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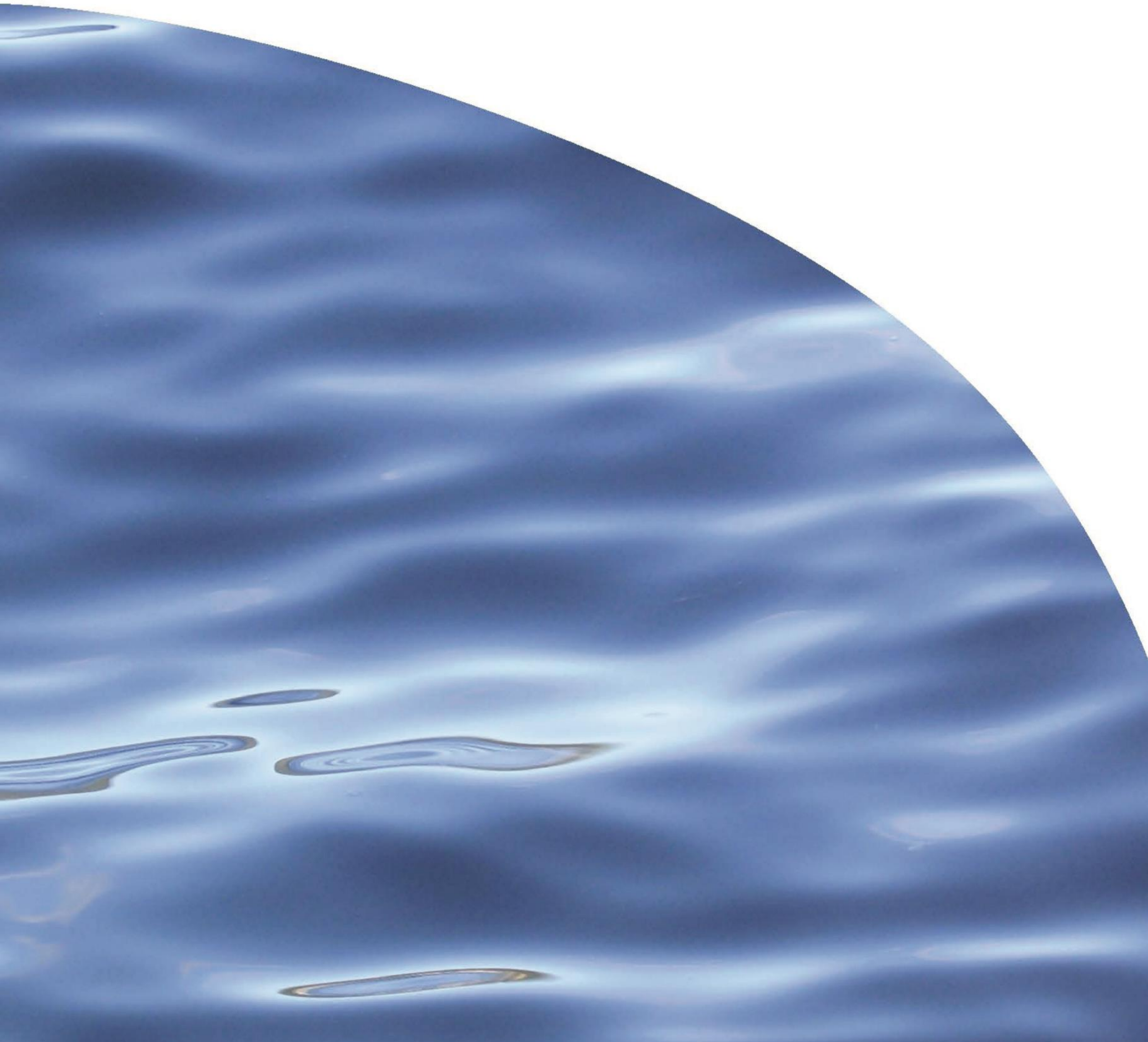
POP2019-01 ELECTRONIC DEVICES TO ASSESS DISTRIBUTION, DIVING AND FORAGING BEHAVIOUR OF HECTOR'S DOLPHINS



POP2019-01 ELECTRONIC DEVICES TO ASSESS DISTRIBUTION, DIVING AND FORAGING BEHAVIOUR OF HECTOR'S DOLPHINS

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EXECUTIVE SUMMARY

Previous research programmes on tagging of Hector's dolphins have demonstrated that electronic tagging can aid in investigating important aspects of biology and ecology, which is also supported by many international tagging programmes on other cetacean species reviewed in this report. While both these New Zealand studies had relatively small sample sizes, the researchers concluded that Hector's dolphins are suitable candidates for satellite telemetry studies and that the risk to this species from capture, handling and tagging appears low. Unfortunately, neither of these projects included a comprehensive follow-up research programme and so there is little scientific literature available from which to assess any potential short- or longer-term impacts on tagged animals.

There is a wide range of data that can be collected from electronic tagging projects. Given the variety of data types, there is an equally diverse range of research questions that could be investigated. This report identifies several general research areas that could be addressed by tagging and provides recommendations for the tagging methods that can best address these different research areas. In addition, specific details are provided for two different tagging programmes related to the collection of fine-scale distribution, diving and foraging behaviour of Hector's dolphins including the pros and cons of different tagging approaches.

It is important that any proposed research project is carefully evaluated against specific research questions in any future study to ensure that appropriate methods and tagging techniques can be selected. Whilst the various tagging methods identified can provide useful data in addressing different research areas, the development and specification of any research programme is extremely complex. As previously discussed, it will be necessary to consider a wide range of issues well in advance in order to confirm that the chosen method can deliver required outcomes for a specific research question. These include issues such as sample size, animal welfare, cost, and considerations of accuracy and precision of data but, just as important, are considering public and Treaty Partner views.

Notwithstanding these issues, electronic tagging can address the current knowledge gap in spatial/temporal distribution patterns that is needed in order to better inform Hector's dolphin conservation management. A recent cetacean tagging programme that investigated movement patterns (which led to positive conservation and management outcomes) is the Bryde's whale suction cup tagging study. The results from this research initiated changes in shipping traffic, which has led to reduced vessel strike of whales.

There are a wide variety of electronic tag types and attachment methods suitable for Hector's dolphins, all of which have different advantages and disadvantages, and can be used to answer a diverse range of potential research questions. A range of recommendations about the best tagging method to address each area of research is provided, but it is not possible to determine the optimal tagging programme unless there is a specific research question and the relative weighting of potential competing considerations (e.g. tag retention vs animal

welfare vs sample size vs cost) are stated. Nevertheless, as a general rule, the higher the quality and quantity of data produced, the higher the impact on individual dolphins.

The assessment of any proposed tagging programme should follow a strict evaluation process following international best practice. This will ensure that any tagging programme is carefully assessed against issues such as welfare considerations, likelihood of delivering a robust result for the research question of interest, stakeholder and Treaty Partner consultation, and consideration of alternative methods.

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1. INTRODUCTION

The understanding of the biology of marine mammals and their habitat requirements, and our ability to mitigate threats to them, are challenged by the difficulty of observing animals that spend most of their time beneath the water surface, often in remote areas (Nowacek et al. 2016; Andrews et al. 2019). These factors provide considerable challenges for research studies of marine mammals, including dolphin species (Read et al. 2003; Wells et al. 2017, Balmer et al. 2018). However, an understanding of dolphin biology, ecology, physiology, and behaviour (especially around fishing nets) is essential if these species are to be managed and protected effectively (Nowacek et al. 2016). These challenges can be at least partly overcome by using animal-borne monitoring instruments (bio-logging tags; hereafter referred to as 'tags') (McIntyre 2014; McConnell et al. 2010; Lander et al. 2018; Horning et al. 2017, 2019). Effective development and implementation of appropriate methods to mitigate against detrimental anthropogenic activities, such as fishing, is largely determined by our understanding of species biology (Andrews et al. 2019).

There are a wide variety of tags suitable for undertaking dolphin research including environmental (e.g. water temperature, salinity; Grist et al. 2011), physiological (e.g. heart rate, body temperature; Williams et al. 2015; McDonald et al. 2018) and behavioural aspects (e.g. dive depth and duration, acceleration, geographic position; Skrovan et al. 1999; Andrews et al. 2008; Sakai et al. 2011; Williams et al. 2015). All of these tags are capable of recording and / or transmitting data directly from the tagged animal to deliver fine-scale environmental, biological and behavioural data necessary to inform species management.

Whilst electronic tags provide large amounts of detailed scientific data, which cannot at present be reproduced through other research methods, tagging also presents potential risks to dolphins. These can include alteration of physiology and behaviour, which may lead to undesirable health outcomes. These impacts may also affect data integrity and interpretation, making it essential that any potential impacts are identified and the likely influence on the resulting data is understood. Therefore, it is essential that any field study should be evaluated against costs and benefits. Specifically, tagging studies should consider the benefits from improved data collection that can be used to better inform management practices that will support thriving dolphin populations, with mitigating potential effects on animal health and welfare, and the cost of undertaking such research.

Hector's and Māui dolphin (*Cephalorhynchus hectori*), comprising the South Island subspecies referred to as Hector's dolphin (*C. h. hectori*) and the North Island subspecies known as Māui dolphin (*C. h. Māui*), are endemic to the coastal waters of New Zealand. The reproductive isolation of the Māui subspecies is supported by a more recent genetic analysis with a larger sample size (Hamner et al. 2014a) despite genetic analyses having located four Hector's dolphins off the West Coast North

Island (WCNI) (Hamner et al. 2014b). The New Zealand Threat Classification System lists the two subspecies as and *nationally vulnerable* and *nationally critical* for Hector's and Māui dolphin, respectively (Baker et al. 2019). The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species Reeves et al. 2013) lists the two subspecies as *endangered* and *critically endangered* for Hector's and Māui dolphins, respectively. Both subspecies are vulnerable to a range of threats including fisheries bycatch, toxoplasmosis deaths, habitat loss and fragmentation, coastal development and underwater noise (DOC/FNZ 2019). Conservation and management of Hector's and Maui dolphins is guided by recent decisions by the Government under the Hector's and Māui dolphins threat management plan (TMP), which has increased protected areas and introduced a wide range of other management measures (DOC/FNZ 2020).

The Cawthron Institute was contracted by the Department of Conservation (DOC) to undertake a literature review of internationally accepted best practice marine mammal electronic tagging devices and to provide recommendations for the potential use of these devices to assess fine scale behaviour of Hector's dolphins. This project forms a part of the Conservation Services Programme (CSP) Annual Plan 2019-2020 against contract POP2019-01.

1.1. Project scope

This report assesses electronic tagging technology currently used in cetacean monitoring and provides recommendations of a low-risk method that can be used in any future behavioural studies involving Hector's dolphins. The project has three main objectives:

1. international literature review of marine mammal tagging practices
2. identify operational, biological, and environmental factors that are relevant to the investigation of the fine-scale distribution, diving and foraging behaviour of Hector's dolphins
3. provide recommendations on the most effective electronic tagging method for use in assessing fine scale Hector's dolphin behaviour (spatial/temporal).

2. METHODS

2.1. Review and analyses of international electronic tagging literature

The review of international literature on the use of electronic tagging for cetacean monitoring included the following source material: international scientific literature, government agency commissioned reports, conference proceedings, commercial research and results from industry and scientific trials. In this field of research, there is also a considerable body of grey literature that is difficult to source, but which is a large and valuable source of relevant information in this area. These sources were also reviewed through direct searching of conference, workshop, meeting, and observer programme reports, which are often not well referenced in electronic databases. Electronic search engines and databases were used including: Web of Science, Current Contents, Google Scholar, and general internet searches, using keywords such as: bio-logging, radio-tagging, satellite tagging, tagging, telemetry, dolphin, PTT, animal movement and tracking.

Results from individual reviews were then used to identify the most promising scientific literature and reports for understanding the potential for these devices to be used in future behavioural research with Hector's dolphins. These are summarised in the report. All results from the review of each reference were collated in an Excel spreadsheet allowing fully searchable access to the record summaries. A copy of this spreadsheet is available from DOC upon request[1].

Individual references were evaluated and reviewed against the following criteria:

1. *level of scientific rigour* – this assessment was undertaken through a consideration of how well the reference met accepted scientific norms for the following categories: (i) experimental design, (ii) appropriate statistical analysis, (iii) robust results and (iv) conclusions follow results. References were broadly grouped into low, medium or high depending on how well they met the four criteria identified above. While our assessment of rigour is subjective to a degree, it does provide high-level and consistent means in which to rank references' scientific standards and provides an indication of how well the reference follows scientific protocols.
2. *level of proven efficacy* – this assessment was undertaken through a consideration of how well the research method (e.g. tagging type) met the research question posed. The following aspects were considered: (i) tag duration, (ii) level of adverse effects, (iii) did the outputs address the research question, and (iv) how well did the tags perform? References were broadly grouped into low, medium or high depending on how well they met the four criteria identified above. While our assessment of rigour is subjective to a degree, it does provide high-level and consistent means in which to rank references' scientific standards and provides an indication of how well the reference follows scientific protocols.

[1] Electronic spreadsheet available from csp@doc.govt.nz

3. *caveats and uncertainties in methods* – any caveats or uncertainties noted in the reference or apparent from a review of the reference were listed.
4. *impacts of tagging on animal health* – any impacts noted in the reference or apparent from a review of the reference were listed.
5. *relevance to Hector's or Māui dolphins* – the method in the reference was evaluated against how well the methods could be applied to Hector's and Māui dolphins. For example, tag attachment methods used on a whale would not be appropriate for use on dolphins, but the type of tag itself (e.g. satellite tag) if repackaged into a smaller configuration could potentially be used on a dolphin.
6. *costs and benefits* – these considered a range of different types of costs and benefits including financial, animal welfare, conservation and management outcomes.

2.2. Assessment of tagging methods and other considerations

Based on the data collected in the literature review, expert advice, author experience and expertise, and feedback from the CSP technical working group (TWG), the following issues were assessed and summarised:

- review of previous dolphin tagging work undertaken in New Zealand
- review and comparison of different electronic tagging methods including strengths and weaknesses, time frame for results, and also a brief consideration of methods other than tagging
- review of potential impacts on animal health and other considerations.

All of these issues are summarised in the electronic Excel spreadsheet previously mentioned, but only the key issues are summarised in this report.

2.3. Comparison of methods

Summary tables were compiled providing a comparison of various electronic tagging methods based on the review of all references and analyses undertaken as part of Objectives 1 and 2 outlined in Section 1.1.

2.4. Recommendations for potential electronic tagging methods

Recommendations about potential methods for addressing a range of research questions are also provided but with the primary focus of addressing Objective 3 outlined in Section 1.1, which was to *provide recommendations on the most effective electronic tagging method for use in assessing fine scale Hector's dolphin behaviour (spatial/temporal).*

3. RESULTS

3.1. Literature review findings

A total of 36 papers and reports were included in the literature review spanning the period 1972 to 2020. Most (78%, n = 28) of the papers were from the last 10 years and reflect a relatively rapid increase in dolphin tagging studies worldwide, consistent with increasing availability of electronic tags to researchers (e.g. commercially produced and available). Two recent papers provide excellent and complementary overviews of marine mammal tagging globally:

- Andrews et al. (2019) focuses on summarising the best practice guidelines for cetacean tagging developed by many of the leading taggers in the world. While the document doesn't provide advice or information about specific techniques and tags, it describes an excellent process for the evaluation of tags and tagging programmes with the aim of supporting the development of tagging programmes that are consistent with international best practice and genuinely consider all the potential costs and benefits. Specifically, the review paper discusses tag types and attachment sites, operator training, and protocols for tagging via both remote and capture-release deployment. Importantly, it also highlights the need for ethical and scientific justification for tagging studies to address bona fide research/conservation questions, for the need to minimise impact caused by tagging, and to improve knowledge around post-tagging health status. The authors also discuss exploration of alternative methods for behavioural studies.
- McIntyre (2014) is a comprehensive review of 620 published research papers on marine mammal tagging, most of which were on pinnipeds, which were not covered in our review. The main conclusions were that most tagging research was strongly biased towards pinnipeds (e.g. > 75% of references). Dolphin tagging research only comprised 26 of all references (e.g. < 5%), highlighting the limited amount of dolphin tagging work being conducted in proportion to other marine mammal species. This review concludes that the explanation for the limited number of studies on dolphins was due to the difficulty in attaching devices but notes that the number of dolphin tagging studies has been increasing in recent years as attachment methods have improved. Overall, the results presented indicate that a comparatively small proportion of bio-logging studies on marine mammals directly address applied conservation questions, and that the use of bio-logging technologies is still underrepresented in conservation and management science.

3.1.1. Scientific rigour

One of the issues considered in reviewing scientific literature in this report was the scientific rigour of each study as a useful measure of the potential efficacy/value (detailed in Section 2.1). While our assessment of rigour is subjective to a degree, it does provide high-level and consistent means in which to rank references scientific standards, and provides an indication of how well the reference follows scientific protocols (e.g. experimental design, appropriate statistical analysis, robust results and conclusions). This assessment is important in providing later context for determining how useful and accurate results are from individual studies. For example, a significant result from a study with a high degree of scientific rigour is likely to be more robust (and useful) than one from a study with a low level of scientific rigour. A summary of the highly relevant papers identified from the literature review is provided in Table 1.

Of the 26 references for which rigour could be assessed (e.g. review and other non-experimental studies were excluded), only 7 (27%) were estimated to have moderate or high rigour. This low number is perhaps directly linked to three main issues:

1. Sample size – Tagging studies can be very expensive to undertake and therefore, it is often challenging for tagging research to achieve large sample sizes. Small sample sizes can limit the value of a study's findings as it is unclear if the results are likely to be representative of the wider population, while levels of uncertainty are often very large or not even possible to estimate. Most of the tagging studies (e.g. > 75%) considered had a sample size of less than 20 individuals. However, there are some notable exceptions. Andrews et al. (2015) reported on 307 tag deployments of LIMPET tags over a ten-year period focused on eight different cetacean species with an average number for each species of almost 40 individuals. The size of this programme is unusual and was likely possible as the authors are the developers and manufacturers of these tags (i.e. they likely had access to these tags at lower than normal commercial rates). Overall, it appears that sample size considerations in tagging studies are more driven by budget limitations than experimental design considerations.
2. Sample selection – Most studies do not sample a representative cross section of the population due to limited sample sizes, and in some cases limited access to a full cross-section of individuals. McIntyre (2014) identifies that over 70% of reviewed tagging studies were undertaken on adult age classes and were heavily biased towards females. While this does not limit the applicability of the collected data to the group of individuals that were sampled, it does mean that these data often cannot be extrapolated to other age and sex classes, which can be significantly different ecologically.
3. Complex metadata – Analysis of spatial tracking and other tagging data can be statistically complex and computationally demanding. As computing power and statistical analysis methods have improved over time, more robust use of tagging data can be undertaken allowing for more sophisticated and comprehensive analyses.

Table 1. Summary of references considered useful in the development of any future Hector's dolphin tagging programme

Reference number	Year	Full reference	Type of reference	Species	Attachment and tag type	Scientific rigour[1]	Efficacy in addressing research question	Estimated cost of research
1	2015	Andrews et al. (2010). Improving attachments of remotely-deployed dorsal fin-mounted tags: tissue structure, hydrodynamics, in-situ performance, and tagged-animal follow-up. Grant number: N000141010686. www.alaskasealife.org	Research - tagging	Various small and medium cetaceans	Suction cup, satellite	Low to moderate	Moderate to high	$100,000-300,000
2	2019	Andrews et al. (2019). Best practice guidelines for cetacean tagging. Journal of Cetacean Research and Management. 20: 27-66.	Review - guidelines	Various	Various	NA	Variable	NA
3	2018	Balmer et al. (2018). Ranging patterns, spatial overlap, and association with dolphin morbillivirus exposure in common bottlenose dolphins (*Tursiops truncatus*) along the Georgia, USA coast. Ecology and Evolution. 8: 12890-12904.	Research - tagging	Common & bottlenose dolphins	Bolt-on, satellite	Low to moderate	Moderate to high	$50,000-$100,000
5	2016	Carter et al. (2016). Navigating uncertain waters: a critical review of inferring foraging behaviour from location and dive data in pinnipeds. Movement Ecology 4: 25.	Review - summary	Pinnipeds	Various	NA	NA	NA
22	2014	McIntyre T (2014). Trends in tagging of marine mammals: a review of marine mammal bio-logging studies. African Journal of Marine Science. 36(4): 409-422.	Review - summary	Variety	Various	NA	NA	NA
27	2016	Nowacek et al. (2016). Studying cetacean behaviour: new technological approaches and conservation applications. Animal Behaviour. 120: 235-244.	Review - summary	Various	Various	NA	NA	NA
29	2014	Reisinger et al. (2014). Satellite tagging and biopsy sampling of killer whales at subantarctic Marion Island: effectiveness, immediate reactions and long-term responses. PLoS ONE. 9(11):e111835.	Research - tagging	Killer whales	Anchored, satellite	Moderate	Moderate	$500,000
32	2005	Stone et al. (2005). Hector's dolphin (*Cephalorhynchus hectori hectori*) satellite tagging, health and genetic assessment. Submitted to the Department of Conservation (DOC), Auckland Conservancy. 1 June 2005. 77 p.	Research - tagging	Hector's dolphins	Bolt-on, satellite	Moderate	High	$100,000 - 300,000
34	2020	Teilmann et al. (2020). A comparison of CTD satellite-linked tags for large cetaceans - Bowhead whales as real-time autonomous sampling platforms. Deep-Sea Research 157: 103213.	Research - tagging	Bowhead whale	Consolidated, satellite tag	Low	Variable	$500,000
36	2012	Walker et al. (2012). A review of the effects of different marking and tagging techniques on marine mammals. Wildlife Research 39: 15-30.	Review - summary	Various	Various	NA	Variable	NA
39	1998	Stone et al. (1998). Respiration and movement of Hector's Dolphin from suction-cup VHF radio tag telemetry data. Journal of Marine Technology Society 32: 89-93.	Research - tagging	Hector's dolphins	Suction cup, VHF	Moderate	Moderate	$100,000 - 300,000

Notes: [1] While our assessment of rigour is subjective to a degree, it does provide high-level and consistent means in which to rank references scientific standards, and provides an indication of how well the reference follows scientific protocols (e.g. experimental design, appropriate statistical analysis, robust results and conclusions). A more detailed description is provided in Sections 2.1 and 3.1.1). NA indicates *Not Applicable.* For example, for scientific rigour, NA indicates that given the type of reference it was not possible to provide an evaluation against this category as review papers covered a variety of research and so it was not possible to provide an evaluation of scientific rigour. For example, for estimated cost of research, NA indicates that it was a literature review and therefore, not a primary research project and so no cost was estimated.

We noted that very few of the references clearly stated a hypothesis as to what biological or ecological questions were being tested. Instead, many studies seemed to be more exploratory in nature (i.e. pilot studies to gather initial findings). While there is nothing inherently wrong with this approach if there is little or no impact on the animal, it can lead to poorly designed studies and less robust results. This observation is likely related to McIntyre's (2014) discussion around a noted paucity of tagging research with explicit conservation and/or management implications despite most references claiming that the research was actually to address such specific needs.

Given that electronic tagging of dolphins is rarely undertaken, any data resulting from a tagging research programme are likely to be novel and therefore the results are likely to be published, potentially irrespective of the actual quality of the research. Future tagging projects would positively benefit from improved consideration of experimental design and an accurate assessment of the actual management outputs. Consideration of these two issues is often overlooked or overstated when justifying tagging studies. Specifically, any future tagging study should ensure that all aspects of the tagging programme are appropriately evaluated prior to the programme commencing including: the development of testable hypotheses, experimental design, analysis methods, optimal sampling strategies and sample size considerations and, perhaps most importantly, whether the research will actually provide demonstrable conservation and management benefits.

3.1.2. Tag efficacy

While there are many ways to measure efficacy, the definition used in this review was an assessment of the length of attachment duration weighted by the potential or likely level of impact on the tagged animal. As with scientific rigour, this is a relatively subjective measure, but is useful in identifying references that are likely to be highly informative, but with little impact to the individual.

Of the 19 references able to be assessed, 11 (58%) were scored as being of moderate or high efficacy. It is also important to note that while these studies were assessed as being 'successful', some still had significant caveats or uncertainties associated with their work, which makes it challenging to determine whether a result was actually robust. It is difficult to quantify the impact of many of these caveats. While study results may appear positive, it may retain some fundamental issues that make the conclusions uncertain (see Section 3.1.3 for a list of caveats and uncertainties identified).

One issue that arose while assessing efficacy of the various studies was the influence that the two main tag attachment methods (sub-dermal anchors and suction cups), had on this definition of efficacy. Specifically, anchors had a longer attachment time but with a higher impact, whereas suction cups had a shorter attachment time but with a considerably lower impact on some species. As a result of this relationship, it was difficult to reliably identify less or more effective tagging studies due to the strong influence of attachment type.

3.1.3. Caveats and uncertainties in methods

Given the wide breath and scope of the literature as well as the inherent challenges in undertaking tagging studies, it is no surprise that a range of caveats and limitations were identified. The key message is that all of these issues need to be considered in the development of any future tagging project. While these issues do not necessarily invalidate the results found in all cases, they do make it more difficult to provide definitive conclusions to inform decision-making. We have suggested an evaluation framework to consider these issues in Section 3.5.

A complete list of all caveats and uncertainties identified by reference are available in the full Excel electronic table of results file. Some of the key issues are listed below:

- inadequate description of methods and results
- inappropriate use of analysis methods (e.g. lack of independence of data, autocorrelation, pseudo-replication)
- too small sample sizes to detect a statistically meaningful result (e.g. low statistical power)
- lack of a control in studies (i.e. how representative of normal behaviour is the behaviour of a tagged individual?)
- poor representativeness of tagged animals across whole population (e.g. selection bias based on age, sex, location, behaviour)
- lack of a consistent application of an experimental approach including random elements to design
- inappropriate pooling of results across locations and individuals
- lack of testing of seasonal and/or different behavioural states (e.g. breeding, migratory, feeding)
- poor follow-up studies of tagged individuals to investigate potential short, medium, or long-term impacts
- accuracy of locational information inappropriate to the research question (e.g. variability in the accuracy of a location fix is greater than size of the area being investigated)
- lack of independent oversight and reporting of tagging studies’ impacts on animals
- exclusion of some individuals from analyses as seen as outliers or exhibited unusual/unexpected behaviour
- little monitoring of other covariates that could be useful as explanatory variables (e.g. oceanographic features, behaviours relating to breeding, migration, reproductive status)

- poor reporting of 'failures' (e.g. tags that didn't transmit or collect data, attachments methods that failed, etc.)
- limited open sharing of data on tag development (e.g. proprietary tags mean experiences [positive or negative] are not shared with the research community).

While these issues are all important, one of the most common criticisms of tagging studies is around whether the behaviour of tagged dolphins can be considered to be indicative of 'normal' or untagged behaviour. The reality is that it is difficult to assess 'normal' behaviour in individuals if there is no way of independently monitoring them other than from the tag itself. There are a range of studies that have demonstrated significant behavioural changes in tagged seals including increased respiration, oxygen consumption, dive behaviour (e.g. fin stroke rate, dive speed and angle) and metabolic rates (Costa & Gentry 1986; Feldkamp 1987; Boyd et al. 1997; Cornick et al. 2006; Jones et al. 2013), but there have been fewer comparable studies for dolphin tagging. Hoop et al. (2014) undertook controlled experiments on suction cup tagged and untagged captive bottlenose dolphins which showed that the dolphins modified their behaviour (i.e. significantly reduced swim speed by 11%) to maintain metabolic output and energy expenditure when faced with tag-induced drag. Similar results demonstrating reduced swimming speed and behavioural change have also been reported in studies of other captive dolphins (Lang & Daybell 1963; Davis et al. 1999; Skrovan et al. 1999; Blomqvist & Amundin 2004). Andrews et al. (2015) investigated the potential effects of tagging on a range of species from a long-term database and found no evidence of any significant effect of tagging on dolphin health or survival.

The key conclusion of these data is that tagging can impact and change the behaviour of a tagged dolphin. While these studies were principally from captive dolphin studies, it is logical to assume that similar impacts are likely for free ranging and wild dolphins that are tagged. While the exact nature, degree and duration of impact is unclear, it is critical that any tagging programme considers possible impacts as part of the evaluation process and include an assessment about the degree to which the data they are interested in collecting are likely to influenced by a tagging regime.

3.2. Review of dolphin tagging research in New Zealand

While marine mammal tagging has been used widely around the world, there have only been a few projects carried out in New Zealand over the past 40 years. Six New Zealand-based dolphin tagging projects have been reported in the literature and are summarised in Table 2. In addition to these dolphin projects, four whale tagging projects have been undertaken in New Zealand water and / or whales (e.g. Childerhouse et al. 2010 – southern right whales; Constantine et al. 2015 – Bryde's whales; Goetz et al. 2018 – blue whales; Riekkola et al. 2018 – humpback whales).

The first tagging research on dolphins in New Zealand was aimed at investigating the distribution and abundance of Hector's dolphins in the Marlborough Sounds region between 1978 and 1982 (Baker 1984; Cawthorn 1988). There are few details of this research provided in published literature, but additional information was provided in email correspondence from Dr A. Baker (pers. comms. S. Childerhouse) in 2004 (Appendix A). The project involved pinning individually numbered tags to the dorsal fin. A tail grab was used to capture dolphins and a cradle to lift them onto the vessel. Dolphins settled quickly after capture, sat in the cradle quietly during the 3–4 minutes of attachment, and often reappeared after release and starting bow riding. There were resightings of nine individuals, mostly over a 1–3 month period post-capture, with one resighting after two years and another after nearly five years.

Würsig et al. (1991) and Cipriano (1992) tracked ten individual dusky dolphins at Kaikoura during the winter of 1984 and spring-summer of 1987–88. The tags were pinned to the dorsal fin and had radio transmitters attached to describe movement and diving behaviour. Data included detailed dive data from dolphins by season and also showed movements around Kaikoura (and as far north as Cape Palliser at the southwest tip of North Island) as well as providing information on dive times and locations. Tag technology has moved on considerably in the past 30-years, therefore, the use of results from the dusky dolphin studies, to help inform the study design of any future research on Hector's dolphins, has a low level of relevance. There was also no recorded follow research from which lessons could be learnt from the effects of tagging on dusky dolphins' health and welfare.

Stone et al. (1998) tagged nine free-swimming Hector's dolphins with suction cup tags containing radio transmitters in the Banks Peninsula area (Akaroa). The aim was to describe movements and behaviour. Movement data showed that dolphins spent time in Akaroa Harbour before moving out in the late afternoon or evening and then returning the next morning. Respiration rate data were also collected. These data supported previous studies which described a diurnal pattern of movement for this species. Respiration rates and parameters were also provided.

Table 2. Summary of New Zealand dolphin tagging studies reported in the literature.

Reference	Species	Tag type	Research question	Attachment method	Attachment type	Sample size
Baker (1983) & Cawthorn (1988)	Hector's dolphins	Individual ID number	Distribution, abundance	Live capture	Pinned to dorsal fin	23
Würsig et al. (1991) & Cipriano (1992)	Dusky dolphins	VHF transmitter	Distribution, dive behaviour	Live capture	Pinned to dorsal fin	10
Stone et al. (1998)	Hector's dolphins	VHF transmitter	Distribution	Free swimming	Suction cup on flank	9
Schneider et al. (1998)	Bottlenose dolphins	Dive recorder & VHF transmitter	Dive behaviour	Free swimming	Suction cup on flank	5
Stone et al. (2005)	Hector's dolphins	Satellite transmitter	Distribution	Live capture	Pinned to dorsal fin	3
Pearson et al. (2017, 2019)	Dusky dolphins	Satellite & VHF transmitter, camera	Dive & social behaviour	Free swimming	Suction cup on flank	8

Schneider et al. (1998) tagged five bottlenose dolphins in Doubtful Sound in 1995. The tags were attached with a suction cup to free-swimming dolphins. The tag included a radio transmitter and time-depth recorder to describe movement, dive, and other behaviours. The tagging was relatively unsuccessful with little dive or movement data collected as dolphins showed strong reactions to the attachment of the tag and generally swum rapidly and/or leapt until the tag dislodged. The type of reactions to tagging recorded in this study have not been reported in other studies, suggesting that the dolphins in Doubtful Sound may be more disturbed by suction cup tagging than other bottlenose dolphins elsewhere.

Stone et al. (2005) tagged three Hector’s dolphins with satellite transmitters to describe distribution pattens in the Banks Peninsula area in 2004. Dolphins were captured using a spring-loaded tail grab while bow riding and slowly pulled back to the boat before being lifted aboard and restrained on a table. Tags were pinned to the dorsal fin. All three satellite tags transmitted for more than three months providing information on movements and distribution. The author’s concluded that Hector’s dolphin was a suitable candidate for satellite telemetry studies and that the risk to this species from capture, handling and tagging seemed to be low. However, it is important to note that this conclusion held by the authors was unable to be independently confirmed as there were no resightings of any of the dolphins post-release.

Mattlin and Murdoch (2010)[2] described an approved and funded project to undertake satellite tracking of Hector's dolphins at Cloudy and Clifford bays to investigate overlap with potential threats, but for logistical reasons the project was never undertaken.

Pearson et al. (2017, 2019) tagged eight free swimming dusky dolphin at Kaikoura using a suction cup tag to research movement and social behaviour in 2015. Data collected included dive and social behaviour, prey, and physiology.

While not directly relevant to this project, it is useful to note that there is regular and widespread use of tags for the tracking and research of other many other kinds of marine wildlife in New Zealand including seabirds, turtles, penguins, seals, sea lions, and fish species, including sharks. In many cases, the basic tag technology used for these species is the same general design as for dolphins, although the attachment mechanisms vary significantly. In addition, there is considerable overlap in analytical methods between all these species as fundamentally the data collected by tags are the same, irrespective of the species the tags are placed on.

There were only six dolphin tagging research projects undertaken in New Zealand between 1978–2020. They had varied success in investigating the behaviour of Hector's, dusky, and bottlenose dolphins using suction cup and pinned dorsal tags. It is clear that there is a large knowledge gap in our understanding of fine-scale spatial/temporal behaviour in New Zealand dolphin species that is largely attributable to a lack of scientific data. There is also a clear need to increase our knowledge on welfare outcomes for tagged dolphins.

3.3. Comparison of different tagging methods

3.3.1. Tag instrumentation

There is a large variety of electronic tag types available and these have been grouped into similar types to simplify assessment. Table 3 (tags providing location data) and Table 4 (e.g. tags providing data other than location data) provide summaries of the different kinds of tags reported in the literature. In addition, there are short descriptions of the common use of each tag type plus advantages and disadvantages. The data presented in these tables come from a summary of all the literature reviewed with several key references providing useful summaries of different tag types (McIntyre 2014; Carter et al. 2016; Nowacek et al. 2016; Wisniewska et al. 2016; Andrews et al. 2019; Aguilar de Soto 2020).

[2] Reference: NIWA website accessed at https://niwa.co.nz/publications/wa/water-atmosphere-1-july-2010/balancing-act-for-hector%E2%80%99s-dolphins

The type of tag that is optimal for a research project will be strongly driven by the research question. It is essential that prior to any research project, a clear and concise research question or hypothesis is developed so that the different available tag types can be evaluated to assess which will best meet the research needs. Due to the current lack of data, as previously discussed, the focus of any future study of Hector's dolphins should include the practicality of using electronic tags to fill the knowledge gap on diving performance, nocturnal behaviour and diurnal distribution. This would be useful to better inform management of commercial fishing risks to Hector's dolphins. While the research question will be the primary driver for the choice of optimal tag, the choice will also be influenced by many other factors including:

- what level of animal impact is considered acceptable
- temporal and spatial coverage required to address the research question
- existing data that may already be available
- available expertise
- social license (critically including iwi perspectives)
- availability of devices (e.g. some are commercially available and others only available through collaborations with designers/manufacturers)
- locational coverage (e.g. Argos, GPS-GSM, VHF)
- cost.

There are a range of possible research questions relevant to Hector's dolphin conservation and management that a tagging project could address, but these decision-making processes must be undertaken comprehensively, addressing the factors above, to ensure that the appropriate tag choice(s) is/are made.

A wide range of tag providers offer a huge variety of tags and attachment mechanisms. The list below includes commercial suppliers (who sell to the public) and also research organisations (who may not sell to the public but often collaborate on projects). It is important to review and compare many different providers and tag models before settling on the most appropriate model. Tag suppliers include:

- Starr-Oddi Marine Device Manufacturing: http://www.star-oddi.com/
- Sonotronics Underwater Ultrasonic Tracking Equipment: http://www.sonotronics.com/
- Wildlife Computers: http://www.wildlifecomputers.com/
- Microwave Telemetry Inc. Bird and Fish Tracking Transmitters: http://www.microwavetelemetry.com/
- Sirtrack Wildlife Tracking Solutions: http://www.sirtrack.com/
- Lotek Fish and Wildlife Monitoring Systems: http://www.lotek.com/
- Vemco underwater acoustic telemetry transmitters and receivers: http://www.vemco.com/index.php

- Sea Mammal Research Unit: http://www.smru.st-and.ac.uk/
- Cefas Technology Ltd (CTL): http://www.cefastechnology.co.uk.

A visual representation of some of the main tag attachment methods is shown in Figure 1.

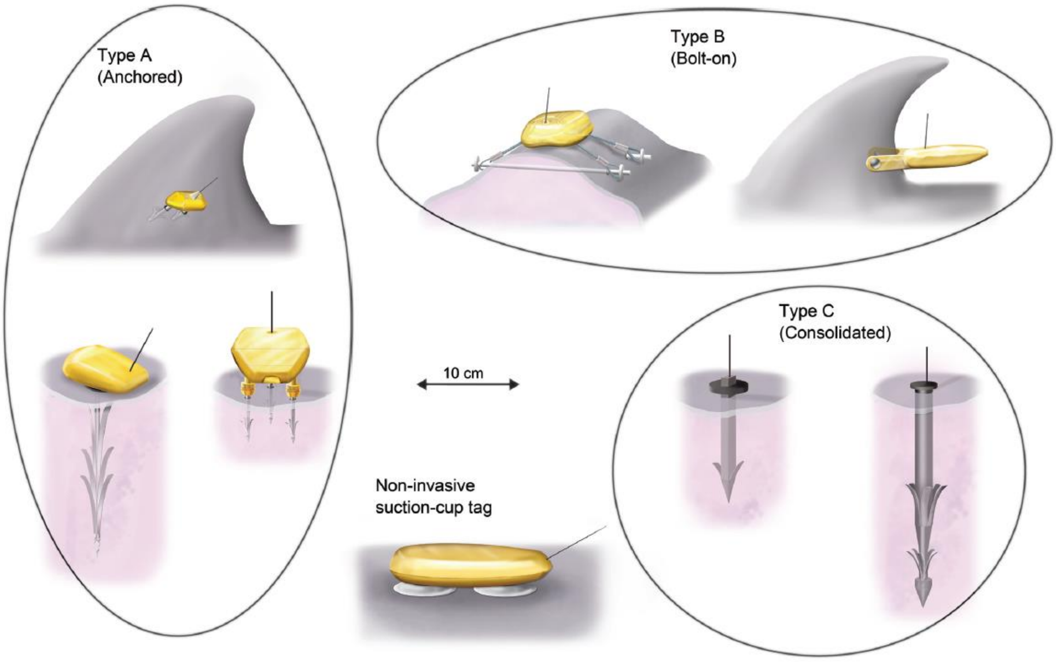

Figure 1. Illustrations of non-invasive (i.e. no break in the skin) and invasive (i.e. break the skin) attachment techniques. Four methods are presented: (A) anchored, (B) bolt-on, (C) consolidated, and (D) suction cup. Reproduced from Figure 3 in Andrews et al. (2019).

Table 3. Summary electronic tag type providing location information reported in the literature. GPS = global positioning system. GSM = global system for mobile (cellular).

Device	Example tag models	Location derivation	Data transmission	Common applications	Typical battery duration	Approx. Weight (g)	Advantages	Disadvantages
Radio tag	Mariner Radar (early studies); Advanced Telemetry Systems MM100 series	Very High Frequency (VHF) or Ultra High Frequency (UHF)	Acoustic telemetry; radio signal (VHF/UHF)	Early pinniped studies; short range studies; relocation for data logger recovery.	6–12 months	80–200 (early studies; 30)	Smaller & lighter than Argos/GPS units. No need to retrieve. Can be used to re-encounter specific individuals on a colony for recovery of archival devices.	Device must be in line-of sight range of base station(s) and/or mobile receiver(s) to record locations. Signal can be interrupted by terrain.
GPS logger	SIRtrack F1G	Fastloc GPS	Archival	Mainly individuals with restricted ranges (e.g. lactating females otariids during pup provisioning).	3 weeks to 6 months	215	Fast and accurate location estimates. Lighter than telemetry units. Salt-water switch turns the tag off when the animal dives/ hauls out to extend battery life.	Must be recovered to extract data, therefore often needs to be deployed in conjunction with VHF transmitter to facilitate re-encounter on the colony. Study limited to specific timescales (e.g. premoult, breeding females)
Argos relay tags	SMRU 9000x SRDL; Wildlife Computers Mk10 SPLASH Tag; Telonics ST-10 PTT	Argos	Argos	Very widely used. Long range pelagic pinnipeds in remote locations.	12 months	370	Can integrate other sensors such as wet-dry, CTD, or accelerometer. Useful in remote areas where no GSM coverage available. Complete data record can be retrieved if tag recovered.	Not all locations and dives transmitted. Data often patchy due to interrupted transmissions. Location estimates can carry high spatial error. Fine-scale reconstruction of movement not possible. Argos coverage poor in areas closer to equator.
GPS relay tags	SMRU GPS SRDL; Wildlife Computers Mk10 SPLASH tag	Fastloc GPS	Argos	Individuals in remote locations with nonGSM coverage or prospect of device retrieval.	3–6 months	370	As Argos relay tag (above). Solar powered option for extended battery life. Fast and accurate location estimates across most of the globe. Can integrate TDR.	Not all locations and dives transmitted. Data often patchy due to interrupted transmissions. Argos coverage poor in areas closer to equator. Entering GSM range data are lost.
GPS-GSM tags	SMRU GPS Phone tag	Fastloc GPS	GSM (FTP/SMS)	Pinnipeds in non-remote locations (with GSM coverage).	1–12 months	370	Many power options including solar panel. All dives and locations can be transmitted. Fast and accurate location estimates across most of the globe.	Individual must enter GSM range in order to transmit data (time lag in data retrieval). Not useful in remote locations. If tag detached at sea before entering GSM range data are lost.
GLS/SPOT tags	Wildlife Computers TDR-Mk9	Solar geolocation	Archival	Fish, birds, turtles, penguins.	8 years	5–120	Very small and with an extremely long battery life. Can log detailed foraging behaviour over long term. Cost effective.	Locational accuracy can be relatively poor. Must be recovered to retrieve data. Doesn't work in places without day/night cycle (i.e. polar regions). Limited data types collected.
Pop up tags	Wildlife Computers PAT tags	Geolocation	Archival until tag released when data are transmitted	Fish, turtles.	2 years	60	Archives data over long periods which is transmitted when tag is released and floats to surface. Cost effective.	Locational accuracy can be relatively poor. Doesn't work in places without day/night cycle (i.e. polar regions). Limited types of data collected.

Table 4. Summary of types of electronic tags providing information other than location data reported in the literature.

Device	Examples	Description of data collected	Common applications	Advantages	Disadvantages
Time-depth recorders	Wildlife Computers Mk9, Mk 10; Little Leonardo ORI400-D3GT	Depth (pressure), temperature.	Widespread application across a range of marine species for diving studies.	Cost effective. Simple. Advanced and robust technology with long development history. Satellite linked models available (but only data summaries available).	Limited covariate data collected. Collection of high-quality data can require recapture/recovery of tag.
CTD tags	SMRU CTD SRDL	Conductivity, temperature depth, fluorescence.	Regularly used on elephant seals for oceanographic research.	Long term duration with high-quality data. Satellite linked models available (but only data summaries available).	Large units for deployment on large animals only. Collection of high-quality data can require recapture/recovery of tag.
Magnetometer & Accelerometer tags	Wildlife Computers TDR10; Little Leonardo GPL400-D3GT, ORI400-PD3GTC	Depth, 3D movement data.	Fine scale movement data from seals and penguins.	High resolution diving and movement data.	Requires recapture/recovery of the unit to access data. Relatively short term (limited by memory).
Camera tags	Customised VC-VISS; Little Leonardo DVL1300M-VD3GT	Video, acoustic.	Video data from whales, seals, and dolphins to investigate dive and social behaviour, prey.	Visual record of behaviour and activity. Can attached with other tags to provide full record of diving.	Can be limited by low light levels (e.g. deep water) or murky water. Moderate term (limited by battery and memory). Generally small field of view and limited range of video.
Active acoustic tags	Vemco V16-6x-L	None.	Commonly used on teleosts and elasmobranchs to record presence/absence at recording stations.	Low cost (although it is necessary to have receiving stations to collect data). Can integrate with receiving stations from other projects to achieve high levels of coverage. Small units and easy to attach. Long term operations.	No data on movements away from receiving stations. No other data than position. Introduces additional noise into the ocean. Tag may make the animal more detectable by prey and/or predators. This type is not recommended for Hector's dolphin.
Passive acoustic tags	Acousonde 3A; AquaSound AUSOMS-mini	Acoustic.	Recording of animal and ambient acoustic data.	Full record of sound around the animal including vocalisations, heart rate, and fin beats. Can be used to measure and identify ambient & anthropogenic noise in the ocean.	Can be limited by background noise levels (e.g. water flow noise). Moderate term (limited by memory).
Physiological tags	Acousonde 3A; FirstBeat Technologies HR	Range of bio-logging data: heart rate, stomach temperature, jaw movement.	Monitoring of physiology of seals but less commonly on cetaceans	Provides insight into physiological of free ranging individuals. Wide range of data possible to be collected.	Can be difficult to attach and keep operational. Can be invasive to an individual.
Multi-sensor high-resolution acoustic recording tags (MHARTs)	SMRU DTAG; CATS CAM; UQ Z-tag	Various combination of the data identified from the previous tags above.	Deployed on larger species for general ecological studies.	Can provide integrated data from many sensors in one unit.	Generally larger units that cannot easily be deployed on smaller animals (e.g. Hector's dolphins) although there are now some smaller tag packages available. The large amount of data and energy drain leads to short deployment times.

3.3.2. Tag attachment methods

A major limitation in the use of bio-logging instruments on cetaceans has been attachment techniques (Hooker & Baird 2001). The additional difficulties in locating and attaching devices to exclusively aquatic marine mammals (compared with marine mammals that haul out on land) likely explains the high proportion of tagging studies for seals compared with cetaceans (McIntyre 2014).

Current attachment techniques for cetaceans include the use of stainless-steel barbs designed to penetrate the blubber of study animals (Minimikawa et al. 2007; Andrews et al. 2008) or potentially less-invasive suction-cups for shorter-term deployments (Amano & Yoshioka 2003; O'Malley Miller et al. 2010). Scientists generally rely on either capturing smaller cetaceans (Lydersen et al. 2002) or remotely deploying instruments using tagging poles (Davis et al. 2007), crossbows (Mate et al. 2011), firearms (Tyack et al. 2011) or air guns (Heide-Jørgensen et al. 2001).

While not strictly related to attachment type, the capture of a dolphin may be required to attach a tag. Although capture-release techniques in general involve greater risk to animals and to people than remote tagging techniques that do not involve restraint and handling, for some cetacean species of smaller body size, or whose behaviour does not allow for remote tagging, capture-release may be the more effective option (Andrews et al. 2019). Responses to capture vary by species, and risks must be weighed carefully against the benefits of tagging. One added advantage of capture is that there are additional data that can be collected to provide useful background, context, and information. It goes without saying that these opportunities should be maximised as long as the collection of these data does not unduly extend the length of the capture.

However, there have been some mortalities and injuries from captures reported overseas. Specifically, seven finless porpoises died during captures in China (Wang Ding et al. 2000), one bottlenose death out of 133 captures in the United States (Odell & Asper 1990), one Heaviside's dolphin died out of 24 captures in South Africa (Meÿer 1997), one vaquita death from two captures in Mexico (Rojas-Bracho et al. 2019), and there is documented damage to dorsal fins from attachment procedure on bottlenose dolphins in the United States (Mazzarella et al. 2002). While these studies only highlight some of the potential risks from captures, it has not been possible to accurately assess the mortality risk any further as little information is available in the published literature about the number of deaths as a function of sample size.

Whereas the practicality, effectiveness, and safety of available attachment techniques for cetaceans remain a challenge, the increasing number of publications for Odontoceti and Mysticeti tagging studies suggest that these limitations are being overcome (McIntyre 2014). The range of potential attachment mechanisms are summarised in Table 5. A description of the attachment type is provided as well as a brief summary of advantages and disadvantages of each method.

3.3.3. Attachment tag methods on Hector's dolphins

There have been two Hector's dolphin tagging projects in New Zealand, one of which used the bolt-on method (Stone et al. 2005) and the other used the suction cup method (Stone et al. 1998). Both these methods have been demonstrated to be effective at attaching tags to Hector's dolphins, albeit with significantly different attachment durations.

In Stone et al. (2005), the authors provided some detailed descriptions and observations about the tagging undertaken using the bolt-on method for three Hector's dolphins. This attachment method would require the capture of dolphins to attach a tag. Stone et al. (2005) concluded that Hector's dolphin was a suitable candidate for satellite telemetry studies and that the risk to this species from capture, handling and tagging seems to be low, based on their experience with capturing three Hector's dolphins. Stone et al. (2005) is also a good example of the additional data that can be collected from a dolphin capture, including skin and blood samples for genetic and health testing, ultrasound for assessment of pregnancy and blubber thickness, body measurements, basic physiological information (e.g. heart rate, breathing rate, blood pressure), and bacteria, virus and hormone screening.

There are a range of examples of suction cup tagging from other similar sized cetacean species to Hector's dolphin. Detachable suction cup tags have been successfully applied to Yangtze finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) and remained attached for an average of approximately nine hours (Akamatsu et al. 2005), and to Dall's porpoises (*Phocoenoides dalli*) for a maximum of 41 minutes (Hanson & Baird 1998). In the Dall's porpoise study, 15 attempts were made to attach tags with suction cups and three succeeded. In a recent Danish study archival multi-sensor DTAG3 tags were placed on ten wild harbour porpoises to study noise exposure and behaviour in the Danish Straits. The suction-cup attached tags provided continuous recordings for up to 24 hours, while logging stereo sound (500 kHz sampling rate), triaxial magnetometry, acceleration and depth (250–625 Hz) (Sarnocinska et al. 2020). These types of tags have been temporarily attached on small cetaceans without requiring capturing and handling of the animal. Such remote deployment is achieved using a pole (for bow-riding or bigger species) or a crossbow (for smaller species).

The only other attachment method for consideration is the anchored method whereby a tag with short anchors is attached to a cetacean via a pole or fired from a crossbow. While this method has not been trialled on Hector's dolphins, it has been used on more than 20 other species of cetaceans, including harbour porpoises, which are slightly larger than Hector's dolphins (see Andrews et al. 2015). This method generally supports smaller tag sizes (and therefore fewer electronics) but tag retention sits somewhere between the other two methods at approximately 1-3 months. This method is not recommended for Hector's dolphins due to observed injuries in previous research projects undertaken on similar-sized cetaceans.

As discussed previously, the optimal attachment will be a function of the size of instruments required to answer the research question of interest, the longevity of attachment required, and the level of impact that is considered acceptable. It is also important to note that while tags have been used widely overseas, Hector's dolphins are among the smallest of all cetacean species and therefore tags that have be used on other, larger species may not be appropriate for Hector's dolphins.

3.4. Methods other than tagging

It is important that a range of potential methods are considered when determining the best approach to address a research question as all methods come with various advantages and disadvantages. While the focus of this review has been on electronic tagging, it is useful to briefly consider other methods that may be able to answer the same or similar questions to tagging. There is considerable experience and demonstrated success with the use of line transect surveys by both vessels (Dawson et al. 2004) and aircraft (MacKenzie & Clement 2014) in providing detailed information about Hector's dolphins abundance and distribution. Long-term photo-identification research has also been conducted on Hector's dolphins providing important insights into biologically survival and reproductive rates (Gormley et al. 2012). In addition to these methods, there are also other methods that have the potential to answer research questions about Hector's dolphins. Some of these are discussed briefly in the following sections.

Table 5. Summary of attachment types for electronic tags as reported in the literature. Information in columns 1-3 is broadly based on data provided in Andrews et al. (2019) and remaining columns is summarised from the literature review.

Attachment type	Level of Invasiveness	Description	Deployment method	Target species	Deployment time	Advantages	Disadvantages
Anchored	Invasive	Anchored tags have the electronics package external to the skin, attached by one or more anchors that puncture and terminate below the skin. The anchors, often solid shafts with retention barbs or petals, are designed to terminate in the internal tissue of the dorsal fin or in dermal or hypodermal tissue along the dorsum.	Anchored tags are usually deployed using remote-attachment methods that do not require capture and restraint of the animal, such as projection from a crossbow or air gun, or placement with a pole.	Commonly used on a wide range of cetaceans including small and large dolphins, killer whales, and large whales.	1–3+ months	Remotely deployed with relatively high success rate. Well tested on a wide range of cetaceans. Small size limits the electronics that can be included in the tag.	Relatively short tag longevity. Challenging to use with small dolphins due to size and strength of dorsal fin able to hold tag. Increased drag due to external placement.
Bolt-on	Invasive	Bolt-on tags have external electronics and one or more piercing anchors. An element of the tag is attached to the external end(s) of one or more bolts that pierce tissue, creating a tunnel around the bolt with an entry and exit site (like a pinniped flipper tag); e.g., single-point dolphin tags that trail behind a v-shaped piece that is bolted to the dorsal fin, or the three-pin design with the tag bolted on one side and a flat plate held on the opposite side. Another example of a bolt-on design is sometimes called a ‘spider-legs’ tag, where the tag sits as a saddle over or near the dorsal ridge, connected via cables to piercing pins, rods or bolts.	Creating the hole for the bolt currently requires capture and restraint of the animal, and manual contact with the skin.	Used for small and medium dolphins and beluga.	6–12+ months	Relatively long transmission time and high success rate once attached. Little movement in tag after release.	Requires the capture of an animal to attach the tag. Challenges in identifying optimal location to place pins to avoid blood vessels. Increased drag due to external placement.
Consolidated	Invasive	The electronics and retention elements are consolidated into a single implanted anchor. The electronics are typically inside a metal case, usually a cylinder, designed to be partially implanted in the body, with only a small part of the top of the tag and antenna and/or sensors projecting above the skin. Retention barbs, or petals, are connected directly to the implanted package. Puncture of the skin typically occurs on the body or the base of the dorsal fin (not the central part of the dorsal fin), and the distal end of the tag sometimes terminates internally to the muscle/blubber interface.	Application of these tags does not require restraint and they are deployed with remote methods.	Used on large whales with a thick blubber layer.	3–6+ months	Tag is a single unit that sits internally with only the aerial external. Low drag and little chance of damage or being knocked off. Remote deployment.	Although most tags with implanted parts are likely to be fully shed within a few months, there are reports of implanted tags or parts of tags that have been retained within the tissue of cetaceans for many years. Possible internal muscle shearing during locomotion leads to injuries and tags sites can show persistent regional swellings or depressions.
Harness	Non-invasive	Tags are attached using a harness fitted securely to the animal. The harness generally fits around the body (e.g. the dorsal and/or pectoral fins).	Attaching the harness requires capture and restraint of the animal, and manual contact with the skin.	Not used much anymore on marine mammals except for captive studies. Used in birds and turtles.	1–3 months	Harness easily attached and removed. No damage (e.g. holes or scars) to individual when harness removed.	Harnesses that encircle the body can impose significant drag loads, an increased risk of entanglement, and can lead to skin chafing. Therefore, the use of harnesses is not recommended with free-ranging cetaceans.
Peduncle belts	Non-invasive	A collar is fitted around the peduncle of the tail and the tag is suspended from the collar. The tag is free floating on a long tether and dragged behind the animal so the tag can reach the surface and transmit.	Attaching the harness requires capture and restraint of the animal, and manual contact with the skin.	Only used for dugong and manatees.	3–6 months	Quick and easy to capture. Relatively high transmission rate.	Peduncle belts are still experimental but placing an object on a part of the body that moves as much as the caudal peduncle presents obvious challenges that have yet to be resolved, including the potential for altering the biomechanics of swimming and/or skin chafing. Potential risk of entanglement from tether.
Suction cups	Non-invasive	While any tag configuration can be used, these are generally archival tags with a radio or satellite transmitter to recover the tag. A tag is attached to the animal by either passive or active suction using one or more suction cups on the tag body. The tag can be programmed to release at a certain time so it can be recovered, and the data downloaded.	Suction cup tags are usually deployed using remote-attachment methods that do not require restraint of the animal, such as projection from a crossbow or air gun, or placement with a pole.	Used on a wide range of cetaceans including small and large dolphins, killer whales, and large whales.	Hours to days	Can be remotely deployed and doesn’t break the skin. No impact to the animal and nothing left on animal once the tag comes off. Benign attachment mechanism.	Excessive vacuum pressure can cause complications such as blistering or hematomas below the cup (Shorter et al. 2014). A suction cup that does not cause significant discomfort is also likely to reduce the possibility that the tagged animal will intentionally remove the tag. Relatively high drag from large external tag.

3.4.1. Acoustic research

Acoustic research is an area of significant growth in marine mammals with the increasing sophistication and decreasing cost of acoustic recorders (Nowachek et al. 2016). A range of acoustic research has been undertaken on Hector's and Māui dolphins over the last 30 years, the majority of which has been reported in the last 10 years (e.g. Dawson 1991; Rayment et al. 2009, 2010; Tregenza et al. 2016; Leunisson et al. 2019; Nelson & Radford 2019). The major strength of acoustic research is that long-term monitoring can be undertaken relatively cheaply with the placement of acoustic recorders at sites of interest. While the effective detection range of Hector's dolphins is likely to only be a few hundred metres around a recorder, it does allow for the systematic collection of data. In an example of applied acoustic research, Nelson and Radford (2019), estimating the usage patterns of Māui dolphins from acoustic loggers and recorders, suggested that these dolphins are routinely found outside of protected areas on the west coast of the North Island. Some of the limitations of acoustic monitoring are that detection ranges can be limited to very short range, recording instruments can be lost to trawling, or other activities and background noise levels can mask dolphin vocalisations. This method is likely to be less suitable for monitoring fine-scale distribution patterns of individual Hector's dolphins as it requires animals to be close to the acoustic recorder and therefore, data on movement patterns would be restricted spatially and temporally. However, towed hydrophone arrays or extensive arrays of fixed recorders could be used to describe fine-scale behaviour over a relatively small spatial scale, and would have less of an impact on the dolphins.

3.4.2. Unmanned aerial systems

Unmanned aerial systems (UAS or drones) are becoming more commonly used for marine mammal research. From surveys for population assessment (Torres et al. 2005) to the use of aerial systems to observe behaviour (Nowacek et al. 2001) and photogrammetry (Dawson et al. 2017), the benefits of viewing marine mammals from aerial platforms have been reported for many years. Currently most reasonably priced UAS have somewhat limited in-flight time, although increasing battery power and rapid advances in charging technology are likely to increase these flight times in the near future. The advantages of UAS are that they can be rapidly deployed and provide an insight into dolphin behaviour without any disturbance. Larger UAS can be used for systematic survey work to investigate distribution and movements. A recent UAS project by MĀUI63 is investigating Māui dolphin distribution using artificial intelligence (AI) techniques to analyse and distinguish video footage of Māui and Hector's dolphins from other species with over 90% accuracy (Farrell 2019; WWF 2019)[3]. If the efficient use of UAS becomes possible, then it reduces the need for manned aerial surveys, which uses considerable resources and also carries inherent human risks. Whilst useful for answering some research questions, such as the

[3] Article downloaded from: https://www.wwf.org.nz/?16501/INTRODUCING-MISSION-POSSIBLE

distribution of Hector's dolphins at the population or local level, this method only allows for above-water observations and is not suitable for monitoring below-water behaviour, particularly for investigations of how behaviour relates to direct interactions with dolphins and fishing nets.

3.4.3. Biopsy research

For several decades now, molecular ecology (e.g. DNA analysis) has been using biopsies or other skin samples to understand and investigate a wide range of marine mammal questions including such things as population structure and size, systematics, diet, individual identification, and kinship. Biopsy samples can be easily collected from free swimming Hector's and Māui dolphins with little or no impact. The combined collection of these samples over time provides considerable power to detect individual and population level changes. At present, the only way to distinguish a Hector's from a Māui dolphin is through molecular discrimination and therefore it is a fundamental part of research on these species (Hamner et al. 2014a). Perhaps more importantly, genotype capture-recapture estimates are now used as the primary means of estimating the population size of Māui dolphins (Hamner et al. 2014b; Baker et al. 2016). The advantages of biopsy sampling and molecular analysis allows for the long-term monitoring of individuals allowing a range of additional questions to be answered. Whilst this method provides population level data, it is less suitable for studying fine-scale spatial/temporal changes in movement patterns of Hector's dolphins, especially when studying deep dive profiles.

3.4.4. Environmental DNA

Direct genetic sampling of cetaceans at sea can be challenging and resource intensive (Baker et al. 2018). Advances in analyses of environmental DNA (eDNA) now offer an alternative for detection and identification of rare, cryptic, or vulnerable cetacean species by means of extracting their DNA from the habitat. As eDNA is relatively new, the methodology for eDNA sampling is advancing rapidly as the number and range of applications increases. While there are still challenges in replicating lab trials in the field, Baker et al. (2018) confirmed the potential to detect eDNA in the wake of killer whales for up to 2 h, despite movement of the water mass by several kilometres due to tidal currents. eDNA trials are presently being undertaken for Māui dolphin by the University of Auckland (R. Constantine, pers. comm.). The benefit of this technique is that if detection sensitivities can be increased, then it may be possible to detect dolphins from background water samples without the need for biopsy sampling or even seeing them. This could provide a valuable insight into individual movements and home range of particularly rare species, such as Māui dolphins. Whilst this method shows potential for complementing other methods used in identifying fine-scale distribution patterns in Hector's dolphins, once technology has developed further, as it currently stands eDNA is a useful research tool for providing a 'snapshot' of presence/absence data, rather than a continuum of data on spatial/temporal distribution patterns.

3.4.5. Methods other than tagging that could be used to assess fine scale behaviour of Hector's dolphins

There are a range of potential methods that could be used to assess the fine scale behaviour of Hector's dolphins including four that were briefly reviewed above. While these four methods have the potential to contribute to a wide range of important conservation and management issues relevant to Hector's dolphins, a key focus of this report is to assess how tags might be used to assess fine scale behaviour of this species. While each of these methods has the potential to provide relevant data towards this specific question, tagging is the method that is most likely to provide high resolution data for addressing this issue, including the 3-dimensional diving and foraging behaviour of Hector's dolphins. As has been discussed previously, once a specific research question has been identified, then all methods, including tagging, should be evaluated to determine the relative advantages and disadvantages of each approach and what is likely to lead to the best overall outcomes for the dolphins.

3.5. Summary of best practice considerations

There were some common themes to those tagging studies that had a moderate or high degree of scientific rigour. In essence, many of these are the polar opposites of the caveats and biases that were identified as poor studies as outlined in Section 3.1.3. Some of the best practice approaches from these more scientifically rigorous studies include the following components:

- clear and transparently defined research questions followed by a comprehensive evaluation of pros and cons of various tagging and other methods to address research aims. Also, clear articulation of any other relevant issues or standards that must be considered (e.g. animal welfare and iwi concerns). If these issues are all clearly and well laid out, then the decision-making process is made more transparent and the methodological outcome justifiable.
- strong experimental design including use of appropriate controls (e.g. quantifying any differences in behaviour between tagged and untagged dolphins).
- identification of how the tagging data will be used including analytical methods. Evaluation of whether the study design will be able to answer the research questions (e.g. variability in the accuracy of a location fix is greater than size of the area being investigated).
- sample sizes large enough to address the research question robustly.
- consideration and monitoring of a range of potential explanatory variables, e.g. CTD tags, and fixing variables such as age, sex, area, and behavioural state wherever possible.
- formal necropsies of any mortalities resulting during or after tagging.
- ideally, multi-year and multi-regional studies to investigate temporal variation.

- calculation of statistical power for results to aid in accurate interpretation of any significant (and non-significant) results.
- clear instructions, communication, and training provided to all parties involved in the trials to ensure experimental designs are implemented accurately.
- inclusion of a detailed and structured follow-up study of tagged dolphins to ensure any long-term effects are understood as part of the main study. This is frequently overlooked in tagging studies and should be an integral part of any study given this component can cost more than the main tagging programme itself.
- well-funded; tagging programmes are generally expensive to undertake.
- well-developed consultation process with Treaty Partners and the public prior to tagging being approved followed by good communication of results. A Communication Plan is essential.
- improved reporting of ‘failures’ (e.g. tags that didn’t transmit or collect data, and attachments methods that failed).
- clear agreement for the open sharing of data on tag development. Currently, the use of proprietary tags often means experiences (e.g. positive and negative) are not shared with the wider research community.
- genuine independent oversight of tagging operations. Generally, only pro-tagging people are involved which can lead to biased and inaccurate reporting.
- capture and tagging operations videoed so process can be shared with different groups (e.g. Animal Ethics Committee (AEC) and Treaty Partners).
- inclusion of clear criteria for any tagging programme to identify situations or issues (either during or post-tagging) that would lead to a halt to the programme if any significant negative or potentially adverse animal welfare issues are identified. This constitutes a ‘traffic-light’ approach to field studies.
- tagging can represent a risk to dolphins and therefore the most experienced research team possible should be brought together, including bringing international experts to New Zealand to lead and/or train local personnel.

There are also some best practice guidelines and standards that should be carefully considered in addition to New Zealand regulatory requirements (e.g. Marine Mammal Protection Act permit and Animal Ethics Approval):

- The Society for Marine Mammalogy has published the Guidelines for the Treatment of Marine Mammals in Field Research (Gales et al. 2009) which scientists contemplating tagging of cetaceans should follow.
- Two recent documents have provided best practice recommendations for the use of tags with pinnipeds; one for implanted tags (Horning et al. 2017) and one for external tags (Horning et al. 2019). It should be noted that while these are for pinnipeds, many of the issues are the same for dolphin tagging.

- Andrews et al. (2019) produced the Best Practice Guidelines for Cetacean Tagging, which represent an excellent guide from tagging practitioners. They also provide a suggested approach to guide decision process for those considering a cetacean tagging study (Figure 2).

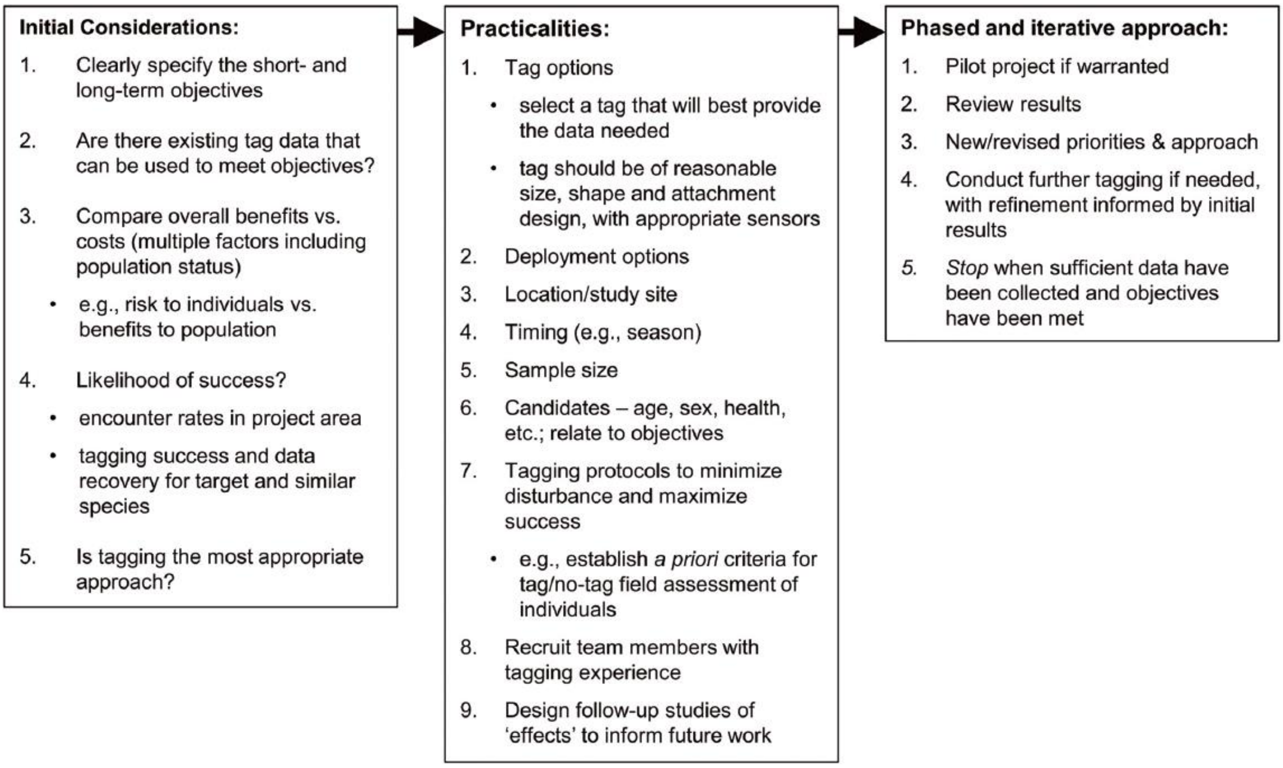

Figure 2. Recommended approach to guide decision process for those considering a cetacean tagging study. Reproduced from figure 2 in Andrews et al. (2019).

3.6. Research costings

It is extremely difficult to provide reliable costings for tagging projects given the considerable variation in the scope, nature, and extent of a field trial. However, it is possible to summarise what was found in the literature review, although many references did not provide costings and so it was necessary to estimate them.

Generally, robust tagging studies are likely to be very expensive (e.g. 47% of studies were between NZD$100,000 and NZD$1,000,000) due to the large sample sizes that are likely to be required to achieve robust, statistically significant results. In general, most costs in such a study are split between (i) tag purchase and satellite time, and (ii) field research costs including vessel time and personnel. There are some tagging projects that were estimated to cost less than NZD$100,000 but these are generally projects with very low sample sizes.

Also, while the costs of field programmes are normally the focus of operational budgets, it is also important to consider and include the development costs of the research programme. There are likely to be considerable costs associated including pre-field work planning, data analysis, equipment, staff costs, and public consultation/ stakeholder engagement prior to the project even being approved. If this is a government-led process, then these costs may be able to be absorbed by the agency leading the work, but if it is being led privately, then these costs should be factored in. While most costs are likely to be relevant to all cetacean tagging research projects, it is likely that a Hector's dolphin tagging programme will generate more than normal levels of work given the public profile and nationally critical threat classification status of this protected species.

It is unhelpful to speculate about what an electronic tagging programme may cost without knowing the research question under consideration. However, what is clear is that there is a breadth of research projects that range in scale from small experimental projects to large scale projects with a multi-year and multi-regional focus. While there were some small-scale field experiments reviewed in the literature, which were undertaken for less than $100,000, and which provided useful data, these were generally limited in their applicability due to small sample sizes.

3.7. Other considerations

3.7.1. Cultural and social science considerations

The use of electronic tagging (e.g. acoustic, archival and satellite telemetry) to study the behaviour and ecology of marine animals has increased dramatically over the past decade. As scientists continue to use these tools, it is inevitable that other researchers and the public will either encounter animals carrying such tags or become aware about them through media and/or social media with increasing frequency. If the animals appear adversely affected or injured by the tag (e.g. showing signs of trauma), then this information has the potential to generate conflict with various wildlife stakeholders (e.g. tourists/operators, divers, fishers, hunters) that can negatively affect existing and future research efforts and potentially undermine conservation work. Yet, the sharing of this information also presents an excellent opportunity to advance the field of biotelemetry by improving animal welfare, tagging technology and practices, whilst also gaining the trust and support of stakeholders through effective communication about tagging research (Hammerschlag et al. 2014).

Māui and Hector's dolphins have an extremely high public profile in New Zealand and are routinely the subject of media attention. There are various stakeholder groups that regularly use Māui and Hector's dolphins in conservation advertising campaigns raising the profile further. In addition, Māui and Hector's dolphins are taonga species for many iwi, hapu and other New Zealanders. They are also formally listed in the

Ngai Tahu Deed of Settlement. Formal and open consultation with our Treaty Partners will form a key part of any discussions around future research programmes for this species and in particular, the use of dolphin tagging methods.

Social science considerations are important with any research but are particularly relevant to studies that involve potential injury or mortality of animals. While the public would welcome any new data that contribute to the improved conservation and management of Hector's dolphins, a reasonable proportion are likely to be opposed to any research project that could, or does, lead to injuries or mortalities. While different tagging and attachment systems pose different risks to dolphins, each system will need to be assessed on its relative merits. Any decisions will, therefore, need to be based on weighing a combination of both objective (e.g. will a tag provide sufficient resolution data to address the research question?) and subjective judgements (e.g. animal welfare or cultural and spiritual values). This may be a challenging process and therefore it is important that the assessment process evaluating any proposed tagging project must have a strong and up-front component of not only technical decisions but also public and Treaty Partner consultation. Furthermore, any experiments or research projects will require permits (e.g. Marine Mammal Research Permit) and approvals (e.g. AEC) of which public input is a key component further highlighting that a social license to operate will be essential.

Careful consideration of the potential implications from any tagging projects will be necessary to ensure stakeholders, the public and Treaty Partner are all aware of the proposals and implications. Given the potential for possible injuries or mortalities, it underpins the strong need for a structured approach to any evaluation process with a thorough consideration of risks and benefits prior to any decision being made. Finally, there will need to be a media and consultation plan in place to support any trials, although the existing DOC CSP and / or FNZ Aquatic Environment Working Group process may be appropriate processes to consult about any trials, noting that the focus of these groups is primarily technical advice.

3.7.2. Animal welfare considerations

While there can be significant scientific and conservation benefits of tagging cetaceans, there can also be negative effects on individuals (Andrews et al. 2019). Therefore, prior to any decision to use tags, researchers should weigh the positive and negative factors to determine if tagging is scientifically and ethically justified (Andrews et al. 2019). All methods available to address identified research questions (including thorough examination of existing data) should be evaluated prior to the decision to use tags to ensure that the data required can best be provided by these instruments. Andrews et al. (2019) provide a guide that can be used when considering a cetacean tagging project with a flow chart of an example decision process (Figure 2).

While there are regulatory requirements for animal welfare in New Zealand (e.g. Animal Welfare Act 1999) that cover tagging projects, there are also a range of other ethical and welfare issues that, while not necessarily regulated for, are important to consider. Andrews et al. (2019) provide some excellent recommendations for evaluating ethical and legal considerations for tagging projects that are outlined below: Through following these steps, it will be possible to robustly assess the risks and benefits of a tagging programme and reach a sound decision:

1. Determine if tagging is appropriate
    a. Consider alternative methods for addressing research questions
    b. Review relevant existing data for the species and area of consideration
    c. Ensure that there is a scientific or conservation justification for obtaining new data and that those data are best provided by tags
2. Follow best practices of research design
    d. Develop the research plan with animal welfare as a high priority.
    e. Evaluate equipment options and choose the instrument and attachment that provide the data needed
    f. As much as possible, ascertain required samples sizes and statistical approaches in advance, obtaining expert advice if needed
    g. Tag the fewest number of individuals necessary in the least invasive and unimpactful manner possible to achieve the project goals
3. Prepare adequately for field work
    h. Conduct a thorough risk assessment in advance
    i. Prepare for unexpected risks to the safety of animals and humans.
    j. Ensure the capture/tagging team is trained in the safe and proper procedures for boat approaches (and capture-release techniques if required) and use of tagging equipment
4. Comply with all applicable local, national, and international legal requirements
5. Obtain review and approval by an animal ethics committee, even if not locally required
6. Reach out to stakeholders, including those with subsistence, cultural and economic interests in the study subjects, by:
    k. sharing research goals and soliciting input
    l. coordinating during planning
    m. communicating results throughout and at the completion of the study

One of the key conclusions of our literature review that is echoed by other work (i.e. McIntyre 2014; Andrews et al. 2019) is that there were very few research projects that included explicit aims to address instrument and/or instrument deployment influences on the study animals and/or the marine environment. The need for more studies assessing device impacts has also been recognised by other authors (Wilson & McMahon 2006; Hart & Hyrenbach 2009; McMahon et al. 2011). Godfrey and Bryan (2003) reported, from an analysis of radio-tracking papers of various taxa, that only

4.5% of mammal studies (including terrestrial mammals) explicitly assessed tag effects on study animals. Interestingly, 61% of these studies reported substantial tagging effects, thereby further illustrating the need for more information on potential tagging impacts. McMahon et al. (2011) summarised potential negative effects of biologging devices either in association with capture (e.g. stress, anaesthesia side-effects, etc.), device types (e.g. inducing drag, attracting predators, etc.), attachment method (e.g. generation of excessive heat by glues) or timing / duration of attachment (which may have an influence during breeding seasons, etc.). Nevertheless, whereas some assessments have shown no consequences of instrument attachment in terms of long-term survival (e.g. McMahon et al. 2008), the results of this review illustrate a paucity of studies quantifying the influences of biologging devices on the energetics, fitness and survival of free-ranging animals that are used to carry instruments. This field of investigation, therefore, apparently remains an important one that requires more focus in order to ensure the ethical use of biologging instruments.

It is also worth mentioning that most[4] of the tagging studies considered had approved animal welfare/ethic permits which means they must have had some degree of independent consideration of animal welfare. While, animal ethic committees are deemed to be independent, they are generally only provided with information from the applicants (e.g. presumably pro-tagging researchers) and therefore, rely on the balanced presentation of information. There are examples of when this has not been the case. Godfrey and Bryan (2003) stated that only 4.5% of studies explicitly assessed tag effects on study animals. This suggests that AECs were convinced that the tags wouldn't have any significant effects on animals and therefore, didn't require investigation of tag effects. Godfrey and Bryan (2003) found that 61% of studies that investigated tagging effects found substantial tagging impacts. An improvement in the evaluation of potential controversial tagging programmes could likely be achieved if AECs were able to receive advice independent of the applicant which may aid in the thorough investigation of tagging applications.

Finally, while animal welfare is defined under the Animal Welfare Act 1999, it is important to be aware that whilst the effects of animal manipulations are assessed as part of the AEC application process for any research proposal, animal welfare is not strictly an objective measure, and that any assessment will include a high degree of personal opinion and subjectivity. There are also likely to be a range of differing cultural values that need to be considered. In essence, while animal welfare considerations may seem simple to address and, in fact researchers may be convinced that they have addressed them, it is important to consider the wider picture and ensure that all perspectives have at least been considered.

[4] Not all studies stated whether they had one or not.

3.8. Advantages and disadvantages of electronic tagging for Hector's dolphins

Table 3, Table 4, and Table 5 identify specific advantages and disadvantages of the different types of tags and attachment methods; however, in the context of investigating dolphin behaviour, we cannot implicitly state the suitability of a specific tag or attachment type for Hector's dolphins without a clearly defined research question. As previously discussed, electronic tagging could be used to address a range of issues, including the knowledge gap in fine-scale spatial/temporal distribution patterns of Hector's dolphin, particularly around diving performance, nocturnal behaviour, and diurnal distribution. This would provide valuable data to better inform Hector's dolphin conservation management, especially in relation to interactions with fishing nets. The benefits of sub-dermal anchors and suction cups for use on Hector's dolphins are to a large degree dependent on the type and time-scale of data required (e.g. daily foraging behaviour and seasonal distribution movements). Specifically, anchors have a longer attachment time but a potential for higher impact to the animal. Suction cups have a shorter attachment time but with a lower impact for some species. Obviously these two issues are rarely considered in isolation of each other (and other considerations). Therefore, it is essential that any electronic tagging study involving Hector's dolphins clearly articulates the project objectives so that informed decisions can be made about how to balance and weigh potentially competing issues.

3.9. Risk assessment

A risk assessment should form part of the assessment and evaluation process undertaken for any potential tagging project. As with all animal welfare considerations, risk assessment needs to be undertaken within the context of a research question so that risks can be quantified and mitigated. Without a research question, it is not useful to assess risk other than at the highest level, which is unlikely to be useful given the large trade-offs in relative between issues (e.g. tag retention vs animal welfare vs sample size vs cost).

3.10. Examples of study designs for Hector's dolphin electronic tagging programme

It is useful to provide some specific examples of what a Hector's dolphin research tagging programme may look like and how it might work. Noting that developing and evaluating such a research programme is complex, we have considered two research questions related to Hector's dolphins and then evaluated how tagging could be used to address these questions, including brief consideration of alternative approaches. These examples are reviewed at a high level and should not replace a full and open evaluation of any tagging programme such as have been recommended previously in this report.

It is important to state that the options outlined here are not indicative of approval for any future Hector's tagging study. Rather, they are simply to provide some background material that could be useful in the formal evaluation of a tagging programme. They also provide an outline of what such a project might look like if it was designed to answer a specific research questions and how tagging could be used as a data collection tool to support population management decisions for this taonga species.

The two research questions we evaluated were:

1. Describing the diving behaviour of Hector's dolphins to investigate their activity in the water column – specifically, this would include consideration of dive depths, dive duration and timing, 3-dimensional dive and feeding behaviour
2. Describing the spatial and temporal distribution of Hector's dolphins– specifically this would consider seasonal variation in distribution patterns.

An evaluation of these two research questions against a range of criteria is provided in Table 6 and Table 7 including a description of a potential tagging research programme.

Table 6. A preliminary evaluation and assessment of tagging methods in describing the diving behaviour of Hector's dolphins to investigate their activity in the water column.

Research question	Describing the diving behaviour of Hector's dolphins to investigate their activity in the water column
Potential management use	Data would be used to evaluate physical overlap of Hector's dolphins in the water column with fishing effort (e.g. trawl operations). Application for the SEFRA modelling approach.
Data required/desirable	Dive depths, dive duration and timing, 3-dimensional dive and feeding behaviour, and location data
High level evaluation of potential research methods	
1. Visual observations	Dolphins could be directly observed from land (e.g. people, cameras), drones or vessels. **PROs**: No impact on dolphins **CONs**: Data only available on surface activity with no indication of underwater activity. Large amount of effort required to collect observations (e.g. person and vessel time) **Feasibility**: None – method could not deliver adequate data to address the research question
2. Acoustic tracking	Dolphins could be tracked by passive detection of vocalisations using multiple hydrophone array to confirm their 3D location. **PROs**: Possible to collect full range of 3D activity while vocalising. No impact on dolphins **CONs**: Data only available while vocalising. Tracking only possible over short range (e.g. 100 m) due to high frequency nature of vocalisations. Considerable development work to get hardware and software systems operational. Difficulty in getting and keeping dolphins within range of array **Feasibility**: Low – while technically possible, limitations in effective range of tracking system would mean collection of adequate sample size unlikely.
3. Electronic Tagging	Dolphins could be tagged to provide diving data from a range of different tag types. **PROs**: Highly accurate and detailed data. Integrated with simultaneous location data. Long term (3+ months) data if using bolt-on tags **CONs**: Impacts to dolphins: suction cup tag – low, bolt on-tag – high. Potential influence of tag on dolphin behaviour (e.g. swimming activity). Potential sample size limitations: less so for suction cup than bolt-on tags. **Feasibility**: Moderate to high – depending on level of impact considered acceptable to Hector's dolphins, electronic tagging could address the stated research question. Sample size considerations would be important depending on whether local or national data was required.
Conclusion	If interested in collecting data on 3-dimensional dive and movement patterns of Hector's dolphins in the water column, then electronic tagging is the most suitable method noting that there would be some level of negative impact on the tagged individual depending on the method used.
Potential tagging methods	
Type of tags	3D data logging tags (e.g. time-depth recorders, magnetometer and accelerometer tags, camera tags, multi-sensor high-resolution acoustic recording tags) would be useful especially if integrated with location data. Small-sized tags of an appropriate size for Hector's dolphins are commercially available. The three main types of tags used are: (i) satellite linked dive tags which transmit summaries of dive and location data without requiring tag recovery and data are collected over several months, (ii) data logging tags which record high resolution data on tag but the tag needs to be recovered to access the data and data are collected over a period of days, and (iii) camera tags could record diving behaviour, but the tag needs to be recovered to access the data. Given the small size of Hector's dolphins, the larger multi-sensor tags are unlikely to be feasible for deployment, but there are small tags which can collect dive and behaviour data.

Potential tagging methods, cont.	
Data outputs	Outputs are dependent on tag type. High resolution, long term dive data can be collected for the most comprehensive tags, but as noted above the small size of Hector's dolphin will limit the options to smaller units. Typical data collected includes sampling of simple depth and temperature, to the more complex 3D dive data which can be collected at second intervals. If the tag has location data, location information is dependent on the programmed duty cycling (e.g. how often it is set up to sample), but typically 3-6 locations per day are available. Other data can also be collected depending on the configuration of the tag including recording of vocalisations and video (e.g. to provide data on feeding and prey). The number of data points collected is determined by a range of factors including tag retention time, duty cycling, satellite coverage (for transmitted data), battery and memory constraints. There are also trade-offs between satellite linked tags which only transmit summary data (e.g. summary dive data by depth bins) and tags that need to be recovered which log high resolution data for every second.
Attachment types	**Bolt-on**: typical attachment time to 6+ months and requires capture and handling to attach. **Suction cup**: Short attachment time (therefore reduce data outputs); a typical attachment time of hours to days and can be deployed remotely without need for capture. **Anchored**: Given the small size of Hector's dolphins, anchored tags are not feasible for attaching tags on this species. Both bolt on and suction cup tags are feasible and offer different strengths and weaknesses and will require trade-offs of data quantity versus impact on dolphin.
Sample sizes	The exact sample size is dependent on variables including local vs national data, single or multi season/year, cross section of age and sex classes. As a general rule of thumb, a sample size between 20-40 deployments would be desirable to capture a range of individual variation. However, while data from a single tag could provide useful information it is not considered sufficient for a robust statistical analysis. Suction cups collect far fewer data than bolt-on tags, due to shorter attachment times, but potentially 20-40 deployments using the suction cup attachment method could describe local behaviour relatively well. A smaller sample size could be reasonable for bolt-on tags due to the longer deployment time, but it would still need to be sufficient to cover individual variability.
Animal welfare	Animal welfare is primarily a function of the tag attachment type. **Bolt-on tags** require capture, restraint and surgical procedures and there are potential ongoing and long-term impacts (e.g. increased energy expenditure due to drag, behavioural changes, wound injuries, and the tag pulling out of the dorsal fin). **Suction cup tags** can be remotely deployed on free swimming dolphins and any impacts (e.g. increased energy expenditure due to drag, behavioural changes) are limited to the short period of deployment until they fall off. Given the shorter deployment time, suction cup tags are likely to require a higher sample size than bolt-on tags. Any tagging project should include tag follow up studies to assess potential impacts.
Permits required	AEC approval (any approved AEC), Marine Mammal Research Permit (DOC)
Treaty Partner and stakeholder consultation	Careful consideration of the potential implications from any tagging projects will be necessary given general interest in these projects to ensure stakeholders, the public and Treaty Partner are all aware of the proposals and implications and are able to provide genuine input into the process.
Limitations	The key issue in any tagging study is the potential impact of tags on typical species behaviour and therefore, how well does the behaviour of a tagged individual reflect the typical behaviour of untagged dolphins.

Summary of potential tagging options	
Option 1	20 bolt-on tags are deployed on Hector's dolphins with satellite linked GPS tags that transmit both location and summary dive data (e.g. Wildlife Computers SPLASH10-F-333 tag[5]). Individual tags with bolt-on mounts cost ~$6,000 per tag plus an additional ~$100/month/tag for satellite transmission costs. It is anticipated that approximately three months of tracking and dive data would be available from each individual. Tagging events could be spread over the year to provide information on seasonal variation. This would provide a useful data set from which to evaluate Hector's dolphin diving behaviour. Overall, cost of the project would be in the order of $130,000 for tags plus significant additional costs (likely around NZD$1 million in total) for bringing expert tagging personnel to New Zealand to support the research, field costs, analysis costs, follow-up study costs, and costs associated with stakeholder consultation.
Option 2	40 suction cup deployments on Hector's dolphins. Use of high-resolution data recording tags (e.g. C-VISS tags[6]) which could include time, depth, location, and either HD video or 3D tracking units. There are no off-the-shelf tags available for this, but indicative costs are ~ NZD$9,000 per unit. While a single unit can be deployed multiple times, it would be desirable to have several units (n=4) to account for potential losses and breakages. It is anticipated that each deployment could collect between 3-12 hours of high-resolution dive data per deployment. Given the short duration time for recording data it would be sensible to limit all deployments to the same coastal area and season to maximise data collection to address a single research question. This would also provide a useful data set from which to evaluate Hector's dolphin diving behaviour. Overall, cost of the project would be in the order of $36,000 for suction cup tags, plus significant additional costs (likely around NZD$800,000 in total) for bringing expert tagging personnel to New Zealand to support the research, field costs and analysis costs. It is likely that this option would be cheaper than Option 1.

[5] See https://wildlifecomputers.com/taxa/cetacean-limpet/
[6] See details in Pearson et al. (2017)

Table 7. A preliminary evaluation and assessment of tagging methods in describing the spatial and temporal distribution of Hector's dolphins to investigate how much time dolphins spend outside of protected areas. AEC = Animal Ethics Committee.

Research question	Describe the spatial and temporal distribution of Hector's dolphins to investigate how much time dolphins spend outside of protected areas
Potential management use	Data would be used to evaluate the physical location of Hector's dolphins over time and to quantify the proportion of time spent outside of protected area. Application for the SEFRA modelling approach.
Data required/desirable	Location and movement data. Additional data to address other questions can also be collected concurrently with location data.
High level evaluation of potential research methods	
1. Visual observations (i.e. aerial or vessel surveys)	Line transect aerial and vessel surveys have been regularly used to assess Hector's dolphin distribution and abundance. **PROs**: Well established and tested methodology. Can provide range wide and population level data. Provides no impact on dolphins. **CONs**: Relatively time demanding (e.g. weather limited) and financially expensive. Generally, only provides a single snapshot of distribution (but repeat surveys of the same area can be undertaken). Access to appropriate aircraft limiting. Health and Safety risks with offshore surveys **Feasibility**: High – demonstrated as being able to address the broader research question (but with limited temporal coverage i.e. single winter and summer survey).
2. Drone surveys	Similar to method #1 but with drones rather than planes. Line transect aerial surveys have been successfully used to quantitatively assess marine mammal distribution patterns in international studies. **PROs**: No Health and Safety risks for people. Can provide range wide and population level data. Standard line transect methodology well developed and applied. Provides no impact on dolphins **CONs**: New technology requires development and trial work (e.g. AI detection of dolphins in video). Limited access to appropriate drones and experienced operators in New Zealand. Relatively time demanding (e.g. weather limited) and expensive. Generally, only provides a single snapshot of distribution (but repeat surveys of the same area can be undertaken). **Feasibility**: Moderate – yet to be demonstrated as effective in New Zealand but has the potential to be at least as effective than aerial surveys.
3. Acoustic tracking[7]	Dolphins can be tracked by passive detection of vocalisations using hydrophone stations located within the marine area of interest **PROs**: Autonomously collects data 24/7 once deployed. Detects all vocalising dolphins within effective detection range (e.g. hundreds of metres). Previously demonstrated as an effective tool for Hector's and Maui dolphins. Relatively cost effective compared to other methods in this section. No impact on dolphins. **CONs**: Only detects vocalising dolphins. Relative measure of detections only (i.e. no absolute estimates). Detections only possible over short range (e.g. 100s of m) due to high frequency nature of vocalisations potentially requiring large numbers of recorders to monitor a large area. **Feasibility**: Moderate – limitations in effective detection range means only small areas are covered by each recorder and only relative rather than absolute data are available

[7] The focus here is on moored, automated acoustic recorders, but it is worth noting that acoustic surveys could be integrated into line transect vessels surveys or even undertaken by autonomous ocean gliders although these have not been considered here.

High level evaluation of potential research methods, cont.	
4. eDNA	Dolphins can be detected from eDNA in water sampling **PROs**: Potential remote detection of dolphins. No impacts on dolphins **CONs**: Present technology is not sufficient to provide adequate resolution for the detection of dolphins over anything other than short time frames (e.g. hours). Only gives a snapshot of spatial/temporal presence/absence data. **Feasibility**: Low – not yet sufficiently well developed to be used as a singular method to provide robust monitoring for assessing distribution patterns.
5. Electronic tagging	Dolphins could be tagged to provide continuous location and other data from a range of different tag types **PROs**: Highly accurate and detailed location data. Can be integrated with other location data (e.g. depth profiles). Long term (e.g. 3+ months) data if using bolt-on tags **CONs**: Impacts to dolphins is considered high from bolt on-tag methods. Potential influence of tag on typical dolphin behaviour. Potential sample size limitations in tagging sufficient numbers of dolphins to statistical test research questions. **Feasibility**: Moderate to High – depending on level of impact considered acceptable to dolphins, Electronic tagging will address the stated research question. Sample size considerations would be important depending on whether local or national scale data was required.
Conclusion	If interested in collecting spatial/temporal distribution data from Hector's dolphins, tagging is one of several possible methods that could be used. Each method has various pros and cons that need to be carefully evaluated based on a range of criteria including animal welfare, cost and how well it addresses the research question.
Potential tagging methods	
Type of electronic tags	There are a range of location tags including tags which also collect ancillary data (e.g. diving). While both VHF radio tags and satellite linked tags are possible, VHF tags are not considered further here as they will provide a substantively lower level of data points compared to satellite tags. The accuracy of locations provided by tags vary between the different satellite systems (e.g. ARGOS vs GPS) and there are trade-offs between these such as accuracy vs size of tag vs tag transmission time. GPS location tags are preferred given the high degree of accuracy of positions they provide. Small-sized tags of an appropriate size for Hector's dolphins are commercially available. While location logging (rather than transmitting) tags are also available, these are unlikely to adequately address the research question (as they need to be recovered to access the data) and so are not considered here. While there are tags that can also collect ancillary data, given the primary research question is related to distribution patterns, it is recommended that location only tags are used as this increases the tag transmission time. However, if other research questions are also of interest, then location and dive tags could be used noting that overall transmission time is likely to be reduced. Overall transmission time will vary depending on duty cycling but are likely to be in the order of up to 12 months based on battery life.
Data outputs	Outputs are dependent on the tag type but GPS location data are recommended as they provide accuracy levels of < 50 m on location fixes. The tag transmission rate can be modified, but again is based on trade-offs (e.g. more frequent locations use more battery and therefore will lead to a shorter overall transmission time). Typically, 3-6 locations per day are available from existing studies (as reviewed in this report), but ideally one data point per hour would provide a high degree of confidence in distribution data. Data quantity is determined by a range of factors including tag retention time, duty cycling, satellite coverage (for transmitted data), battery and memory constraints. There are also trade-offs between satellite linked tags that also transmit ancillary data and which generally have a shorter overall transmission time as the batteries expire at a faster rate compared with position only tags.

Potential tagging methods, cont.	
Attachment types	**Bolt-on**: Typical attachment time is 6+ months and requires capture of dolphin to attach. **Suction cup**: Given the short attachment time, suction cup tags are unlikely to be useful in addressing questions of Hector's dolphin distribution other than if interested in very fine scale and short term (e.g. 24 hours) movements. **Anchored**: Given the small size of Hector's dolphins, anchored tags are not feasible for attaching tags on this species. Both bolt on and suction cup tags are feasible and offer different strengths and weaknesses and will require trade-offs of data quantity versus impact on dolphin. Bolt-on tags are more useful for providing long term movement data and are therefore preferred for this research question but do have higher impacts on dolphins.
Sample sizes	While the exact sample size dependent on variables including local vs national data, single or multi season/year, cross section of age and sex classes, as a general rule of thumb between 20-40 deployments would be desirable to capture a range of variation in Hector's dolphins.
Animal welfare	Animal welfare is primarily a function of the tag attachment type. **Bolt-on tags** require capture, restraint and surgical procedures and there are potential ongoing and long-term impacts (e.g. increased energy expenditure due to drag, behavioural changes, wound injuries, and the tag pulling out of the dorsal fin). Any tagging project should include tag follow up studies to assess potential impacts.
Permits required	AEC approval (any approved AEC), Marine mammal research permit (DOC)
Treaty Partner and stakeholder consultation	Careful consideration of the potential implications from any tagging projects will be necessary given general interest in these projects to ensure stakeholders, the public and our Treaty Partner are all aware of the proposals and implications and are able to provide genuine input into the process
Limitations	The key issue in any tagging study is the potential impact of tags on typical dolphin behaviour and therefore, how well does the behaviour of a tagged individual reflect the typical behaviour of untagged dolphins.
Summary of potential tagging options	
Option 1 (GPS Location & dive data)	20 bolt-on tags are deployed on Hector's dolphins with satellite-linked **GPS** (e.g. <50 m accuracy) tags that transmit both location and summary dive profile data (e.g. Wildlife Computers SPLASH10-F-333 tag[8]). Individual tags with bolt-on mounts cost ~NZD$6,000 per tag plus an additional ~NZD$100/month/tag for satellite transmission costs. It is anticipated that approximately **3 months** of tracking and dive data would be available from each individual. Individual tagging events could be spread over a year to collect data on seasonal variation. This would provide a useful data set from which to evaluate Hector's dolphin diving behaviour. Overall, cost of the project would be in the order of NZD$130,000 for tag purchase plus significant additional costs (likely around NZD$1 million in total) for bringing expert tagging personnel to New Zealand to support the research, field costs, staff wages, analysis costs, follow-up study costs and costs associated with stakeholder consultation.

[8] See https://wildlifecomputers.com/limpet-suite-product-sheet-splash10-f-333/

Summary of potential tagging options, cont.	
Option 2 (ARGOS location only data)	20 bolt-on tags are deployed on Hector’s dolphins with satellite linked **ARGOS** (e.g. < 250 m accuracy) tags that transmit only location data (e.g. Wildlife Computers SPOT-365 tag[9]). Individual tags with bolt-on mounts cost ~NZD$3,500 per tag plus an additional ~NZD$100/month/tag for satellite transmission costs. It is anticipated that approximately **12 months** of tracking and dive data would be available from each individual. Individual tagging events could be spread over the year to provide information on seasonal variation. This would provide a useful data set from which to evaluate Hector’s dolphin diving behaviour. Overall, cost of the project would be in the order of NZD$94,000 for tags plus significant additional costs (likely around NZD$1 million in total) for bringing expert tagging personnel to New Zealand to support the research, field costs, analysis costs, follow-up study costs and costs associated with stakeholder consultation.

[9] See https://wildlifecomputers.com/limpet-suite-product-sheet-spot-365/

4. SYNTHESIS AND CONCLUSIONS

Previous tagging research programmes of Hector's dolphins have demonstrated that electronic tagging can aid in investigating important aspects of biology and ecology (Stone et al. 1998, 2005), an outcome also supported by many international tagging programmes on other cetacean species reviewed in this report. While both these New Zealand studies had relatively small sample sizes, the researchers concluded that Hector's dolphin are a suitable candidate for satellite telemetry studies and that the risk to this species from capture, handling and tagging appears low. Unfortunately, neither of these projects included a comprehensive follow-up research programme and so there are few data available from which to assess any potential short or longer term impacts on tagged animals.

4.1. Research areas that can be addressed by tagging

As outlined in Table 3 and Table 4, there are a wide range of data that can be collected from electronic tagging projects. Given the variety of data types, there is an equally diverse range of research questions that could be investigated. Table 8 identifies several general research areas related to fine-scale distribution, diving and foraging behaviour of Hector's dolphins and provides recommendations of the tagging methods that can best address these research areas.

It is important that the research areas outlined in Table 8 are carefully evaluated against specific research questions in any future studies. Whilst the tagging methods identified in Table 8 can provide useful data in addressing these research areas, the development and specification of any research programme is extremely complex. As previously discussed, it will be necessary to consider a wide range of issues well in advance in order to confirm that the chosen method can deliver required outcomes for a specific research question. These include issues such as sample size, animal welfare, cost, and considerations of accuracy and precision but, just as important, is considering public and Treaty Partner views.

Notwithstanding these issues, electronic tagging has the potential to address the current knowledge gap in spatial/temporal distribution patterns that is needed in order to better inform Hector's dolphin conservation management. A recent example of a cetacean tagging programme that investigated movement patterns (which led to positive conservation and management outcomes) is the Bryde's whale suction cup tagging study (Constantine et al. 2015). The results from this research initiated changes in shipping traffic and reduced vessel strike of whales.

4.2. Conclusions

There are a wide variety of electronic tag types and attachment methods suitable for Hector's dolphins, all of which have different advantages and disadvantages, and can be used to answer a diverse range of potential research questions. Table 8 provides recommendations about the best tagging method to address each area of research, but it is not possible to determine the optimal tagging programme unless there is a specific research question and the relative weighting of potential competing considerations (e.g. tag retention vs animal welfare vs sample size vs cost) are stated. Nevertheless, as a general rule, the higher the quality and quantity of data produced, the higher the impact on individuals.

The assessment of any proposed tagging programme should follow a strict evaluation process. This process should follow international best practice which is the decision-making approach described in Andrews et al. (2019). This will ensure that any tagging programme is carefully assessed against issues such as welfare considerations, likelihood of delivering a robust result for the research question of interest, stakeholder and Treaty Partner consultation, and consideration of alternative methods.

Table 8. Summary of Hector's dolphin research questions that could be addressed by electronic tags.

Potential research areas	Recommended tag types	Tagging comments	Other possible methods
Distribution			
Individual dolphin movement and home range Seasonal and regional differences in home range Offshore distribution Proportion of time spent outside protected areas Use of harbours Spatial and temporal overlap with fishing	Satellite - Argos or GPS	Depending on the desired data resolution, tagging could use bolt-on (long term) or suction cup (short term) attachment techniques. GPS tags provide a much higher level of location accuracy than Argos tags and are therefore preferred but can have shorter battery life. Active acoustic tags could also be used but would require setting up receiving stations in key locations.	Aerial (aircraft or drone) or vessel surveys. Acoustic monitoring stations. Photo-identification or biopsy sampling for tracking of individual dolphins.
Diving & foraging			
Characterising diving behaviour (e.g. depth, time, velocity)	TDR tags	Depending on the desired data resolution, tagging could use bolt-on (long term) or suction cup (short term) attachment techniques. Physiological tags are likely to require additional sensors (e.g. jaw, head, heart) to the main tag. Multi-sensor tags could be used which could integrate various tag types into a single tag to collect a range of this data. Tags could be archival (data logging) in which case they would need to be recovered or transmitting where data summaries are remotely broadcast.	Behavioural observations from drones, boats or nearshore elevated cliffs. Various diet study methods on tissue, faeces and / or stomach samples.
3D diving behaviour	Magnetometer/Accelerometer		
Identification of prey & feeding	Camera		
Diving physiology (e.g. heart rate, energetics)	Physiological tags		
Characterising marine foraging environment	CTD tags		

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7. APPENDICES

Appendix 1. Details of Hector's dolphin tagging research undertaken between 1978 and 1984 by Dr A Baker.

Details of Alan Baker's Hector's dolphin tagging programme conducted between 1978 and 1984 with quotes from an email sent to Simon Childerhouse dated 17 December 2003.

The study area was Cloudy Bay Marlborough, and my base was Whekenui in Tory Channel. I had a skipper and 2 crew. The route was down the coast to Fighting Bay, and from there a grid search across Cloudy bay to the White Bluffs. I worked from January 1978 to April 1984, mostly in spring/summer/autumn. I did make a few trips in mid-winter, but basically the weather was not with me. I operated under a permit from the Minister of Fisheries.

Between 1978 and 1982, I caught 27 Hector's and tagged 23. Of the remaining 4, 3 had natural markings which I considered OK for resighting purposes, and 1 dolphin was released untagged because I was unhappy about the way it was behaving alongside the boat.

The dolphins were caught from the bow using a rubber padded stainless steel tail grab on a long detachable pole (the boat also had a bow pulpit). The grab was designed by Rod Abel, former manager of Marineland of NZ at Napier, and by then Director of Ocean Park at Hong Kong. Rod's son Grant came as crew on several occasions and instructed me in the use of the grab. There is a knack to it, and it was not necessary to use much force to apply the grab as it was quite sensitive. We had our share of misses though. The grab was attached to a rope which included a bungee spring, the length of which was the exact distance from the bowsprit to the cockpit.

When a dolphin presented its tail appropriately while bow wave-riding, the grab was placed over the tailstock and a trigger at the base of the grab was activated closing it around the tailstock. The boat accelerated forward and to port as the dolphin swam off to starboard pulling on the bungee and swinging around towards the boat's stern. Within a few seconds the dolphin was in position alongside the cockpit and the boat was stopped and two crew reached over and stroked the animal and spoke to it while a canvass cradle was being manoeuvred underneath. Once this was in place, a derrick was attached to the cradle and the dolphin lifted out and placed athwart ships across the cockpit (see photo on p118 of the 1983 edition of my guide book - the one with right whale and calf on the cover). There it was examined, photographed, measured, weighed, and an Allfex tag applied to the posterior part of the dorsal fin. The tags were about the size of a 10 cent coin, colour-coded and stamped with a number. The tagging gun needle was sterilized in alcohol, and an antibacterial *ointment was applied. I also tried freeze branding, but the Argon I used was not cold enough for the dolphin skin - it bleached my fingertips though!*

With the one exception noted above, the dolphins settled down very quickly, usually once they had been handled while still in the water. There was no struggling once the animal had been lifted out - they just sat there in the cradle quietly while we went about our business - about 3-4 minutes worth. One crew was responsible for keeping the dolphin wet and talking to it (that made us feel good anyway!). Once the work was completed, the cradle was up-ended on the port side and the dolphin simply slid off into the sea. Most often the animal took off at high speed circling the boat, but we were amazed to find that once the boat got underway, the tagged dolphins often reappeared at the bow with their mates!

Nine tagged dolphins were resighted on following trips, all but one in the general area where they were tagged. The resighting times mostly ranged from 1-3 months, although there was one at 2 years and another almost 5 years later (which was a surprise), and most animals were identified to individuals through the colour code on the tag. One tagged dolphin was sighted from the Fisheries research vessel W.J. Scott in Pegasus Bay. One of the naturally marked dolphins was resighted by me in Queen Charlotte Sound about 60 km away.

The tail grab was very carefully engineered, and it went through a number of versions before we felt it was suitable. There were 2 grabs, and I believe they are still extant, in the care of the Perano family in either Blenheim or Picton. If DOC was wanting to see a grab, or even use it, I think I could contact the right people to arrange that. I would not feel confident about using a tail grab after all this time (and my back would not stand it!), so if this programme goes ahead, I would suggest that DOC contract Grant Abel.