Addressing the threat of toxoplasmosis to Hector's and Māui dolphins: an action plan

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

Context

Hector's and Māui dolphins are small coastal dolphins found only in New Zealand. Hector's dolphins live mainly around the South Island and Māui dolphins are only found on the west coast of the North Island (WCNI).

Hector's dolphin is ranked as Nationally Vulnerable by the New Zealand Threat Classification System (NZTCS, Baker et al. 2019) and has a population of around 15,000 (MacKenzie & Clement 2014, 2016). Māui dolphin is ranked Nationally Critical under the NZTCS (Baker et al. 2019) and has an estimated population of around 63 individuals above 1 year of age.

Key terms

- Hector's dolphin – *Cephalorhynchus hectori hectori*
- Māui dolphin – *C. h maui*
- Māui dolphins were recognised as a separate subspecies in 2002 (Baker et al. 2002).

The New Zealand Government's response to the threats facing these dolphins is determined through the Hector's and Māui dolphin Threat Management Plan (TMP) www.doc.govt.nz/tmp-review. A review of this TMP was conducted between 2017 and 2020. During this review it become clear that, although there remain divergent views on impact and best mitigation options, one serious threat to the dolphins is the disease toxoplasmosis, and that there is a need to address this threat.

Toxoplasmosis is spread through the faeces of felids (cat species). Aotearoa/New Zealand has no wild cat species present but has the domestic cat which falls into three categories: 'owned' (pet) and 'unowned' (feral and stray).

This action plan reflects consultation to date, and is based on existing scientific evidence, but it will inevitably evolve and change as information gaps are filled and experience is gained finding and testing solutions. More information can be found at www.doc.govt.nz/toxoplasmosis-action-plan.

Key terms

- Toxoplasma: *Toxoplasma gondii*, the parasite that causes the disease toxoplasmosis
- Toxoplasma oocyst: the 'egg' of the toxoplasma parasite
- Toxoplasmosis: the disease caused by the toxoplasma parasite.

Key points

- Toxoplasmosis is a significant cause of population decline in Hector's and Māui dolphins.
- Māui dolphins are especially impacted due to their small population size (63 individuals over the age of 1 year).
- Toxoplasmosis is caused exclusively by cats, which shed toxoplasma oocysts in their faeces.
- Failing to act effectively on the toxoplasmosis issue will increase the risk of extinction for Māui dolphins.
- This document seeks to outline the problem and propose possible actions The Department of Conservation (DOC) might take to address it. To do this, it summarises the known and unknown factors, draws conclusions, identifies priorities and outlines a pathway of action.
- More detailed and fully referenced analysis of the issue can be found in a literature review and a background information document. Part 2 of this action plan – a more detailed breakdown of proposed actions over 4 years – is also available on DOC's website. This more detailed breakdown of actions will be updated and amended as the work evolves.

Stakeholder and scientific engagement

As part of addressing this challenging issue, national and international experts, including from stakeholder organisations (DOC, Ministry for Primary Industries (MPI), university researchers, regional councils) have been engaged in a Toxoplasmosis Strategic Science Advisory Group (SSAG), which held its first meeting on 20 November 2019. The SSAG process has been used in response to other complex government science issues, including kauri dieback disease and *Mycoplasma bovis* in dairy cattle. The current document is the result of feedback by that SSAG. It was recognised that it would be beneficial to the SSAG process to include further stakeholders (such as Ministry of Business, Innovation and Employment (MBIE), public health agencies and officials and Crown Research Institutes (CRIs)) and overseas experts experienced in dealing with toxoplasmosis in other marine mammal species.

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The purpose of the SSAG is to provide advice and recommendations to the Hector's and Māui dolphin Threat Management Plan Governance Group on the requirements for strategic science prioritisation and aid in the coordination of research programmes focused on understanding and managing the effects of toxoplasmosis on these dolphins in New Zealand.

A literature review commissioned by DOC to examine current knowledge on the effects of toxoplasmosis in New Zealand and overseas is now due for publication. Priorities for research identified by that work have been incorporated into this plan. Ongoing research and engagement with the scientific community will continue to inform the plan as it evolves, allowing new information and opportunities to be taken into account.

What *do* we know about toxoplasmosis and Hector's and Māui dolphins?

- Toxoplasmosis is caused by the parasite *Toxoplasma gondii* and can infect all warm-blooded animals, including humans.
- Toxoplasmosis has been recorded as the primary cause of death in Hector's and Māui dolphins, as well as other New Zealand native wildlife including kiwi, kererū, kākā and kākāriki.
- Toxoplasmosis is an important cause of sheep abortion and most New Zealand sheep are vaccinated against it
- The toxoplasma parasite only sexually reproduces in cats, forming oocysts that are spread through cat faeces in runoff into rivers and streams and then to the sea. Only cats produce these oocysts.
- Preventing oocyst-infected cat faeces entering the marine environment is the only way to reduce toxoplasmosis in dolphins. No direct vaccine for the dolphins is available.
- Toxoplasma oocysts are very durable and once in the environment can persist for long periods (months to years) and can be transported some distance (e.g. via hydrological networks) from the original point of loading.
- Toxoplasma is present in cat prey species (e.g. mice) but is not transmitted by them into the wider natural environment as they do not produce oocysts. Female rodents can pass on the parasite to their offspring (vertical transmission) and can infect cats that prey on them. Therefore, toxoplasma can persist in a cat-free environment for some time.
- There are multiple strains of toxoplasma in New Zealand – one (Variant Type II 'toxoDB#3') is a virulent threat to dolphins; the others to date have not been identified in fatal cases in dolphins.
- For Māui dolphins, urgent action is required because the population is so small (about 63 individuals over the age of 1 year, compared with 15,000 Hector's dolphins).
- Cat ownership in New Zealand is high compared with many other countries. In 2015, 44% of households had at least one cat and the owned cat population was estimated to be 1.13 million individuals.
- Unowned cats have shorter life spans (at most a few years compared with 15+ years for pets), breed more rapidly and have a greater population turnover. Oocyst shedding typically occurs early in cats' lives, which results in greater oocyst loading from unowned cats (on a per-cat basis).
- New Zealand made the only commercially available toxoplasma vaccine in the world – Toxovax® – used for sheep and goats. Yet the disease continues to be a major economic burden on the New Zealand sheep industry, due to lost production and the cost of vaccinating ewes.
- There is no vaccine currently available for cats.
- Oocysts are not killed by current wastewater treatment methods, including disinfectants and ultraviolet light.

What *don't* we know about toxoplasmosis and Hector's and Māui dolphins?

- Whether, in addition to leading directly to some dolphin deaths, toxoplasmosis may also pose an indirect threat through reducing dolphins' health and predisposing them to other forms of mortality (e.g. predation).
- Exact numbers of Māui dolphins that die from toxoplasmosis each year. Modelling using available information suggests as many as two per year.
- How to measure the toxoplasma loading to the marine environment and in rivers, streams, estuaries etc. that discharge into the marine environment.
- How much toxoplasma is in the marine environment already, whether there are hotspots and where these are.
- If there is a level of toxoplasma loading to the marine environment that is safe for Māui dolphins and, if there is, what is it.
- How much time we have to save Māui dolphins. The window for action is estimated to be about 10–15 years based on Māui dolphin population modelling that shows the threat from toxoplasmosis must be reduced by 50–75% within 10 years, and that significant threat reduction must happen within 5 years to ensure the dolphins do not go extinct.
- The relative contribution of populations of feral and stray (unowned) cats and owned cats to transmission of the toxoplasma strain that appears to be virulent to dolphins into the environment.

- Absolute population sizes and distribution of feral and stray cats across the New Zealand landscape. Estimates for unowned cat populations in New Zealand have high levels of uncertainty (e.g. c. 160,000–760,000 cats). The total New Zealand cat population (i.e. owned and unowned) could be as high as 1.9 million individuals.
- The ability of environmentally sustainable infrastructure (such as vegetated areas or constructed wetlands in stormwater and wastewater treatment plants) to reduce or remove toxoplasma oocysts from waterways is uncertain.
- The ability of riparian planting of catchments to reduce or remove toxoplasma oocysts from waterways. At present this is uncertain. How much planting is required? What kind of plants? Are there priority areas that should be targeted for planting?
- How important different catchments are to the transport of toxoplasma to the marine environment. Do some catchments play a larger role than others?
- Whether other factors (such as contamination with pollutants, other infections, genetics, pregnancy and prey availability) increase susceptibility of individual dolphins to infection with toxoplasma, and associated morbidity or mortality.

Conclusions

Based on the information available at the time of writing in 2020, DOC has concluded that:

- Effort should be focused where the need for action is greatest. The initial focus should be on Māui dolphins and, consequently, catchments that flow into the Tasman Sea along the west coast of the North Island (WCNI).
- The urgency of the problem requires a precautionary approach to be taken. Waiting for all uncertainties to be resolved before taking action is not acceptable. For example, it may not be possible to determine what is a 'safe level' for dolphins of toxoplasma oocysts entering the marine environment. However, based on the best available information, action can be taken on an assumption that reducing the toxoplasma loading will benefit the dolphins.
- One uncertainty that needs to be resolved urgently is how to measure toxoplasma loading in the marine environment. Until this can be done, there is no way of measuring the impact of efforts to reduce this loading. Therefore, a vital first step is to find out if toxoplasma loading in estuaries and coastal habitats can be consistently and comparably measured. Once such measurement is possible, different approaches and solutions can be trialled while any scientific uncertainties associated with the method are addressed.
- Several government departments have mandates and responsibilities under various legislation in relation to the management of conservation, the environment, cats and diseases such as toxoplasmosis. These include DOC, MPI, MfE, Ministry of Health and local government. Thus, an effective management response will have to be coordinated across multiple agencies.
- Two main pathways need to be examined to determine the best approaches to reducing the amount of *Toxoplasma gondii* entering the marine environment:

  1. Reducing the transfer of toxoplasma oocysts from cats to the environment – interventions focussed on the disease carriers.
     - Unowned (feral and stray) cat populations
     - Owned cat populations
     - Controlling parasite reservoirs in pest species populations that are the prey of cats – these pests (e.g. rodents) can be infected with the parasite which is passed on to the cat when the pest species is eaten.
  2. Limiting the transfer into the sea of toxoplasma oocysts already in the environment – interventions focussed on hydrological networks:
     - Restoring wetlands
     - Riparian planting
     - Storm/waste water treatment

  Management strategies aimed at reducing toxoplasma loading at the source by reducing feral cat numbers, or containing cats indoors and managing disposal of faeces, are more likely to be effective in terms of reducing environmental contamination with toxoplasma, but present significant challenges in terms of social license to operate and how to achieve behaviour change among cat owners.
- Management strategies that aim to mitigate or remediate an environment already contaminated with toxoplasma oocysts, while likely being more socially acceptable, also present significant challenges in terms of investment, design and implementation.
- It therefore makes sense at this stage to investigate and trial both types of intervention to test efficacy and viability.

The way forward: a twin track approach

The urgency with which action must be taken to reduce the risk of toxoplasmosis to Māui dolphins means we cannot wait to fill the considerable knowledge gaps. The Department of Conservation is therefore proposing a twin track approach to:

1. **Test and refine potential solutions that could reduce the threat from toxoplasmosis.**
2. **Fill knowledge gaps to establish greater certainty about both the extent of the problem and scale of the management action that will be required.**

The first step will be to secure funding for the work and collaboration from the appropriate authorities and stakeholders. Depending on the nature and extent of funding and collaboration, the proposed actions will need to be prioritised. A possible prioritisation approach is described below.

1. Testing and refining possible solutions

Proposed priority focus areas:

1. Develop a way to measure toxoplasma loading in estuarine and/or coastal habitats, and other water systems.
2. Trial a feral cat control approach in a specific catchment on the WCNI.
3. Trial a riparian planting/estuarine planting approach in one estuary/river on the WCNI.
4. Trial an environmentally sensitive technology solution to remove oocysts from storm/waste water.
5. Genotype toxoplasma strains within unowned and owned cat populations in key catchment areas.
6. Research effective cat-owner behaviour change approaches.
7. Maintain a watching brief domestically and internationally on the potential for a cat vaccine in case opportunities arise to support or fast track such an approach.

2. Filling knowledge gaps to establish greater certainty on the problem and our goals

Proposed priority research needs are:

1. An assessment of the prevalence of toxoplasma infection in Hector's and Māui dolphins and collection of information for assessing the mortality and population risk associated with toxoplasmosis. Currently, estimates of mortality associated with toxoplasmosis rely on the assumption that the examinations of beachcast dolphins are representative of all possible causes of death, which is unlikely to be the case. There is a need to review existing information with respect to stranding rates by cause of death to explore this assumption. Increased necropsy data, gained from an increased recovery rate of dolphin carcasses, would also reduce uncertainty in the estimation of dolphin mortality rates due to toxoplasmosis and other causes of death.
2. Spatial analyses to identify hotspots of toxoplasma contamination in marine and freshwater environments, focussing on catchments on the WCNI. Spatial analysis can initially concentrate on how oocycts reach the key core habitat of Māui dolphins; e.g. via the Waikato river plume.
3. Genotyping of toxoplasma strains related to different cat populations (i.e. by location or ownership status) to identify cat populations shedding the toxoplasma strain known to be lethal to Hector's and Māui dolphins.
4. Determining if there is a 'safe' level for Māui dolphins of toxoplasma 'loading' in the marine environment. If there is, what is it?

Science workshops:

Two series of workshops will be conducted with key researchers with the participation of international experts. The first will focus on refining research objectives and identifying research gaps and priorities beyond those identified above. The second will be held to develop the social science and management pathways. These workshops will provide guidance to decision makers in DOC on the direction and focus of the science work in the Toxoplasmosis Action Plan. Shaping and conducting this science will also require communication strategies and partnerships.

References

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Addressing the threat of toxoplasmosis to Hector's and Māui dolphins: an action plan

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

Context

This document sets out a proposed 4-year work programme to address the threat of toxoplasmosis to Hector's and Māui dolphins. It will be updated on an ongoing basis as understanding of the problem evolves and as choices are made based on research, partnerships and funding.

The summary rationale for this proposed 4-year plan is set out in a separate document. A more detailed and fully referenced analysis of the toxoplasmosis issue is available in a literature review and a background information document. More information can be found at www.doc.govt.nz/toxoplasmosis-action-plan.

The urgency with which action must be taken to reduce the risk to Māui dolphins from the threat of toxoplasmosis means not waiting to fill the considerable knowledge gaps. The Department of Conservation (DOC) is therefore proposing a twin track approach to:

1. **Test and refine potential solutions that could reduce the threat from toxoplasmosis.**
2. **Fill knowledge gaps to establish greater certainty about both the extent of the problem and scale of the management action that will be required.**

Track 1: testing and refining potential solutions to reduce the threat from toxoplasmosis – 4-year plan

The proposed workstreams below are dependent on both securing the necessary funding and on collaboration from a range of potential partners both within and outside government. Priorities will need to be identified, depending on the funds secured and the willingness of others to collaborate. The Department will continue to scope out potential collaborations and funding opportunities, and then modify the plan accordingly with input from DOC's Toxoplasmosis Strategic Science Advisory Group.

Updates on progress in addressing the risk from toxoplasmosis through the action plan will be presented to the north and South Island iwi and stakeholder group which will have independent oversight of the management of these important species. They will be responsible for reporting to the Minister of Conservation and Minister of Fisheries annually on the performance of the overall Māui dolphin Threat Management Plan and the measures in place. They will also put forward ideas for any changes they consider important to improve effectiveness.

Proposed activities:

1. Measure toxoplasma oocyst loading to the marine environment.
2. Trial a feral cat control approach in a specific catchment.
3. Trial a riparian planting/estuarine planting approach in one estuary/river on the west coast North Island (WCNI).
4. Trial an environmentally sensitive technology solution to remove toxoplasma oocysts from waste/storm water
5. Identify which cats – unowned (feral, stray) and owned (pets) – have the distinct strains of toxoplasmosis (lethal and non-lethal to dolphins).
6. Research effective cat-owner behaviour change approaches.

The actions required over the 4-year period of the plan are detailed in Tables 1 and 2 below. The details in these tables are expected to change as new information becomes available, and thinking and planning evolve. Changes to the actions will be reported on through the DOC website under the Māui dolphin TMP pages.

Table 1. Actions proposed for the 4 years of the Hector's and Māui dolphins toxoplasmosis action plan

Trialling solutions	Year 1	Year 2	Year 3	Year 4
1. Methodologies for measuring toxoplasma oocyst loading in hydrological networks	**Outcomes** 1. Potential methodologies for measuring toxoplasma oocyst levels are identified and prioritised. 2. Possible sites for trial application of each methodology have been examined.	**Outcomes** 1. Methodologies are analysed and the most promising approaches prioritised.	**Outcomes** 1. Suitable methodologies are established and implemented more broadly. 2. Oocyst baseline loadings are determined.	**Outcomes** 1. Results are analysed and findings integrated into a programme review.
	Outputs 1. A review of available methodologies. 2. Key catchment trial areas identified.	**Outputs** 1. Successful methodologies are signalled as early as possible so they are available to other work streams.	**Outputs** 1. Reports circulated.	**Outputs** 1. Results published.
	Activities 1. Small-scale trials are conducted, e.g. using filter-feeding marine or aquatic organisms (such as mussels) to monitor toxoplasmosis oocyst densities in riverine and marine environments).	**Activities** 1. Trial programmes are conducted using prioritised approaches.	**Activities** 1. Drawing conclusions, writing up results.	**Activities** 1. Discussion of results in a science working group.
2. Trial a feral cat control approach in a specific catchment on WCNI	**Outcomes** 1. Appropriate catchments or sub-catchments are identified as trial sites. 2. Barriers to trials are identified. 3. A social science workshop is held.	**Outcomes** 1. Year 1 of trial completed.	**Outcomes** 1. Year 2 of trial completed.	**Outcomes** 1. Results evaluated to prioritise further trials and approaches to reduce or contain cat populations in key catchments.
	Outputs 1. Report. 2. Workshop report.	**Outputs** 1. Development of a communications strategy aimed at increasing public concern for dolphin health.	**Outputs** 1. Outcome report.	**Outputs** 1. Conclusions from science working group.
	Activities 1. Evaluate existing programmes (e.g. Port Waikato dotterel work) and possible expansion of this work. 2. Through engagement with National Cat Management Strategy, look at appropriate areas and voluntary approaches to examine key catchment cat populations. Education, voluntary community cat containment trial? 3. Social science workshop held and workshop report incorporated into science plan.	**Activities** 1. Social science strategies trialled. 2. Samples from trials used to examine toxoplasma genotype distribution.	**Activities** 1. Review and analysis of oocyte mitigation as a result of cat control trials. 2. Review of social science communication strategy.	**Activities** 1. Discussion of results in a science working group.

Table 1. Actions proposed for the 4 years of the Hector's and Māui dolphins toxoplasmosis action plan (cont.)

Trialling solutions	Year 1	Year 2	Year 3	Year 4
3. Trial a riparian planting/estuarine planting approach in one estuary/river on WCNI	**Outcomes** 1. Key relationships are established. 2. Key catchment and sub-catchment areas determined. 3. Extent of existing riparian planting and revegetation efforts in key catchments is mapped. 4. Key projects prioritised.	**Outcomes** 1. Catchment revegetation programmes are underway. 2. Measurement trials using appropriate methodologies are being used.	**Outcomes** 1. Results of trials have been analysed and reported, comparative efficacy of different approaches is evaluated.	**Outcomes** 1. Scale required for effective management of toxoplasma oocyst loading to the marine environment is known and the feasibility of expanding management activities is reviewed.
	Outputs 1. Plan for years 2–4.		**Outputs** 1. A draft report of status of work and efficacy of approaches.	**Outputs** 1. Final report.
4. Trial a technology solution to remove toxoplasma oocysts from waste/storm water	**Outcomes** 1. Key areas for waste/storm water treatment and site-specific technologies identified for trials. 2. Systems to measure reduction in toxoplasma oocyst loading are trialled.	**Outcomes** 1. Trials progressing at prioritised site(s).	**Outcomes** 1. Trials progressing at prioritised site(s).	**Outcomes** 1. Efficacy of different technological solutions are evaluated (reliant on finding a viable and effective method to measure oocyst loadings). 2. Recommendations and costing of retrofitting existing water treatment systems are evaluated.
	Outputs 1. Plan for years 2–3.	**Outputs** 1. Progress report.	**Outputs** 1. Progress report.	**Outputs** 1. Recommendation of effective systems available to inform next steps.
	Activities 1. Planning. 2. Relationships development.	**Activities** 1. Trial year 1.	**Activities** 1. Trial year 2.	**Activities** 1. Final analysis and reporting. Discussion of results in science working group.
5. Identify which cats – unowned or owned – shed the known lethal strain of toxoplasma oocysts	**Outcomes** 1. Network of collaborators is established to access and sample cats and/or cat faeces. 2. Standardised methods of sample collection and analysis are determined.	**Outcomes** 1. Sampling programme continued.	**Outcomes** 1. Toxoplasma oocysts shed by cat populations within key catchment areas are genotyped.	**Outcomes** 1. Key contributing cat populations are identified.
	Outputs 1. Archive (year 1) of samples for testing. 2. Methods established and validated.	**Outputs** 1. Archive (year 2) of samples for testing. 2. Data.	**Outputs** 1. Full sample archive established and genetic analysis complete.	**Outputs** 1. Future planning review.

Table 1. Actions proposed for the 4 years of the Hector's and Māui dolphins toxoplasmosis action plan (cont.)

Trialling solutions	Year 1	Year 2	Year 3	Year 4
	Activities 1. Design of study for representative sampling from target cat populations. 2. Systematic sampling of feral and stray cats in the Waikato catchment and South Auckland (Manukau catchment). 3. Recovery of toxoplasma oocysts from cat faeces. 4. Approaches considered for sampling from owned cat populations.	**Activities** 1. Continuation (year 2) of sampling and oocyst recovery. 2. Oocyst recovery and preliminary identification, DNA extraction, sequencing confirmation and genotyping of Year 1 samples.	**Activities** 1. Oocyst recovery, DNA extraction, sequencing confirmation and genotyping of Year 2 samples. 2. Data analysis: determination of oocyst shedding prevalence in target cat populations; profile of genotypes present.	**Activities** 1. Final data analysis and reporting. Discussion of results in science working group.
6. Research into effective cat-owner behaviour change approaches	**Outcomes** 1. Priority areas for research identified. 2. Viable and affordable methodologies identified. 3. Potential research partners identified.	**Outcomes** 1. Research project on effective techniques for behaviour change scoped and initiated.		**Outcomes** 1. Recommendations for action drawn from research.
		Outputs 1. Terms of Reference. 2. Research contract.	**Outputs** 1. Interim report on research progress.	**Outputs** 1. Results of behaviour change research.
	Activities 1. Meetings of an advisory group on social science/ behaviour change.	**Activities** 1. Meetings of an advisory group on social science/ behaviour change. 2. Drawing up of Terms of Reference and research contract. 3. Liaising with potential contractors.	**Activities** 1. Meetings of an advisory group on social science/ behaviour change. 2. Tracking progress.	**Activities** 1. Meetings of an advisory group on social science/ behaviour change and discussion of research conclusions.

Track 2: Filling knowledge gaps to establish greater certainty on the problem and our goals – 4-year plan

The proposed workstreams below are dependent on both securing the necessary funding and on collaboration with a range of potential partners both within and outside government. Priorities will need to be identified, depending on the funds secured and the willingness of others to collaborate. The first step will therefore be to scope potential funding and partners and then modify the plan accordingly with input from the Toxoplasmosis Strategic Science Advisory Group.

Proposed activities:

1. Improve certainty of the estimate of Hector's and Māui dolphin deaths from toxoplasmosis.
2. Identify and target hotspots of toxoplasma contamination in the marine environment and associated catchments.
3. Genotype toxoplasma strains to better understand which cat populations shed the strain that is known to be lethal to Hector's and Māui dolphins.
4. Improve understanding of the other factors contributing to death of dolphins from toxoplasmosis (e.g. environmental contaminants, concurrent disease).

(Note – these will then feedback to guide further activities in Track 1).

The actions required to address uncertainties and knowledge gaps over the 4-year period of the plan are detailed in Table. 2.

Table 2: Actions to address uncertainties and knowledge gaps over the 4 years of the toxoplasmosis action plan

Addressing uncertainties	Year 1	Year 2	Year 3	Year 4
Improve certainty of the estimate of Hector's and Māui dolphin deaths from toxoplasmosis	**Outcomes** 1. Existing information is reviewed. 2. Carcass recovery programme is enhanced.	**Outcomes** 1. Any required changes to carcass recovery programme are signalled.	**Outcomes** 1. Early estimates of any changes are signalled. 2. Any required changes to carcass recovery programme are instigated.	**Outcomes** 1. Greater certainty around estimates of dolphin mortality from toxoplasmosis.
	Outputs 1. Assessment of the prevalence of toxoplasma infection in Hector's and Māui dolphins.	**Outputs** 1. Progress report on reviewed data. 2. Review of efficacy of approaches to alerting and recovery of carcasses.	**Outputs** 1. Draft report circulated.	**Outputs** 1. Report incorporated into review.
	Activities 1. Collect information for assessing the mortality and population risk of toxoplasmosis for the dolphins. 2. Review existing data. 3. Carcass recovery programme (including PR outreach, e.g. citizen science) involving dedicated patrols of beaches at the most important time of year for carcass recovery. 4. Expand the necropsy programme (see Trial 4). 5. Look at seasonal and sex bias in dolphin deaths based on carcass recovery.	**Activities** 1. Increase recovery rate of carcasses. 2. Review currently available data and analyse necropsy results. 3. Genotyping of different strains of toxoplasma recovered from dolphin carcasses, including latent infected dolphins (i.e. toxoplasma present but not the cause of death).	**Activities** 1. Report drafting.	**Activities** 1. Discussion with science working group.
Identify and target hotspots of toxoplasma contamination in the marine environment and associated catchments	**Outcomes** 1. Spatial analyses have identified potential hotspots of toxoplasma contamination in marine and freshwater environments.	**Outcomes** 1. Models of hotspots are available for review.	**Outcomes** 1. Early indications of hotspots are signalled.	**Outcomes** 1. Spatial analyses have identified hotspots of toxoplasmosis contamination in marine and freshwater environments.
	Outputs 1. Modelling of turbidity and plumes from catchments and their dispersal in coastal currents.	**Outputs** 1. Model maps are available.	**Outputs** 1. Draft report/paper.	**Outputs** 1. Report to input into review programmes.
	Activities 1. Spatial analyses to identify hotspots of contamination in marine and freshwater environments, focussing on catchments on the WCNI (e.g. through modelling using a coupling of the Top Net Hydrological model with coastal hydrodynamic models). Terminal load dispersal of different catchments will be examined. Spatial analysis will initially concentrate on how oocycts reach the key core habitat of Māui dolphins.	**Activities** 1. Evaluate models to inform management options and trial decision making.	**Activities** 1. Draft report/paper.	**Activities** 1. Discussion with science working group.

Table 2: Actions to address uncertainties and knowledge gaps over the 4 years of the toxoplasmosis action plan (cont.)

Addressing uncertainties	Year 1	Year 2	Year 3	Year 4
Genotype toxoplasma strains to better understand which cat populations shed the strain that is known to be lethal to Hector's and Māui dolphins	**Outcomes** 1. Protocols are established. Target cat populations and study approaches are determined.		**Outcomes** 1. Initial understanding of the genotypes of toxoplasma strains in WCNI cat populations is available for review.	**Outcomes** 1. Genotyping of toxoplasma strains of different cat populations (i.e. by location or ownership status) is underway to identify which cat populations are shedding strains that are known to be lethal to Hector's and Māui dolphins.
	Outputs 1. Research plan finalised.	**Outputs** 1. Samples from year 1.	**Outputs** 1. Draft report.	**Outputs** 1. Final report.
	Activities 1. Sampling protocol established. 2. Appropriate methodologies scoped. 3. Ethics approval obtained.	Activities 1. Samples analysed. 2. Samples archived.	Activities 1. Report drafting.	Activities 1. Discussion with science working group.
Improve understanding of the other factors contributing to death of dolphins from toxoplasmosis (e.g. environmental contaminants, concurrent disease)	**Outcomes** 1. Reviewed sampling protocol.			
	Outputs 1. Sampling protocol developed. 2. Existing samples analysed where feasible.	**Outputs** 1. Progress report.	**Outputs** 1. Draft reports.	**Outputs** 1. Final reports available for review of overall research programme.
	Activities 1. Increased and expanded necropsy work (e.g. determination of organic pollutant levels etc.)	**Activities** 1. Analysis of samples.	**Activities** 1. Draft reports circulated.	