priority needs for research for the management of *T. gondii* and the disease toxoplasmosis. Researchers can refer to this plan to demonstrate to potential funders how their proposed research will be impactful and aligned with government priorities.

# Appendices:

## Appendix 1: The legislative framework

The table below lists legislative and policy frameworks guiding DOC and MPI in the development of the Hector's and Māui dolphin Threat Management Plan 2020 and associated research strategies.

| **Legislative/ policy framework** | **Guiding principles** | **Relevant agency/ies** |
|---|---|---|
| The Wildlife Act 1953 | Provides for the protection of all absolutely protected wildlife throughout New Zealand and New Zealand Fisheries Waters. This Act lays out wildlife that is whole or partially protected and restricts hunting, killing or possession of wildlife unless under specified conditions. It also gives the Minister of Conservation the ability to designate Wildlife Sanctuaries within which specified activities can be regulated or restricted. | DOC |
| Marine Mammals Protection Act 1978 (MMPA) | To make provision for the protection, conservation, and management of marine mammals within New Zealand fisheries waters (the Territorial Sea and EEZ). Two key tools within the MMPA are:<br>• Marine Mammal Sanctuaries – an area designated by the Minister of Conservation within which specified activities can be regulated or restricted.<br>• Population Management Plans – a management plan that sets maximum allowable human-induced mortality, and maximum allowable fishing-related mortality. | DOC |
| Convention on International Trade in Endangered Species (CITES) implemented through Trade in Endangered Species Act 1989 | The object of this Act is to enable New Zealand to fulfil its obligations under the Convention on International Trade in Endangered Species of Wild Fauna and Flora and to promote the management, conservation, and protection of endangered, threatened, and exploited species to further enhance the survival of those species. Therefore, no person shall trade in any specimen of an endangered, threatened, or exploited species into or from New Zealand, unless under an appropriate permit or certificate. In addition, the Act gives the Minister of Conservation the following powers:<br>(a) to conduct research and investigations into and surveys of species in New Zealand—<br>(i) that are, or are likely to become, threatened with extinction; or<br>(ii) the existence of which is likely to be affected,— by trade in specimens of those species:<br>(b) to disseminate information relating to the import and export of endangered, threatened, and exploited species. | DOC |
| Conservation Act 1987 (CA) | New Zealand's principal Act concerning the conservation of indigenous biodiversity and promotes the conservation of New Zealand's natural and historic resources. It sets out the functions of DOC and the management of public conservation land in New Zealand. | DOC |
| Resource Management Act 1991 (RMA) | Part 2, Purpose, and principles<br>• To promote the sustainable management of natural and physical resources… including safeguarding the life-supporting capacity of air, water, soil, and ecosystems (s 5(b)).<br>• Recognise and provide for…the protection of areas of… significant habitats of indigenous fauna (s 6(c)).<br>• Have particular regard to…intrinsic values of ecosystems (s 7(d)).<br>**New Zealand Coastal Policy Statement (NZCPS)**<br>It is mandatory to have at least one in place at all times (s 57(1)) – NZCPS 201o is the current policy statement[11].<br>• The Minister of Conservation is required to prepare, monitor, and review the NZCPS. | MfE<br>DOC<br>Local authorities |

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|---|---|---|
| | • The Minister of Conservation also approves regional coastal plans developed by regional councils and unitary authorities.<br>• Local Authorities are required to give effect to the NZCPS in their Regional Policy Statements, Regional Plans and District Plans (sections 62(3), 67(3)(b) and 75(3)(b)). Local authorities must also have regard to the NZCPS when assessing consent applications. (Section 104(1)(b)(iv))<br>• A number of policies within the NZCPS are relevant to the protection of Māui dolphins (e.g.,).<br>• Policy 7 – Strategic planning<br>• Policy 11 – Indigenous biological diversity<br>• Policy 13 – Preservation of natural character<br>• Policy 14 – Restoration of natural character<br>• Policy 21 – Enhancement of water quality | |
| New Zealand Coastal Policy Statement | Local Authorities (Regional, Unitary, City and District) must give effect to the NZCPS in their regional policy statements and plans.<br>Regional Coastal plans (mandatory in all regions) can:<br>• Include objectives, policies, and rules<br>• Can include spatial planning, e.g., zoning | Local authorities |
| Marine Mammals Protection Regulations 1992 (MMPR) | Provide a regulatory framework for behaviour around all marine mammals and a permitting regime for commercial tourism. | DOC |
| The Fisheries Act 1996 (FA) | • Purpose of the FA<br>• Environmental principles (section 9)<br>• Information principles (section 10)<br>• Sustainability measures (section 11)<br>• Avoid, remedy, or mitigate the effect of fishing-related mortality on any protected species (section 15(2)) | MPI |
| The Animal Welfare Act 1999 (AW) | • Purpose of the AW<br>• Parts therein. | MPI |
| Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy (ANZBS) 2020 | provides the overall strategic direction for biodiversity in Aotearoa New Zealand for the next 30 years. It provides overarching direction and guidance to related strategies and work programmes, of which the Hector's and Māui Dolphin TMP is one.<br>Four of the five ANZBS outcomes align directly with the vision, goals, and objectives of the TMP:<br>• Outcome 2: Indigenous species and their habitats across Aotearoa New Zealand and beyond are thriving.<br>• Outcome 3: People's lives are enriched through their connection with nature.<br>• Outcome 4: Treaty partners, whānau, hapū and iwi are exercising their full role as rangatira and kaitiaki.<br>• Outcome 5: Prosperity is intrinsically linked with a thriving biodiversity. | DOC |

## Appendix 2: Priority research questions by theme: Table 2.

| Theme / Priority | Importance of the risk of toxoplasmosis in Hector's and Māui dolphins? | Risk factors for *T. gondii* infection in Hector's and Māui dolphins? What increases the risk | Understanding the *T. gondii* genotypes: presence, distribution, and prevalence in NZ and the genotype(s) fatal to dolphins | Understanding cats and their role in the spread *of T. gondii* and the opportunities for management | Characterising and monitoring potential control/mitigation methods and broader questions |
|---|---|---|---|---|---|
| 1 | *How can we improve confidence in our current estimate of the prevalence of fatal toxoplasmosis in this species?* | *Are there temporal or spatial hotspots for oocyst contamination?* | *What is the distribution and prevalence of the T. gondii genotypes in different cat populations and groupings (Feral, unsocialized strays, socialized strays, and companion cats)?* | *What are the current population abundances and densities of different categories of cat (i.e., feral, unsocialised stray, socialised stray, companion ), particularly in catchment areas that flow to Māui dolphin habitat?* | *What is the total economic burden of Toxo on NZ?* |
| 2 | *What percentage of dolphins are infected?* | *What do the bioaccumulation pathways look like in NZ waters?* | *What is the distribution of the T. gondii genotypes and prevalence in different cat prey species?* | *Are there differences in prevalence, shedding rates or genotypes of T. gondii present in different cat populations?* | *Can we develop a Spatial analysis/ spatial database to inform targeted effort by pulling together modelling from the other streams of research such as hydrographic/hydrological models, cat population densities, parasite genotype distribution, and other factors into a GIS tool at sub catchment scale?* |
| 3 | *Is there a true female bias in dolphin deaths?* | | *What is the human health impact of T. gondii in New Zealand?* | *How do pest ("prey") populations contribute to the distribution and concentration of infection in cats?* | *How could we do better health screening for Hector's and Māui dolphins?* |

| | | | | | |
|---|---|---|---|---|---|
| **4** | *What other factors contribute to deaths of dolphins from toxoplasmosis?* | | *How do we detect and quantify the loadings of T. gondii oocysts in freshwater systems?* | *Are cat vaccines possible?* | *Are there other emerging diseases and health threats? (What is the next toxoplasmosis?)* |
| **5** | *What are the sub-clinical impacts?* | | *What is the prevalence of T. gondii in other marine mammal species?* | *What scale of management is important?* | *How do we measure the success of various management interventions?* |
| **6** | | | | *How can we develop better landscape level control for feral cats?* | *what effective waste-water treatments are possible?* |
| **7** | | | | | *What opportunities are there for effective storm water management?* |
| **8** | | | | | *Is it viable to vaccinate dolphins?* |
| **9** | | | | | *How could or should we develop a One Health approach in NZ?* |
| **10** | | | | | *Is there a 'safe' level of T. gondii in the environment?* |
| **11** | | | | | *What role will climate change, changes in prey distribution, water quality and emerging issues (e.g., microplastics) have on dolphins?* |

## Appendix 3: Rationale for themes and research questions

The rationale for the five different research themes identified in the workshops (see *Research themes* page 5) are described here from responses from experts participating in the workshops. They are focussed on better understanding the importance of the parasite in the dolphins (and other wildlife) and research to help identify hot spots of the parasite in the New Zealand environment. Some will help localise management options that may either reduce loading of toxoplasma oocysts to the environment (i.e., those aimed at cats) or limiting the transport of toxoplasma oocysts that are already in the environment (i.e., by restoring wetlands, or treating water). Given the naturally slow population growth potential of the dolphins and difficulties with detecting changing population size, other ways of demonstrating the success of controlling the parasite must also be found to evaluate the success of management approaches.

The parasite has been detected from multiple locations around New Zealand, through pathological examination of beach cast and bycaught dead dolphins. The estimated number of Māui dolphins has been critically low for at least two decades and highlights the continued need for prioritising conservation action for this sub-species. While the Māui dolphin's future is precarious, experts consider the dolphin can still be saved if additional management actions are taken promptly to address all anthropogenic threats (including the threat of *T. gondii* as described in the context of this document), noting that removing the bycatch threat would not be sufficient alone. Research and management interventions will therefore be prioritised for areas with the greatest benefit for the critically endangered Māui dolphin population.

There are multiple genotypes of *T. gondii* worldwide, but only one genotype has been implicated in deaths of the dolphins here in New Zealand. Whether this is the dominant strain of *T. gondii* present in New Zealand is unknown.

The questions that appear under each theme are considered those of greatest priority within that theme and are prioritized in order within that theme following the outcome of the toxoplasmosis workshops.

**1. Magnitude of the risk from toxoplasmosis in Hector's and Māui dolphins?**

Our understanding of the parasite in the dolphins has come from the assessment of beach cast or bycaught dead dolphins that have been available for post-mortem examination by marine mammal veterinary pathologists. Questions remain over how representative this is of the wider dolphin population. A high prevalence is indicated from post-mortem findings to date.

We are limited in our understanding of how representative the post-mortem findings are of the overall population, because our sampling is constrained to the recovery of dead dolphins. Live health assessments, whilst potentially feasible, are contentious for the critically endangered Māui dolphin population, particularly as live health assessments require the temporary capture of the dolphins for examination and invasive sampling (blood) on board a small boat. This has been successfully done with a few Hector's dolphins with no ill effects, however it creates substantial risk for the individual dolphins (i.e., dolphins are known to experience capture myopathy, which can result in death) and would require considerable social licence to allow consideration of this approach.

With new fisheries restrictions, by-caught animals are increasingly less likely (a good thing), meaning that there will continue to be uncertainty around the disease in these animals. Vigilance in looking for beach cast-animals or dead animals at sea becomes ever more important, as does retention of any bycaught dolphins for pathological examination.

The key research priority questions with respect to the parasite in the dolphins themselves are:

***1.1 How can we improve confidence in our current estimate of the prevalence of fatal toxoplasmosis in this species?***

There is still a need to further assess seasonal and spatial bias to determine if the necropsy sample is representative of the wider population. This will require approaches for increasing vigilance for detection of dead dolphins (beach cast or at sea) for post-mortem pathological examination across the whole year. Citizen science programmes to encourage beach surveys and reporting, particularly in winter months when there are fewer beach goers will be useful. With the development of the Māui63 drone and the associated development of AI for identifying Māui dolphins from the air, there is a possible role for the use of these tools to recognise dead dolphins from the drone in real time during targeted surveys, by including beach sweeps within those surveys.

***1.2 What percentage of dolphins are infected?***

Beyond the approaches above new policy and protocols have been developed to enable the collection of dead dolphins from fisheries by-catch. While we hope there will be zero fisheries bycatch, any that do occur can help inform this work. By examining dead dolphins from fisheries bycatch, otherwise presumably healthy dolphins, can be examined to understand if they are also infected with the lethal strain of the parasite.

Live health assessments are a possibility, however, would put the dolphins at risk, be very costly, and require social licence.

We still need to understand whether fatal cases of toxoplasmosis in the dolphins are from acute (newly acquired) infections or reactivation of latent infections. The histology suggests recent infection, but it is difficult to be sure based on histology alone.

***1.3 Is there a true female bias in dolphin deaths?***

If the disease is particularly impacting females (7 out of 9 dolphins that died from toxoplasmosis were female, of which 6 were mature females), this has real implications for the population, and would further heighten the need for management.

***1.4 What other factors contribute to deaths of dolphins from toxoplasmosis?***

Immunosuppression has been shown to be a factor in toxoplasma deaths in other species, including humans. Although research to date for Hector's dolphins does not indicate that immunosuppression is a factor in disease, this has not been fully investigated. For example, stressors associated with pregnancy could potentially explain the observed bias towards pregnant females, which are over-represented in the group of fatal cases.

***1.5 What are the sub-clinical impacts?***

In other species, the parasite is known to cause impacts on reproductive success, and behavioral changes that may influence exposure to other threats, however these will be very difficult to discern in dolphins. Behavioural studies of free-living dolphins are unlikely to provide answers to these questions particularly as it will be very difficult to correlate with disease. The necropsy sample of Hector's and Māui dolphins used to assess the population risk of toxoplasmosis was small and potentially prone to biases associated with only using dead beach cast animals. Using such samples to further infer that toxoplasmosis is an influencing factor in other causes of death is probably not feasible

DOC is funding full necropsies for dead Hector's and Māui dolphins from both dead stranded or beach cast animals, and now also has the ability to examine animals from fisheries bycatch. The bycaught animals will not help us understand the subclinical (behavioural) impacts of the diseases sample size are likely to remain too low, and we do not have a comparison population to draw assumptions from, however they might be able to tell us about the prevalence of infection in otherwise healthy dolphins, which may be useful.

## 2. Risk factors for *T. gondii* infection in Hector's and Māui dolphins? (What increases the risk?)

Once oocysts are shed into the environment in cat faeces, they are infective in soil and freshwater for at least 2 years and in sea water for at least 6 months and can spread long distances through terrestrial and aquatic environments. The source of entry into the marine environment is from the contamination of fresh water with oocysts, in rainwater runoff, rivers, streams, stormwater and wastewater. Identification of key transport and transmission pathways are needed to understand contributing sources to marine hotspots and for targeting intervention responses (e.g., riparian planting, novel stormwater, and wastewater management). However, methods for detecting *T. gondii* oocysts in the environment are underdeveloped relative to other protozoan parasites, which is hindering the direct monitoring of oocysts in the environment.

### *2.1 Are there temporal or spatial hotspots for oocyst contamination?*

An understanding of the difference between terrestrial and coastal hotspots and the dynamics of which cat populations are contributing *T. gondii* oocysts to the marine environment, how they get there, and which factors drive this is lacking. Some parts of a catchment may contribute oocysts to the marine environment more than others. When key spatial areas are identified, it will help to further focus research and target management**.** Existing hydrological and hydrographic models could be applied to this purpose**.**

Studies in Hawaii[15] and California[16][17] have provided understanding of the connections of rainfall and catchments to affecting oocyst distribution. Understanding how rainfall and catchments affect distribution of oocysts in a New Zealand context will allow comparability with international management strategies and initiatives.

### *2.2 What do the bioaccumulation pathways look like in NZ waters?*

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[15] Robinson S, Barbieri M. 2020. Evaluating the risk of *Toxoplasma gondii* exposure for Hawaiian monk seals: a conceptual map and research directions. NOAA Admin Rep. H-20-12, 45 p. doi:10.25923/3jb5-6m07

[16] Van Wormer, E., Carpenter, T. E., Singh, P., Shapiro, K., Wallender, W. W., Conrad, P. A., Largier, J. L., Maneta, M. P., and Mazet, J. A. K. (2016). Coastal development and precipitation drive pathogen flow from land to sea: evidence from a *Toxoplasma gondii* and felid host system. *Scientific Reports* **6**, 29252. doi:10.1038/SREP29252

[17] Shapiro, K., Conrad, P. A., Mazet, J. A. K., Wallender, W. W., Miller, W. A., and Largier, J. L. (2010). Effect of estuarine wetland degradation on transport of *Toxoplasma gondii* surrogates from land to sea. *Applied and Environmental Microbiology* **76**, 6821–6828. doi:10.1128/AEM.
01435-10

Understanding the bioaccumulation of oocysts in different systems will help validate hotspots. Useful work has already been undertaken to look at sentinels in the marine environment (e.g., in bivalves[18]), that should be further developed, however different strategies may be required in freshwater.

Sentinel species within food webs of the dolphins may be another way to look at bioaccumulation and signal how the parasite is getting into the dolphins. This may not directly change management; however, it may be very useful in building public awareness of these processes. Accumulation of the parasite has already been described from commercial mussel species[19] in New Zealand and has been demonstrated in fish species and marine invertebrates in studies overseas

Answering these questions will help focus management interventions, and the techniques developed here will help to test their efficacy.

3. **Understanding the *T. gondii* genotypes: Presence, distribution, and prevalence in NZ and genotype(s) fatal to dolphins.**

All fatal cases of toxoplasmosis in the dolphins to date have been the same genotype of *T. gondii*, and fatal cases have occurred throughout the range of dolphin distribution, hence the assumption is that this genotype is broadly distributed. Currently it is unknown if the strain of *T. gondii* that is lethal to the dolphins is the dominant strain in New Zealand cats, or what other strains are present. Understanding the distribution and prevalence of different genotypes of the parasite will help inform the scale of management required and how localized or broad that needs to be.

***3.1 What is the distribution and relative prevalence of the T. gondii genotypes in different cat populations and groupings (Feral, unsocialized strays, socialized strays, and companion cats)?***

This is a fundamental question to answer to be able to target appropriate cat management interventions at local scales, as not all cat populations/groupings may be contributing equally to shedding oocysts of the lethal strain of *T. gondii*, and loadings into the environment.

Understanding the distribution of the genotypes of the parasite within cat populations will enable prioritization of catchments within transport and transmission pathway models to trial and test management interventions.

***3.2 What is the distribution of the T. gondii genotypes and prevalence in different cat prey species?***

Cat prey species may act as useful sentinels, acting as a proxy for *T. gondii* genotypes distributed in cat populations within the same area without having to directly target the cats themselves for sampling.

***3.3 What is the human health impact of T. gondii in New Zealand?***

Toxoplasmosis is not currently a notifiable disease in New Zealand, however the disease caused by the parasite can and does affect the human population. Although no toxoplasmosis outbreaks have been reported in New Zealand, seropositivity rates of 28% and 43% have been reported in two surveys,

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[18] K. Shapiro, E. Van Wormer, B. Aguilar, P.A. Conrad Surveillance for *Toxoplasma gondii* in California mussels (*Mytilus californianus*) reveals transmission of atypical genotypes from land to sea Environ. Microbiol., 17 (2015), pp. 4177-4188

[19] Coupe, A., Howe, L., Shapiro, K., & Roe, WD. (2019). Comparison of PCR assays to detect *Toxoplasma gondii* oocysts in green-lipped mussels (*Perna canaliculus*). *Parasitology Research*. 118(8), 2389-2398

indicating that a significant proportion of New Zealanders are being exposed to *T. gondii* during their lifetime.

Toxoplasmosis can cause serious health issues for people, particularly those with weak immune systems. It is very serious for pregnant women as it can induce miscarriage, they can pass an infection to an unborn baby, which can cause foetal abnormalities (including congenital blindness) or other potentially tragic consequences later in the child's life. Toxoplasmosis is a leading source of foodborne death in the USA (Centre for Disease Control), and foodborne illness, and the parasite is a significant cause of blindness worldwide. The parasite is also implicated in neurological conditions.

Water-borne oocysts can infect humans, including through the consumption of raw shellfish. In New Zealand *T. gondii* is a known source of contamination in green-lipped mussels, which may represent a source of infection for humans.

***3.4 How do we detect and quantify the loadings of T. gondii oocysts in freshwater systems?***

Developing techniques to enable detection of *T. gondii* oocysts, identification of genotypes and quantification of oocyst loading in freshwater systems would provide a non-invasive way to evaluate *T. gondii* pathways indirectly without the direct sampling of cats.

This will be critical in understanding the scale of management and provide a means for testing the efficacy of management interventions (e.g., the effectiveness of riparian planting, stormwater management systems etc).

***3.5 What is the prevalence of T. gondii in other marine mammal species?***

Currently necropsies that examine for *T. gondii* in marine mammals are limited to recovery of Māui and Hector's dolphins, and New Zealand sea lions, found dead on beaches or from fisheries bycatch. As these are rare events it may be possible to expand our sample size by targeting the collection of information from other marine mammals that strand and die within the range of Hector's and Māui dolphin's habitat. Some of these species also inhabit the nearshore environment e.g., bottlenose dolphins, and offer opportunities to understand the distribution of the parasite more broadly. It may also reveal a broader problem with the parasite. The same genotype of the parasite that has killed Hector's and Māui dolphins has been implicated in the death of a New Zealand sea lion[20], and other marine mammals globally (including two species of porpoise).

Species other than Māui and Hector's are currently collected by New Zealand researchers within other research programmes. It would require training these researchers in how and what tissues to sample, along with the proper preservation of these samples. If other species are dying of toxoplasmosis this may be informative. However, full necropsy investigation, including interpretation by a veterinary pathologist, would be needed for this to be comparable to the data from Hector's and Māui dolphins.

Broadening our examination to wildlife species other than dolphins or seals would allow for expanded opportunities to identify marine hotspots for the lethal strain of *T. gondii* oocysts. Sampling other species within the dolphin's environment and associated estuaries and rivers that flow into the coastal waters used by the dolphins may be a consideration (e.g., little blue penguins, wading birds?), with these animals acting as sentinels for the parasite. The tools already exist for this but will require an expansion of protocols and training with scientists that are already collecting samples from these species. There is also the potential to re-examine existing archived pathological samples.

[20] Roe WD, Michael S, Fyfe J, Burrows E, Hunter SA, Howe L (2017) First report of systemic toxoplasmosis in a New Zealand sea lion (*Phocarctos hookeri*). N Z Vet J 65:46–50

## 4. Understanding cats and their role and the opportunities for management?

With cats being the definitive host of the parasite, understanding the size, distribution, and abundances of feral and domestic cat populations across the New Zealand landscape to better inform our understanding of the distribution of the parasite and the scope of the problem. Management strategies for dealing with potential *T. gondii* loading into the environment from the different cat category groups will likely be quite different. For instance, owned and cared for cats will be indoors more, live longer, and owners tend to want to make sure they don't negatively impact on other species; whereas stray cats live almost exclusive outside, live shorter lives, are more likely to become ill, and breed more often, all factors that can lead to an increase in infection rates and subsequent shedding of oocysts to the environment.

The Companion Animal Council do a regular survey of cat ownership in New Zealand. Cats are the most popular companion animal in New Zealand. Forty-one percent of households in New Zealand have at least one cat, with an estimated 1.219 million cats in households across the country. About 83% of household cats are allowed to roam outdoors. Very few cats are kept indoors only, with an estimate of 135 thousand.

Population numbers and distribution of feral cats are not well resolved. Feral cat population densities vary greatly, and they live in most terrestrial habitats in New Zealand, from sea level to 3000m.

The techniques currently used to control feral cats are trapping, sometimes supplemented by poisoning and shooting. Feral cats will also be killed by secondary poisoning following aerial 1080 operations to target rodents and possums in forests. Where cats are lethally controlled, DOC uses efficient and humane best-practice techniques and adheres to the Animal Welfare Act 1999. Manual ground-based techniques like trapping are likely insufficient for landscape scale control of feral cats, in part because of continual re-incursion from stray cat populations or feral cat populations from adjacent areas. To be able to manage at local scales we need more information on the distribution and densities of feral cat populations, and their associated *T. gondii* genotypes.

A separate series of social science workshops is envisaged to consider the broader issues of behaviour change for cat owners and the social license issues associated with domestic cat management.

### *4.1 What are the current population densities of different categories of cat (i.e., feral, unsocialised stray, socialised stray, companion), particularly in catchment areas that flow to Māui dolphin habitat?*

The *Toxoplasmosis Action Plan* identified catchments that flow to Māui dolphin habitat as priorities for action, making the Waikato River and Manukau Harbour catchment areas the critical area to initially target. These areas were predicted from modelling to be the greatest contributors of oocysts into the core Māui dolphin habitat.

### *4.2 Are there differences in prevalence, shedding rates or genotypes of T. gondii present in different cat populations?*

A single cat can shed millions of oocysts in a shedding event; however, rates of shedding may differ by genotype and by cat population. This will help predict loadings of the parasite in the environment and so inform modelling.

### *4.3 How do pest ("prey") populations contribute to the distribution and concentration of infection in cats?*

Pest prey species can act as reservoirs for the parasite in the environment. Recent studies suggest that by reducing populations of cat pest prey species, elimination of the parasite may be achieved within cat populations in a given area at lower levels of cat depopulation.

***4.4 Are cat vaccines possible?***

There is no commercial vaccine currently available for cats, and no timeline for the delivery of one. Various new approaches are being tried in other parts of the world. If a vaccine were to be developed, it would provide game changing opportunities in tackling the production of oocysts. Costs of producing a vaccine at a commercial scale are very high and work is unlikely to be funded in New Zealand, so we are reliant on programmes elsewhere. A watching brief must be maintained domestically and internationally on the potential for a cat vaccine in case opportunities arise to support or fast track such an approach. The difficulty of deploying a cat vaccine in different cat populations is unknown, even if one should become available.

***4.5 What scale of cat management is important?***

The management of toxoplasmosis requires a mountains-to-sea approach, i.e., catchment scale, because toxoplasmosis arises from *T. gondii* in the terrestrial environment. Understanding the distribution of the lethal genotype of the parasite to the dolphins, hotspots and the transmission pathways in a New Zealand context will help to localise the scale of management. The scale of management will be dependent on understanding genotype distributions and cat population concentrations. Management of cats is particularly contentious, and not all cat populations may be contributing equally to the problem. Constraining management to key areas will enable managers to focus initiatives in the most appropriate ways. As management tools are developed and evaluated, scalability will be an important consideration.

The scale of management will also dictate the levels of coordinated action between agencies and stakeholders that will be required.

Mana whenua aspirations with respect to managing the toxoplasmosis threat can be built from the terrestrial and freshwater environments through DOC (and other agencies') work. For example, relevant DOC initiatives include Predator Free 2050 (e.g., Farms as Barriers - The goal of the Farms as Barriers programme is to stop predator movement across farms, so they do not reach natural habitats beyond farms) and the Ngā Awa River restoration programme. To support toxoplasmosis work, continuing DOC's engagement with whānau, hapū and iwi at site is required.

***4.6 How can we develop better landscape level control for cats?***

The consensus is that managing the impact of the parasite on dolphins ultimately comes down to how we can manage cat populations through:

- developing appropriate controls for feral and stray cats and their pest species prey,
- de-sexing of companion and stray cats; and,
- improving containment of companion cats (and dolphin-safe management of their faeces).

DOC is trialling bait that can be used to control feral cats (the nature of this bait currently supports controlled localised applications rather than broadcast distribution over large areas). Research and development work on bait continues, and if successful, may support additional options for cat control in time.

Complementing the technical tools for cat management, social research and outreach is necessary to develop, embed and maintain the social licence for cat control work at different scales through appropriate agencies, and to ensure control work achieves the best possible outcomes for dolphins.

Building and maintaining social licence will require significant collaboration, which has been signalled by the National Cat Management Strategy Group. Aligned with managing toxoplasmosis on dolphins, the Group was formed to develop a national overarching strategy for responsible, caring, and humane cat management in New Zealand achieved through a collaborative approach. The Group includes members from the New Zealand Veterinary Association (NZVA), NZVA Companion Animal Veterinarians, New Zealand Companion Animal Council, SPCA, Morgan Foundation, and Local Government New Zealand.

**5. Characterising and monitoring potential control/mitigation methods and broader questions.**

***5.1 What is the total economic burden of Toxoplasma gondii and the disease toxoplasmosis on NZ?***

An Australian study from October 2020 attempted to estimate the economic burden of cat-dependent pathogens in Australia, with most of the burden ascribed to *T. gondii*. The study focussed on the impact of the parasite on people and livestock.

People infected by *T. gondii* may appear asymptomatic, or have a mild illness, or experience severe, potentially lethal symptoms; the parasite may also affect behaviour and mental health. *T. gondii* is also a major contributor to abortion in sheep and goats.

The study collated national and global data on infection rates, health, and production consequences. The study looked at two cat-dependent diseases, with the greatest cost attributable to toxoplasmosis and *T. gondii* infection with an estimate annual economic cost of AUS$6 billion (with a plausible range of between AUS$2.11 and 11.7 billion), based on costs of medical care, lost income, and related expenses.

The analysis suggests that substantial benefits to public health and livestock production could be achieved by reducing the impact of toxoplasmosis. This did not take into consideration the loss of wildlife to the disease, or the greater impact that cats have on the environment.

As toxoplasmosis is not a notifiable disease in New Zealand, it is unclear if such data that underpinned the Australian study would be readily available here. However, there is already a recognised cost burden to the sheep industry associated with the parasite due to lost production and the cost of vaccination.

Most information on the risk to humans from *T. gondii* in New Zealand revolves around activities associated with soil contamination with cat faeces (e.g., gardening), and undercooked red meat, however raw shellfish consumption (and possibly water-borne infection) could also be important.

A study of this nature in New Zealand may be useful to identify the broader issues caused by *T. gondii* here and provide or influence broader support for actions that would benefit the dolphins.

***5.2 Can we develop a spatial analysis/ spatial database to inform targeted effort by pulling together modelling from the other streams of research such as hydrographic/hydrological models, cat population densities, parasite genotype distribution (if and when it becomes available), and other factors into a GIS tool at sub catchment scale?***

Such a tool would be useful for focussing and testing management interventions. A first step would be to identify what available information there is to input into such models.

***5.3 How could we do better health screening for Hector's and Māui dolphins?***

Full surveillance programmes already exist for disease and death. DOC provides funding for full pathological investigation for every dead Hector's or Māui dolphin that is recoverable to determine cause of death. It is because of this programme that toxoplasmosis was first identified as a cause of death, along with other diseases such as brucellosis. Pathological investigation remains the best way to detect existing and emerging diseases and can be extended to include surveillance for a range of suspected pathogens, dependent on funding and on the development of appropriate tests.

***5.4 Are there other emerging diseases and health threats to the dolphins? (What is the next toxoplasmosis?)***

Toxoplasmosis was identified through the vigilance of existing protocols for the pathological examination of dead dolphins. Systems are in place to uncover new threats as they emerge. More can always be done in expanding protocols and would be driven by perceived need and available resources.

Health screening of live dolphins through live capture, while theoretically possible, exposes the dolphins to risk, would be costly, and requires considerable social license. Invasive programmes such as this may yield useful information, however, are unlikely to change the management strategies for toxoplasmosis and the parasite.

***5.5 How do we measure the success of management interventions?***

Recovery of the dolphin population is unlikely to be measurable over timeframes that are short enough for management, therefore management will need to act on the basis that reducing *T. gondii* loading to the marine environment will benefit the dolphins.

It is currently hard to detect and measure oocyst loadings in the terrestrial environment, however there are some tools that have enabled some modelling in terrestrial systems, however this is even less well resolved in water. This is a critical step that is needed to help test the efficacy of management interventions.

There are new molecular detection tools, that may provide techniques to enable both detection and quantification of oocysts of *T. gondii* strains in aquatic transmission pathways.

***5.6 What effective waste-water treatments are possible?***

Wastewater treatment plants may also be a source of contamination if cat faeces/kitty litter have been flushed down the toilet. The currently available management options for the treatment of wastewater are extremely limited. Oocysts appear to be resistant to standard disinfection processes, including ultraviolet treatment, and so are unlikely to be removed by the wastewater treatment process.
New possibilities for waste-water treatment could be explored, such as filtration, sand column systems, or techniques that cause the oocysts to aggregate or flocculate to create a retainable sludge. Such technical solutions should be examined, for although costs to retrofit waste-water treatment plants may be costly, if new plants are being developed opportunities to implement new strategies may be achievable.

***5.7 What opportunities are there for effective storm water management?***

Most storm water is currently untreated and current structures are designed to pipe flows efficiently to the sea or into river system. It is hard to retro fit these systems, however in the design of new areas consideration could be given to the inclusion of vegetated run off areas to retain or limit the passage of oocysts. Public outreach may encourage the development of small, very local level green infrastructure systems that may help reduce pollutants (e.g., "rain gardens"). This may help with reducing loading of the parasite from companion and stray cat populations within urban environments. There is very little space to retrofit for stormwater treatment.

### *5.8 Is it viable to vaccinate dolphins?*

There is no specific vaccine for dolphins under development or testing. There is, however, an existing vaccine to prevent the disease toxoplasmosis in livestock, it's suitability for dolphins is untested. Administering vaccines to wild dolphin populations would be very difficult. The techniques exist to inject dolphins, however as discussed under live health screening, there are risks for the dolphins, huge costs, and uncertainty of a successful outcome. It is unlikely that repeat dosing of dolphins would be achievable (even if a suitable vaccine did exist).

Trialing such experimental vaccination strategies on the Māui dolphin population would be inappropriate, as doing so would put the animals at risk, and it would be very difficult to demonstrate success. Consensus is that such an approach is generally not to be considered viable.

### 5.9 *How could or should we develop a One Health approach in NZ?*

*One Health* focuses on transdisciplinary collaborations to solve issues across human health, animal and plant health, and the environment. As Toxoplasmosis is not a notifiable disease in New Zealand and is unlikely to be, the true magnitude therefore of its impact is unknown. The generally tenet of *One Health* is collaboration and coordination between agencies and stakeholders to find and deliver solutions. As the parasite crosses multiple boundaries from terrestrial, freshwater, to marine, and impacts on wildlife and livestock, that collaborative approaches will be fundamental to achieve a successful outcome. DOC and other agencies will need to develop partnerships to manage and coordinate management. Existing processes can be drawn on e.g., *Farms as Barriers* (an initiative under Predator Free 2050) and potentially *OneHealth Aotearoa*, but need to feed into a collective goal, if we are to save the dolphins.

Collaborative approaches are reliant on adequate funding and the coordinated actions of agencies, and the social license for those agencies to act.

### *5.10 Is there a 'safe' level of T. gondii in the environment?*

The presumptive infectious dose of the parasite is a single oocyst (based on rodent and pig models). The answer therefore is the fewer oocysts entering the dolphins' environment the less likely a dolphin is to encounter the parasite. A lack of cases of infection in the dolphins may not reflect a lack of risk to the dolphins, therefore it is better to consider areas with concentrations of oocyst exposure for management. Thresholds may be very hard to determine, so a presumptive approach that reduction in levels of oocyst loading in the environment equals a reduction in risk (at some level).

### *5.11 What role will climate change, changes in prey distribution, water quality and emerging issues (e.g., microplastics) have on dolphins? (Impact of cumulative pressures)*

Small populations such as Māui dolphins are considered likely to be vulnerable to effects of increasing sea temperature, and the impact this could have on their prey's distribution. While there are likely to be impacts on the dolphins from other emerging threats and changes to their environment, the focus of this science plan needs to be on the known threat of the parasite *T. gondii* to the dolphins. Cumulative pressures such as shifts in rainfall, and coastal erosion may, however, change the levels of exposure the dolphins have to the parasite, and as such should be built into the thinking within models.