Unmanned aerial vehicle (UAV) remote sensing of behaviour and habitat use of the nationally endangered bottlenose dolphin (*Tursiops truncatus*) off Great Barrier Island, New Zealand.

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning".

Signed: Tiaiana F. de Oliveira

Date: 20/04/2018

Co-authored works

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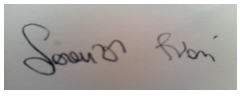
All co-authors have approved the inclusion of the joint work in this master thesis.

Contribution: Ticiana Fettermann conceived the idea, carried out the field work and analysed data, and wrote the manuscript (80% contribution). Lorenzo Fiori helped design and perform the UAV fieldwork and data collection, assisted the data analysis, and contributed to writing the manuscript (15%). Ashray Doshi provided technical drone expertise (1%). Martin Bader assisted to develop the statistical approach and data analysis (1%). Dan Breen reviewed and provided feedback on the manuscript (1%). Barbara Bollard-Breen and Karen A. Stockin conceived the research idea, reviewed and provided feedback on the manuscript (1% each).



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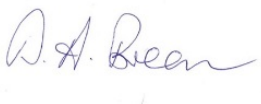

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Abstract

Bottlenose dolphins (*Tursiops truncatus*) are widely distributed in temperate and tropical waters. In New Zealand, Bottlenose dolphins are classified as "nationally endangered", as there are fewer than 1,000 adults. Great Barrier Island, New Zealand has been identified as a potential hotspot for the North Island population of bottlenose dolphins, with dolphins observed year-round, exhibiting evidence of site fidelity. However, it is unclear how many dolphins are using these areas and why. How the animal uses its environment is a critical step in conservation management for this species and behaviour patterns have not been described for this region. Oceanographic features (e.g. currents, fronts and upwelling), other abiotic factors (temperature, bathymetry and topography), prey distributions and human influences (boating, fishing and environmental contaminants) are known to influence behaviour patterns, group size, and group composition in cetaceans. Behavioural observations in cetaceans are, however, challenging to study, that is, most of the animal activities take place below the water surface, out of sight of boat based observers. Vertical take-off and landing (VTOL) unmanned aerial vehicles (UAVs) represent a novel and cost-effective research tool to investigate cetacean behaviour, as conventional aircraft are expensive, limited in the altitude they can fly at and potentially disturb sensitive wildlife. UAVs are an economical, easy to use and operate, safe, portable and a versatile alternative that may cause little disturbance. In addition, the aerial observation from the UAVs allows assessment of cetacean behaviour from an advantageous perspective and can collect high spatial and temporal resolution data, providing the opportunity to gather accurate data about group size, age class and subsurface behaviour.

The use of UAVs is rapidly becoming a common practice both for marine mammal researchers and whale-watchers around the world. However, this new research tool has not yet been used to study bottlenose dolphins in New Zealand waters. In the absence of previously undertaken dedicated UAV surveys, the present thesis is dedicated to investigating and determining how effective lightweight low altitude UAVs are in describing behaviour of bottlenose dolphins off Great Barrier Island. In addition, the thesis compares UAVs with traditional boat-based observations in terms of effectiveness, safety and impact on dolphin behaviour. Surveys were conducted

between July 2015 and March 2017 at the west coast of Great Barrier Island. Initially, boat-based surveys were conducted to assess the short term behavioural responses of resting bottlenose dolphins to the VTOL UAV flown at 10 m, 25 m and 40 m altitude. The number of reorientation and tail slap events increased significantly between controls and flights when the UAV was flown at 10 m altitude over the animals. In contrast, no significant difference was detected when the aircraft was flown at 25 m and 40 m altitude. A total of 71 UAV operations were performed over 21 independent groups of bottlenose dolphins. Aggregations of between 6 to 66 individuals were observed with a median group size of 41, whereas 23.8% (n = 5) of the groups contained between 51 and 55 individuals. Calves and neonates were present in the majority of the groups (85.7%, n = 18). Dolphins were found to travel more in summer and autumn, and rest more in winter and spring. Results derived from UAVs were compared with boat data and showed that overall, group size from UAV-derived counts was 71.4% (n = 15) higher, and UAV-derived observations detected significantly more travelling and less resting and less foraging than observations by boat.

Results indicate that low altitude UAVs can be used for surveys over a short duration and range and represented a non-invasive tool to study dolphin behaviour when flying at and above 25 m altitude. The UAV surveys can minimise bias and deliver data that are more robust. However, the results conservatively suggest that UAV similar to the *Splashdrone* should not be flown at 10 m over bottlenose dolphins. Future research should further identify the threshold at which disturbance occurs (i.e. between 10 and 25 m) and also identify how this differs during different behavioural states other than resting.

Finally, this research provides baseline information on the optimal use of UAV for bottlenose dolphins surveys and behavioural studies. Additionally, this study contributed to the development of guidelines for future operational use of UAVs around cetaceans in New Zealand waters.

Chapter One: Introduction

1 Introduction

1.1 Introduction

Bottlenose dolphins (*Tursiops truncatus*) are widely distributed in temperate and tropical waters (Shirihai & Jarrett, 2006). In New Zealand, bottlenose dolphins are mainly found in coastal regions and are classified as "nationally endangered" as there fewer than 1,000 adults in our waters (Baker et al., 2016; Baker et al., 2010). As they have low levels of gene flow in New Zealand, they are classified into three genetically distinct populations (Tezanos-Pinto et al., 2009) (Figure 1).

Figure 1: Presumed distribution and range of the three New Zealand bottlenose dolphins' populations (shaded) based on live sightings. Map original source from Te Ara: www.teara.govt.nz.

The Northern North Island population is the largest group and is described as a semi-resident population of 317 unique individual dolphins (Tezanos-Pinto et al., 2013),

travelling and changing habitat during the seasons between Doubtless Bay and Tauranga (Peters & Stockin, 2016; Tezanos-Pinto et al., 2009). However, concerns over this population have been reported as there was a decline in the resight rate of unique individuals (Constantine, 2002; Tezanos-Pinto et al., 2009). In fact, the population declined by a rate of 7.5 % per annum between 1997 and 2006, with infrequent sightings of known individuals reported outside of this area, such as in the west coast of the North Island (Tezanos-Pinto et al., 2013). It is unclear if this decline was due to mortality, low recruitment, emigration or a combination of these factors (Tezanos-Pinto et al., 2013). Furthermore, protected areas, such as tourism exclusion zones in the Bay of Islands, were described as no longer being effective at protecting the dolphin population due the shifts in fine-scale habitat use over the 10-year period (1997 – 2006) (Hartel, Constantine, & Torres, 2014).

Great Barrier Island (GBI), located in the outer Hauraki Gulf, has recently been described as a potential hotspot for the bottlenose dolphins Northern North Island population. The region was reported to have year-round sightings, high levels of individual site fidelity, large average group size and high use of these waters by groups containing neonates and calves (Dwyer et al., 2014). Dwyer *et al*. (2014) sighted bottlenose dolphins during all months of the year and estimated that 171 dolphins visited the island between 2011 and 2014. Great Barrier Island seems to be an ideal habitat for bottlenose dolphins due to a combination of factors, including high prey abundance, and low levels of vessel traffic and other human activity, such as commercial marine mammal tourism. However, it is unclear which proportion of the Northern North Island population is using these waters and why (Dwyer et al., 2014). Dwyer believed that the Great Barrier Island region was not a corridor, but a key site for some of this population. She highlighted that their site fidelity could be related to food availability, due to the strong currents (i.e. East Auckland Current) that bring nutrient-rich ocean waters into the Gulf, or to the area acting as a social hub, where small groups fuse for socialising. Prior to Dwyer's study, Great Barrier Island bottlenose dolphins were largely undescribed in literature and there had been little research on behaviour patterns of bottlenose dolphins at that location.

Considering that the Great Barrier Island population could be in serious trouble if the population decline continues, it is important to focus on long-term research in the population range, such as Great Barrier Island. Great Barrier Island also offers a unique

opportunity as a control site to compare against other regions of the home range that are heavily exposed to tourism (Dwyer et al., 2014).

Great Barrier Island is located in the outer Hauraki Gulf, a Marine Park (HGMPA 2000) that covers 1.2 million hectares of ocean. It is one of New Zealand's most valued and intensively used resources – for food gathering, recreation and conservation. As the largest northern offshore island with an area of 285 km^2, it encompasses depths of 50 to 100 m (Dwyer, 2014; Manighetti & Carter, 1999). Water temperature varies between 22°C during summer and 12°C during winter (Booth & Sondergaard, 1989). The island has a low human population density and the Department of Conservation administers a large part of the Island (68 %) (Norgrove & Jordan, 2006). The west coast of GBI, adjacent to Cradock Channel in the North (36°12'S 175°11'E) and Colville Channel (36°23'S 175°25'E) is characterised by a rocky shoreline and diverse shallow embayments (Dwyer et al., 2014). A significant part of the North Island population of bottlenose dolphins (n = 171) is described as using the area consistently during all seasons, with a peak in summer and autumn. It appears that GBI is an important area for this population and should be included in a long-term study with regards to this species (Dwyer et al., 2014). In addition, the area remains free from whale watching tour operators. Therefore, is clear that GBI provides an outstanding location to apply UAV remote sensing techniques to assess and study bottlenose dolphin behaviour, as well as to contribute to improving the understanding of the species.

Studies examining the distribution and behaviour patterns of cetaceans are necessary to understand how these animals use their environment (Whitehead, 2001), and provide crucial knowledge for designing and implementing any conservation or management plans for that species. Studying the population's year-round distribution is ideal to achieve optimal protection (Reeves, 2000). It is also important to examine the functional role of the species in its ecosystem, evaluating the potential impact of extrinsic (e.g. anthropogenic) and intrinsic factors (e.g. predator avoidance) (Bowen, 1997), as well environmental factors (e.g. oceanographic features and abiotic factors). All these factors shape patterns of communication, cognition, life history, behaviour and ecology (Dwyer et al., 2014; Mann, 1999). Bottlenose dolphins are apex predators, highly mobile and very sensitive to anthropogenic stressors. Research on this species

therefore also provides good indicators for environmental health as well as valuable knowledge of this species and its conservation.

In order to investigate habitat use of bottlenose dolphins, it is important to assess their behaviour within a range of habitats. However, behaviour in dolphins is challenging to study, as most of the animal activities take place below the water surface, out of sight of the researchers. Studies of cetacean behaviour, interactions and social relationships normally uses boat-based surveys following strict observation protocols described by Altmann (1974) and Mann (1999). In general, the observations are conducted using focal follow sampling, or scan sampling to assess the group or an individual. However, several authors have highlighted that observer bias can affect focal group follow protocols, as it only records the behavioural state of the group of dolphins that are close to the surface (Mann, 1999) and may not represent the majority of the group. Bias can be reduced using an individual focal follow protocol, where the behaviour of a single individual is sampled (Altmann, 1974). Unfortunately, it is difficult to follow a single individual in large groups of cetaceans, such as the groups that are found off Great Barrier Island, where the average group size is around 36 individuals (Dwyer et al., 2014). Furthermore, the presence of the research vessel may elicit a behavioural response in the animals, thus biasing the observations (Dawson, Wade, Slooten, & Barlow, 2008; Guerra, Dawson, Brough, & Rayment, 2014). Aerial video observation is another method to study behaviour, but conventional aircraft are expensive, limited in the altitude they can fly to and they potentially disturb sensitive wildlife. In contrast, unmanned aerial vehicles (UAVs), also known as remotely piloted aerial systems (RPAS) or “drones”, are now regarded as economical, safe, portable and versatile alternatives that may cause little disturbance, and are a new research tool that has not been used to study bottlenose dolphins before.

UAVs are providing a safe method for scientists to study remote or inaccessible regions to acquire high-resolution remote sensing data at lower costs and increased operational flexibility (Klemas, 2015). Use of UAVs is rapidly becoming common practice for both marine mammal researchers and whale-watchers (Fiori, Doshi, Martinez, Orams, & Bollard-Breen, 2017). Aerial observation from UAVs allows assessment of cetacean behaviour from an advantageous perspective in comparison to standard boat-based surveys and can collect very high spatial and temporal resolution data that is capable of

improving data quality beyond the traditional methods (Anderson & Gaston, 2013; Hodgson, Baylis, Mott, Herrod, & Clarke, 2016; Nowacek, Christiansen, Bejder, Goldbogen, & Friedlaender, 2016). UAVs have been successfully been tested for a number of marine mammal applications, such as for pinniped colony counts (Goebel et al., 2015; Sweeney et al., 2015), cetacean photogrammetry (Christiansen, Dujon, Sprogis, Arnould, & Bejder, 2016; Dawson, Bowman, Leunissen, & Sirguey, 2017; Durban, Fearnbach, Barrett-Lennard, Perryman, & LeRoi, 2015; Durban et al., 2016), and have been used to collect samples of whales' exhaled breath condensate (Acevedo-Whitehouse, Rocha-Gosselin, & Gendron, 2010).

It is clear that sensors mounted on UAVs offer distinct advantages for sampling cetaceans including, but not limited to, collection of high quality videography that can be observed multiples times, and improved assessments of population numbers by reducing bias. In fact, the use of UAVs provides the opportunity to gather more accurate data about group size and age class, and allows researchers to access cetacean behaviour from an advantageous perspective in comparison to boat-based surveys, as most of the activities take place below the water surface. However, there are concerns about the potential risk of disturbance to wildlife caused by the UAVs' visual and acoustic stimuli (Ditmer et al., 2015; Hodgson & Koh, 2016; Pomeroy, O'Connor, & Davies, 2015; Vas, Lescroel, Duriez, Boguszewski, & Gremillet, 2015). It is well documented that the noise produced by conventional aircraft and helicopters elicits strong behavioural responses in cetaceans (Patenaude, Richardson, Smultea, Koski, & Miller, 2002; Richardson & Wursig, 1997; Smultea, Mobley, Fertl, & Fulling, 2008; Wursig, Lynn, Jefferson, & Mullin, 1998). In contrast, research on the impact of UAVs on cetaceans is limited to opportunistic observations, and most studies do not quantify behavioural responses (Smith et al., 2016). Quantifying disturbance levels is not straightforward as several factors including species (Wursig et al., 1998), ecotype (Richter, Dawson, & Slooten, 2006), behavioural state (Wursig et al., 1998), environmental factors (Smith et al., 2016) and the noise levels of the aircraft itself can influence responses to the aircraft presence. With the recent increase in research, commercial and recreational UAV operations around cetaceans (Christiansen, Rojano-Doñate, Madsen, & Bejder, 2016), researchers and regulatory bodies urgently need

baseline data to develop guidelines to avoid animal harassment (Ditmer et al., 2015; Hodgson & Koh, 2016; Smith et al., 2016).

The objective of this thesis was to investigate how VTOL UAVs could be safely used to study cetacean behaviour. This approach was unique in New Zealand waters and I believe that the UAV platform potentially provides a solution to minimise bias and improve the accuracy of data. In addition, this research aimed to provide best practice guidelines to the Department of Conservation and other regulatory bodies on the ethical use of VTOL UAVs around marine wildlife.

1.2 Research Questions and Objectives

This master's research aimed to answer the questions: "Can small UAVs be used to safely collect behavioural data on cetaceans? How does this method compare with other approaches and how can drone based observations support planning for the conservation of this species and the management of threats to their survival?"

The objectives of this research were to:

a) Determine the optimal flight parameters for studying behaviour and population ecology;
b) Investigate the use of low altitude VTOL UAVs to describe behaviour patterns and habitat use of bottlenose dolphins on the western side of GBI, including examining group size, group composition and interaction;
c) Compare results of UAV surveys with boat-based methods, and
d) Contribute to support the conservation and management of bottlenose dolphins, a nationally endangered species in New Zealand.

Finally, this research provides baseline data to help shape guidelines for flying small VTOL UAVs safely around dolphins in New Zealand waters.

1.3 Structure of the Thesis

This thesis comprises six chapters:

Chapter 1 is the Introduction to this thesis.

Chapter 2 presents a review of the relevant literature of the New Zealand bottlenose dolphin distribution and abundance, social structure and behaviour; platforms used to study marine mammals; and UAVs and their application in a broad spectrum of research areas, highlighting how they can provide fine resolution spatial and temporal data for ecology and wildlife monitoring, including cetacean research.

Chapter 3 describes the study site and presents the research methodology. This chapter includes the UAV and boat based platforms, the research design, data collection and data analysis.

Chapter 4 presents the main findings of this research behaviour patterns and group dynamics, behavioural state and interactions and recommendation for the optimal flight parameters to study bottlenose dolphins safely and an assessment of the UAV response level. The latter is a reformatted version of a paper in review in *Scientific Reports*, co-authored with L. Fiori, M. Bader, A. Doshi, D. Breen, K. A. Stockin and B. Bollard-Breen.

Chapter 5 is a general discussion

The Conclusion Chapter 6 starts with an overview of the present study, followed by the main research objectives and methodology employed in this study. A summary of the research findings and recommendations for future research on UAVs around dolphins in New Zealand are provided, as well as the significance of this research and contribution to support conservation and management of bottlenose dolphins outlined.

Chapter Two: Literature Review

2 Literature Review

2.1 Bottlenose dolphins – *Tursiops truncatus*

Bottlenose dolphins (*Tursiops* spp.) are considered to be the most well studied species of cetaceans due to their adaptability and their proximity to the coast (Reeves, 2002). The species belongs to the family Delphinidae, suborder Odontoceti (toothed whales) and order Cetacea. The taxonomy is confused due the wide geographical distribution, but until recently all bottlenose dolphins around the world were recognised as *T. truncatus*. To date, two official species are described based on morphological and mitochondrial DNA data: the common bottlenose dolphin, *T. truncatus* (referred to here as the bottlenose dolphin - Figure 2) and the Indo-Pacific bottlenose dolphin, *T. aduncus* (Wang, Chou, & White, 1999). A third species, the Burrunan dolphin (*T. australis*) has recently been described as endemic to the Southern Australian Coast (Charlton-Robb et al., 2011), although it is not officially recognised by the Committee on Taxonomy for Marine Mammal Species and Subspecies presently.

Figure 2: Bottlenose dolphins (*T. truncatus*) around GBI, New Zealand.

2.1.1 Distribution and Abundance

Globally, bottlenose dolphins have been listed by the International Union for Conservation of Nature (IUCN) as “Insufficiently Known” in 1994, “Data Deficient” in 1996, and finally as “Least Concern” in 2008. The worldwide population has been estimated to be a minimum of approximately 600,000 individuals (Wells & Scott, 2009).

Bottlenose dolphins are widely distributed and inhabit temperate, sub-tropical and tropical waters between the Faroe Islands (62°N 7°W) (Bloch, Mikkelsen, & Ofstad, 2000; Wells & Scott, 2009) and the south of the South Island of New Zealand (45°S 166°E) (Lusseau, 2006a; Wells & Scott, 2009) (Figure 3).

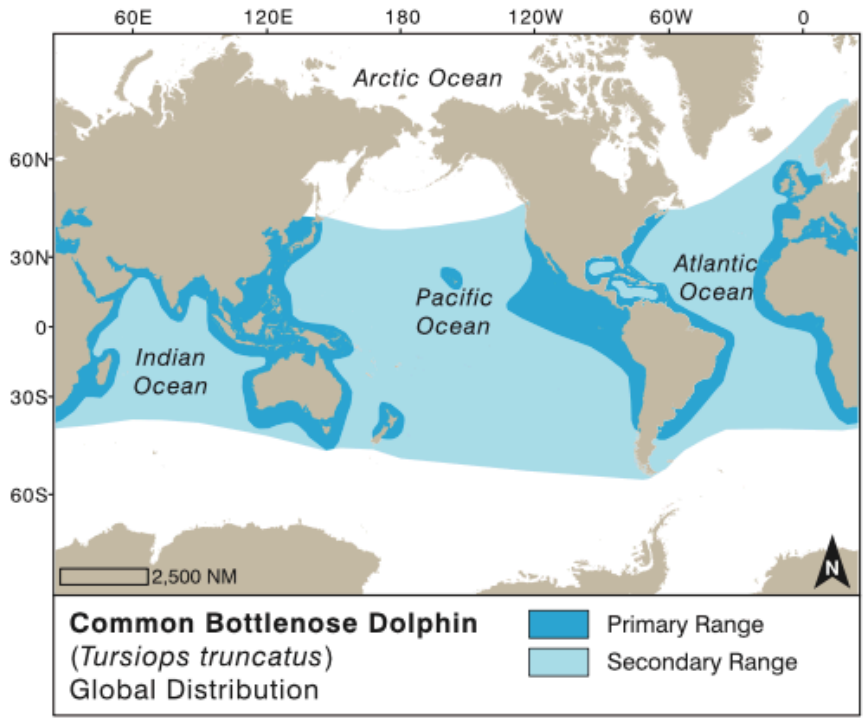


Figure 3. Global distribution of common bottlenose dolphins (*Tursiops truncatus*). Map sourced from (Jefferson, Webber, & Pitman, 2015) (see Appendix 1 for copyright permission).

Bottlenose dolphins are primarily found around coastal areas, although they can also be found in the deep pelagic waters, deep fiords, mangrove swamps, mud flats, estuaries and even rivers (Wells & Scott, 2009). Because of these geographical variations, bottlenose dolphins are described as either an *inshore* or *offshore* form. This variation is based on morphology, haematology and genetic differences (Shirihai & Jarrett, 2006). *Inshore* dolphins tend to be smaller, with larger pectoral fins and a longer, slender beak, whereas *offshore* dolphins are larger, with proportionally smaller pectoral fins and a stubbier beak (Shirihai & Jarrett, 2006). Bottlenose dolphin ranging patterns vary from animals with relatively small ranges to animals being migratory; however, bottlenose dolphins do not perform extensive migrations to high latitude feeding grounds, like mysticetes (Corkeron & Van Parijs, 2001). The *offshore* form seems to be less restricted in range and movement and can travel up to 4,200 km during seasonal movements

(Shirihai & Jarrett, 2006), showing less temperature-dependent distribution as well (Kenney 1990). Bottlenose dolphins are described as inhabiting a wide range of sea surface temperatures, ranging from approximately two to 35°C (Schneider, 1999; Wells & Scott, 2009).

The abundance and distribution of cetaceans, including dolphins, is known to be related to oceanographic features, such as current and upwelling, sea surface temperature (SST) and salinity, and bathymetric variables, such as water depth and seabed gradient, variations in pressure, turbidity and the amount of light penetration. Changes in SST (Constantine, 2002; Merriman, 2007; Schneider, 1999; Wursig & Wursig, 1979) and bathymetric variables (Dwyer, 2014; Hanson & Defran, 1993; Parra, Schick, & Corkeron, 2006) are known to influence dolphin movements and distribution. Water turbidity can also affect movements and distribution, either directly or indirectly affecting visibility due to light penetration, reducing the primary productivity and also the distribution and abundance of dolphin prey (Cockcroft, Ross, & Peddemors, 2010). However, prey abundance and distribution are believed to be the major factors that drive dolphin community dispersal and movements (Barros & Wells, 1998). In the north of New Zealand, bottlenose dolphins are reported to move into deep waters in the warm water months due prey availability driven by the East Auckland current (Constantine, 2002).

Habitat selection depends on the specific species-habitat relationship, such as food availability, access to mates, competition and predation (Flaxman & DeRoos, 2006), as well as oceanographic conditions. Site fidelity may change if conditions become less attractive, as dolphins are highly capable of migrating and shifting habitats. There is no single factor, but a combination of many different factors that determine how the species uses its habitat. Bottlenose dolphins are also subject to many direct and indirect anthropogenic threats, such as tourism, vessel traffic, fishing, aquaculture, agriculture and forestry run off, and noise pollution. These are known to impact and cause changes in behaviour patterns and behaviour budgets, group size and composition, as well as causing habitat loss and range shift of bottlenose dolphins (Buckstaff, 2004; Constantine, Brunton, & Dennis, 2004; Corkeron & Van Parijs, 2001; Filby, Stockin, & Scarpaci, 2014; Guerra & Dawson, 2016; Luís, Couchinho, & Dos Santos, 2014; Lusseau, 2006a, 2006b; May-Collado & Quinones-Lebron, 2014). There is no doubt that the marine ecosystem is threatened. Knowing this, concern in the scientific community is

growing regarding the preservation of these ecosystems, since the animals inhabiting them are increasingly vulnerable.

Understanding the movements and distribution, as well as the species-specific population dynamics and behaviour patterns of small dolphins, such as bottlenose dolphins, is crucial to define residency patterns as well as home ranges and core areas (Whitehead, 2001). The way these animals use their environment provides vital information about the environmental health, as well as a valuable contribution to the knowledge about these species and their conservation.

2.1.2 Social Structure and Behaviour

Bottlenose dolphins live in a highly dynamic fission-fusion society (Lusseau & Newman, 2004; Merriman, 2007; Wells, Scott, & Irvine, 1987), where individuals move from small groups that continually change in composition and behaviour (Connor, Wells, Mann, & Read, 2000). Group sizes vary within populations, ranging from one individual to more than 100. Bottlenose dolphins are commonly found in small groups of two to 15 individuals (Shane, Wells, & Wursig, 1986). However, the group size tends to increase with water depth and openness of the habitat, as this may provide protection from predators and the benefits of foraging in the pelagic environment (Hanson & Defran, 1993; Speakman et al., 2006; Wells et al., 1987).

Bottlenose dolphins are observed to have complex daily patterns of behaviour. Temporal, environmental and social factors, such as time of day, season, tide, water depth, group size and group composition, affect behavioural patterns. Behavioural budget is defined as the proportion of time an animal spends performing each behavioural state. The interpretation of each behavioural state is complex and is based on information about the swimming direction, speed and organization, diving intervals and specific surface or aerial events (Constantine, 2001). These activities include socialising, resting, foraging, milling and travelling. For each population, these budgets are different. The amount of time that they spend on each behaviour varies depending the habitat they live in, as well the variations in prey distribution, mating opportunities, parental care, predators and human disturbances (Mann, Connor, Barre, & Heithaus, 2000). However, it is crucial for dolphin survival to have a balance between cost and benefits of spending energy. For example, common dolphins (*Delphinus delphis*) tend to

be close to higher concentrations of prey to minimise energy demand during foraging (Young & Cockcroft, 1994). Also, mother-calf pairs of bottlenose dolphins in Shark Bay take advantage of higher food availability in shallow habitats during foraging, where there is also a high shark density, reflecting a trade-off between predation risk and food availability, but moving to deeper safer waters to rest (Heithaus & Dill, 2002).

2.2 Bottlenose dolphins in New Zealand & GBI waters

2.2.1 Distribution & Abundance

In New Zealand coastal waters there may be less than 1,000 adult bottlenose dolphins overall, and for this reason their conservation status is a *nationally endangered threatened* species (Baker et al., 2016; Baker et al., 2010). They are mainly found around coastal areas and are divided in three genetically distinct populations: the Fiordland population, the Marlborough Sounds population and the Northern North Island population (Baker et al., 2010; Tezanos-Pinto et al., 2009) (see Figure 1, Chapter 1, pg.2). However, the *offshore* form is also described in New Zealand waters and they have been recently documented to be associated with false killer whales (*Pseudorca crassidens*) (Zaeschmar, Dwyer, & Stockin, 2013; Zaeschmar et al., 2014).

The Fiordland population (Doubtful Sound, Milford Sound and Dusky-Breaksea Sounds to the south and Jackson Bay to the north) is described as a resident closed population of approximately 205 individuals (Currey, Dawson, & Slooten, 2009). Unfortunately, recent studies observed that the population is declining rapidly and is believed to be less than 60 dolphins, hence IUCN has reclassified their status as *critically endangered* due the small sized population (Currey, Dawson, & Slooten, 2009; Currey, Dawson, & Slooten, 2011; Currey, Dawson, Slooten, et al., 2009).

The Marlborough Sounds (Marlborough to Westland) population is described as an open population of approximately 211 (95% CI 195-232) individuals visiting the Sounds annually over an area greater than 890 km^2 with a higher inter-annual migration/emigration rate (Merriman, Markowitz, Harlin-Cognato, & Stockin, 2009).

The Northern North Island population is described as a semi-resident population of 317 unique individual dolphins (Tezanos-Pinto et al., 2013), travelling and changing habitat during seasons between Doubtless Bay and Tauranga (Peters & Stockin, 2016; Tezanos-

Pinto et al., 2009). Unfortunately, this population has shown a decline rate of 7.5% per annum between 1997 and 2006, but it is unclear if this decline is due to mortality, low recruitment, emigration or a combination of these factors (Tezanos-Pinto et al., 2013). During the same 10-year period another study showed the current protected areas around the Bay of Islands region, such as the tourism exclusion zones, are no longer effective at protecting the dolphin population because of shifts in the fine-scale habitat use (Hartel et al., 2014). Furthermore, the population has also been described as extending its range beyond previously known areas, such as to the west coast of the North Island (Tezanos-Pinto et al., 2013).

GBI, situated in the outer Hauraki Gulf, has recently been reported and described to be a potential hotspot for the bottlenose dolphin Northern North Island population. Bottlenose dolphins have been sighted and observed using the west coast of the island all year round with high levels of individual fidelity, large average group size and high use of these waters by groups containing neonates and calves. At least 171 (CI = 162 – 180) individuals were estimated visiting the area during the period 2011 to 2014 (Dwyer et al., 2014). The island has a combination of factors that seem to create an ideal habitat for this species, including prey abundance, suitability of the area for breeding, calving and nursing, and low levels of vessel traffic and other human activities, such as commercial marine mammal tourism. However, it remains unclear what proportion of the North Island population is using these waters and why. Prior to the study by Dwyer, the GBI bottlenose dolphins were largely undescribed in literature and there has been little research on behaviour patterns on bottlenose dolphins in this region.

2.2.2 Social Structure and Behaviour

Inshore bottlenose dolphins are usually observed in small groups of two to 15 individuals (Mann, Connor, Tyack, & Whitehead, 2000; Shane et al., 1986). The group dynamics in New Zealand waters is not different, as they are commonly observed in small groups of five to 20 individuals, both in shallow and warmer waters in the north of New Zealand and the deep and cold waters in the south of New Zealand. For example, in the Bay of Island the median group size of bottlenose dolphins observed is between eight to 15 individuals, and they inhabit regions with relatively warm SST year-round (10 to 22°C) (Constantine, 2002). In the Marlborough Sounds the median group size observed is 12 individuals, living in areas with an SST between 11 and 19.5°C (Merriman, 2007). In

Doubtful Sound the median group size observed is 17 individuals, living in deep and cold waters (2 to 18°C) (Lusseau, 2005; Schneider, 1999). In contrast, the median group size observed in GBI is 35 individuals, considered to be larger than the normal size for New Zealand waters (Dwyer et al., 2014). The larger groups may be related to food availability and/or be based on a protective measure against predators (Mann, Connor, Barre, et al., 2000), as these waters are highly used by groups containing neonates and calves (Dwyer et al., 2014).

Unfortunately, bottlenose dolphins in New Zealand waters are declining due diverse factors, such as impacts from tourism, fishing and environmental contaminants (Constantine, 2001; Constantine et al., 2004; Currey, Dawson, & Slooten, 2009; Guerra & Dawson, 2016; Hartel et al., 2014; Lusseau, 2006a; Tezanos-Pinto et al., 2013). Studies examining distribution and behaviour patterns are necessary to understand how these animals use their environment (Whitehead, 2001) and how potentially adverse human activities can be managed. Bottlenose dolphins are apex predators, highly mobile and very sensitive to anthropogenic stressors. Site fidelity can change if conditions become less attractive, as they are capable of migration. For all these reasons, it is critical that New Zealand's bottlenose dolphins are considered having full regard to the local environmental conditions. Conservation efforts in respect of the bottlenose dolphin population in New Zealand waters, especially in the GBI waters, must account for the specific, available habitats, prey species, predators, competitors and levels of human activity. Furthermore, allowing researchers to assess and study bottlenose dolphins around the island is crucial to establish a knowledge base that may allow researchers to assess and implement possible changes aiming at the conservation of the species and many others.

2.3 Platforms to study marine mammals

Multiple platform approaches are described to study marine mammals, including dolphins. The most common ones are boat-, land-, and aerial-based surveys. Researchers usually choose the approach depending on the objective of the study, as well spatial scale, location, budget and timing.

Boat surveys are conducted from a range of different sized research vessels, from large commercial ships to small fishing boats. At least two observers are always involved, one

on each side of the vessel, using the naked eye and binoculars. Boat-based surveys are used worldwide in studies to identify species, estimate group size, assess behaviour, ecology, as well as to collect information on habitat use, acoustics, for photo identification of individuals, movement and residency patterns, and the social structure of the species. Studies to estimate population density and abundance via line or strips transects are often conducted by a boat-based platform. The boat-based platform is probably the most widely used approach to study bottlenose dolphins, as it is reported from all around the world. For example, in the UK, boat surveys were conducted to observe and describe Aberdeenshire waters as an important feeding area for the mother-calf pair due they regular use (Stockin, Weir, & Pierce, 2006). In New Zealand, calving seasonality and calf survival rate of bottlenose dolphins have been described over a period of 16 years based on data collected using the boat-based platform (Henderson, Dawson, Currey, Lusseau, & Schneider, 2014). Furthermore, the boat-based platform approach to measure and collect data of bottlenose dolphins was used in the Northern Adriatic Sea (Bearzi & Politi, 1999), the Patos Lagoon (Di-Tullio, 2009) and the Island of Santa Catarina in Brazil (Wedekin, Daura-Jorge, Rossi-Santos, & Simoes-Lopes, 2008), the Mediterranean Sea (Diazlopez, 2006), the Sado Estuary in Portugal (Luís et al., 2014) and in New Zealand (Berghan et al., 2008; Dwyer et al., 2014; Lusseau, 2005; Merriman et al., 2009).

Land- or shore-based surveys involve observers on a fixed position on land using the naked eye, binoculars and theodolite. Fixed positions usually include hilltops, cliffs, lighthouses and buildings. The land-based approach is used to identify species, estimate group size, assess behaviour, ecology and residency patterns of coastal marine mammals. This approach is well documented for the study of migratory whales (Department of Conservation, 2015; Hodgson, Peel, & Kelly, 2017) and resident cetacean populations. For example, in Brazil, regular land observations are conducted to study residency patterns of the local resident bottlenose dolphin population (Di Giacomo & Ott, 2016; Simoes-Lopes & Fabian, 1999; Wedekin et al., 2008). Furthermore, land-based surveys are also described to be a great platform to study cetacean occurrence off remotes oceanic islands and archipelagos (Milmann, Danilewicz, Baumgarten, & Ott, 2017) and off offshore oil platforms (Cremer, Barreto, Hardt, Tonello-Junior, & Mounayer, 2009).

Aerial-based surveys are a traditional method to study and document the distribution and abundance of cetaceans, especially to cover a large geographic area in a short period of time. It is primarily conducted by airplanes, helicopters and balloons. Surveys on board of airplanes and helicopters have been widely described to observe cetaceans around the world, for example, to study the body condition and reproductive status of migratory gray whales (*Eschrichtius robustus*) off the California Coast (Perryman & Lynn, 2002), to describe the distribution and abundance of Hector's dolphins (*Cephalorhynchus hectori*) off the west coast of the South Island of New Zealand (Rayment, Clement, Dawson, Slooten, & Secchi, 2011; Slooten, Dawson, & J, 2004) and Maui's dolphins (*Cephalorhynchus hectori maui*) off the west coast of the North Island of New Zealand (Slooten, Dawson, Rayment, & Childerhouse, 2006). Helium balloons (Nowacek, Tyack, & Wells, 2001b), a combination of a balloon kite system (Lewis, Wartzok, & Heithaus, 2011) and hybrid parafoil kite helium balloons (Friedman et al., 2013) have been described to be used as an aerial approach to assess and collect behavioural data using video footage. The footage provides data on social behaviour and patterns of interaction. In addition, it provides a permanent database that can be stored, analysed and reviewed several times.

Finally, the remote sensing platform allows collection of data without disturbing or making a physical contact with the animals. It ranges in resolution and due to the limitation in cost. Remote sensing usually refers to the use of high resolution satellite images, however, it can be helicopters, manned aircrafts, balloons or unmanned aerial vehicles. Researchers normally opt for this platform to detect, count and estimate wildlife populations in remote places. In marine mammal research, remote sensing is successfully described to detect, count and estimate population abundance. For example, elephant seals (*Mirounga leonina*) in the Southern Pacific Ocean (McMahon et al., 2014), Weddell seals (*Leptonychotes weddellii*) in Antarctica (LaRue et al., 2011), and Southern right whales (*Eubalaena australis*) at the Peninsula de Valdes - Argentina (Fretwell, Staniland, & Forcada, 2014) have been successfully detected and counted using high resolution satellite images. In addition, some of the studies proved to be a more compatible tool compared to ground counts (LaRue et al., 2011; McMahon et al., 2014). Furthermore, some places are totally inaccessible and the lack of effectiveness of traditional methods forces researchers to use an alternative approach to assess and

study marine mammals from those regions. For example, on Herald Island and adjacent waters in the Artic, high resolution satellite images were the best alternative approach to successfully detect polar bear tracks (Platonov, Mordvintsev, & Rozhnov, 2013).

Unfortunately, several studies have documented that traditional platforms, such as watercraft and aircraft, can elicit strong behavioural responses in cetaceans. For example, watercraft are described to affect bottlenose dolphin communication, whereas they increased whistle repetitions (Buckstaff, 2004) and emitted longs at low frequencies (May-Collado & Quinones-Lebron, 2014). In Jervis Bay, Australia bottlenose dolphins are described to change traveling direction and surface behaviour when approached by a powerboat with a 90 hp two-stroke outboard motor (Lemon, Lynch, Cato, & Harcourt, 2006). Furthermore, reactions, such as behaviour budgets, swimming speed and direction, respiration and dive patterns, communication, movements and habitat use are described to change in the presence of whale-watching boats in New Zealand waters (Constantine et al., 2004; Guerra & Dawson, 2016; Lundquist, Gemmell, & Wursig, 2012; Lusseau, 2006a; Lusseau & Bejder, 2007; Martinez, Orams, & Stockin, 2010). Aircraft, such as helicopters and airplanes, are also known to disturb cetaceans to some extent. For example, in the north-central and western Gulf of Mexico, different species of cetaceans, including bottlenose dolphins, were reported to be affected and react in the presence of a fixed-wing airplane flying at 229m altitude. These reactions included change of initial behaviour followed by diving or moving away (Wursig et al., 1998). The presence of helicopters and fixed-wing airplanes were also observed to cause short-term behavioural responses of bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) in the western Beaufort Sea, and sperm whales (*Physeter macrocephalus*) off Kaikoura (New Zealand) and at the main Hawaiian Islands (Richter et al., 2006; Smultea et al., 2008). Finally, bottlenose dolphins are also documented to avoid the shade of helium-filled tethered balloons during aerial observations (Nowacek, Tyack, et al., 2001b).

2.4 Unmanned Aerial Vehicle Remote Sensing

2.4.1 Definition and Regulations

Recently, UAVs, also known as RPAS (remotely piloted aircraft) or “drones”, are providing a safe way for scientists to study remote or inaccessible regions to acquire

high-resolution remote sensing data at lower costs and with increased operational flexibility (Klemas, 2015). Usually UAVs are operated by a human “pilot” supported by an additional “assistant or spotter” to ensure safety (Watts, Ambrosia, & Hinkley, 2012). UAVs, in addition to the sensor or payload carried, and a Ground Control Station (GCS) are all components of Unmanned Aerial Systems (UAS). These UAS are classified in more than seven categories, derived exclusively from existing military descriptions (Watts, Ambrosia, & Hinkley, 2012 - Fiori *et al*., 2017 discussed categories of the UAVs for marine mammals). However, in this review I will only describe the vertical take-off and landing (VTOL) category, as this had the most value for my research.

A VTOL is an aircraft or UAV that can take off and land almost anywhere. VTOLs range from nano-aircraft to larger unmanned helicopters, which are electro-powered and contain multiple rotors and three to eight propellers. They are relatively quiet, easy and safe to operate, and fly predominantly at low altitudes. They are typically chosen in situations where field limitations require this special capability, and can be operated flying over the target species groups with great stability and a lower environmental footprint (Goebel et al., 2015; Koski et al., 2015; Watts et al., 2012).

The International Civil Aviation Organization (ICAO) establishes worldwide guidelines to standardise UAS regulations ("ICAO Cir 38, Unmanned Aircraft System (UAS)," 2011). The goal of the ICAO was to address unmanned aviation operations in a safe, harmonised and smooth manner comparable to that of manned operations ("ICAO Cir 38, Unmanned Aircraft System (UAS)," 2011). In addition, operations are to be conducted outside of the controlled airspace and, if not considered recreational, require a certificate or waiver of authorization (CoA) (Watts et al., 2012). The main rules to comply with the guidelines are: 1) If lying outside of controlled airspace - do not fly over 400 feet or 121.92 m above ground level; 2) Adhere to the airport no fly zone (NFZ) - do not fly closer than five nautical miles or 9.26 km to airports; 3) Fly in visual line of sight (VLOS), i.e. always maintain a visual line with the UAV when flying, 4) Abide to the city NFZ - do not fly over densely populated areas; and 5) Follow the building/vehicles NFZ - always maintain a safe distance from buildings and vehicles on the flight path.

In New Zealand, UAV users also need to follow rules established by the Civil Aviation Authority of New Zealand. These guidelines include Part 101 for UAVs of 25 kg and

under, and Part 102 for aircraft bigger than 25 kg, in the latter case the operator must have a pilot license. The main rules for the 25 kg and under category are: 1) You must be able to see the aircraft with your own eyes at all times; 2) Take all practicable steps to minimise hazards to people, property and/or aircraft; 3) Fly the aircraft in daylight only; 4) Give way to all other aircraft; 5) Do not fly your aircraft higher than 120 m (400 feet) above ground level; and 6) Do not fly closer than 4 km to any aerodrome. Full description and rules can be found online at www.caa.govt.nz/rpas .

2.4.2 Advantages and Potential Implications

UAVs have been well known for many years. They are self-propelled aircraft that have no onboard pilot, and can fly automatically based on pre-programmed flights or more complex dynamic automation systems. The technology has been around for at least 50 years, but what is new are the applications and implications of what the UAV can provide and achieve. A platform for hobbyist has become a multi-million-dollar industry, and the potential applications increase every day, e.g. environmental monitoring, wildlife monitoring, inspections, aerial photography, journalism and much more. In the past 15 years UAVs have constantly been improving in technology and have become more accessible and widely available.

UAVs represent a valuable tool that can potentially complement standard methods and enhance many ongoing conservation programs (Sweeney et al., 2015; Wich, Dellatore, Houghton, Ardi, & Koh, 2016). They are a novel tool highlighted to be: economical, user-friendly, versatile, portable, flexible, accurate, small, agile, cost effective and, most importantly, safe, potentially causing little disturbance to wildlife. In addition, UAVs can rapidly survey large areas, obtaining different angles and adding a new perspective to the study, as well as reach places inaccessible from the ground, improving the data collection during field studies. UAVs can collect very high spatial and temporal resolution data, resulting in robust and permanent data sets, which can be reviewed multiples times and are capable of improving data quality beyond traditional methods (Anderson & Gaston, 2013; Hodgson et al., 2016). In many cases the application of this new survey technique has the potential to radically improve scientific understanding of the biology of the animals (Gordon et al., 2012). UAVs can also provide alternatives to human labour and traditional manned aircraft in dangerous or remote situations, eliminating human

risks (Uhlmann, 2015). Finally, UAV technology can hopefully provide solutions to minimise gaps and strengthen data.

2.4.3 UAVs in Conservation and Ecology Applications

UAVs have been used in a broad spectrum of research areas both as a replacement of manned aircraft and as a tool for novel survey designs (Watts et al., 2010). Several studies highlight that they can provide fine resolution spatial and temporal data for ecology and wildlife monitoring, from habitat and range mapping to distribution and location of wildlife. For example, UAVs have been used to map and identify a cyanobacterial mat in the East of Antarctica (Bollard-Breen et al., 2015), capture the micro-topography of Antarctic moss beds (Lucieer, Turner, King, & Robison, 2014), measure habitat quality (Chabot, Carignan, & Bird, 2014), monitor sea turtles in near-shore habitats, reef habitat and nesting beaches (Bevan et al., 2018; Bevan et al., 2015), monitor and collect marine tetrapods strandings (Pontalti, 2017), monitor wildlife (Adame, Pardo, Salvadeo, Beier, & Elorriaga-Verplancken, 2017; Hodgson et al., 2016), define the methodology to survey elephants (Vermeulen, Lejeune, Lisein, Sawadogo, & Bouche, 2013), and study distribution and density of the Sumatran orangutan (Wich et al., 2016).

2.4.4 UAVs in Marine Mammal Research

Operating UAVs while at sea can be challenging for different reasons: they may need to be piloted while the boat is in motion and constantly changing its geographic position; most of the time the use of the “return home” command is not useful as home is where the UAV took off from – likely to be an empty path of ocean by the time it lands; hand-launch and hand-recovery needs to be done on board of a boats, in a limited space; the pilot needs to constantly look after the equipment, especially if it is not waterproof, and the salt in the air can destroy metal; the wind may increase during the flight; and finally, the operator needs to keep track of everything, using the personal view, to avoid unexpected failures or crashes (Marine Mammal Comission, 2016).

Despite the challenges of operating at sea, the use of UAVs is rapidly becoming common practice. To date, UAVs have been successfully tested for a number of marine mammal research applications (Appendix 2) and since 2014 United States government agencies have systematically been using RPAs to conduct several marine mammal surveys

(Marine Mammal Comission, 2016). In particular, it has been demonstrated that VTOL UAVs are effective and economic tools for pinniped colony counts and cetacean photogrammetry. VTOL UAVs have also been used to collect samples of whale exhaled breath condensate and their application for cetacean behavioural studies is now being investigated (Fiori et al., 2017).

2.4.5 UAVs in New Zealand Research

There is a groundswell of use of UAVs for environment research. The technology has been used in different research areas around New Zealand. For example, in the scientific literature fixed-wing UAVs are described to: collect meteorological data (air temperature and humidity) off the Hauraki Gulf in Auckland (Cook, Strong, Garrett, & Marshall, 2013), and classify vegetation of regrowth bush off Dairy Flat, Auckland (Zhang, 2014). Small VTOL UAVs have been used to map the physical and biological characteristics of a geothermal environment near Taupo (Nishar, Richards, Breen, Robertson, & Breen, 2016), to classify coastal wetland vegetation off Whatipu Scientific Reserve (Lawrence, 2015), and to investigate honey bee drone congregations areas (DCAs) in Wellington (Cramp, 2017).

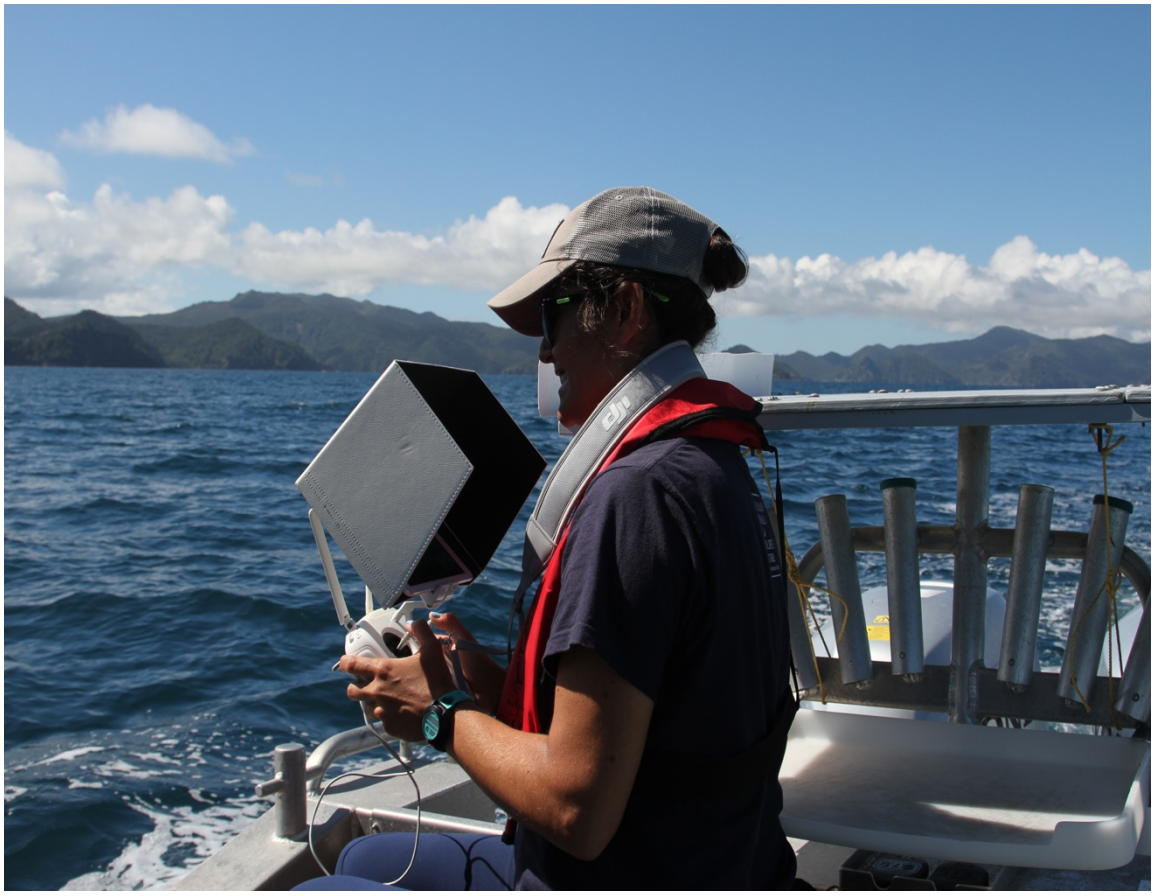
Grey literature and conventional consultancy indicates that numerous other case studies exist in New Zealand. To date there are many drone companies doing environmental research in the country, such as Flightworks, DroneMate, Negative2Positive Photography Ltd. They use aerial UAVs to deliver aerial environmental mapping and agriculture surveys (see more on Airshare You UAV Hub website: - https://www.airshare.co.nz/).

However, the use of UAVs in marine mammal research in New Zealand waters is limited. To this date, only a single scientific publication has been found, which was only recently published and describes the use of UAVs as an inexpensive way to study whales and large marine animals (Dawson et al., 2017). Its surveys using different types of VTOL UAVs were conducted off Auckland Islands to study Southern right whales (*Eubalaena australis*). During an expedition in 2016, a quadcopter was implemented to compliment the boat-based method, and flown over the animals at an altitude of 25 to 35 m to assess their body condition and health. The research was described as being very successful (University of Otago, 2016). VTOL UAVs have also been used in expeditions to study blue

whales (*Balaenoptera musculus*) ecology in the South Taranaki Bight region, and preliminary results have been presented via other sources, such as television and radio news and university internal media releases. The expedition was carried out on board the DJI Phantom 3 to collect morphometric and behavioural data (Torres & Klinck, 2016). The video footage recorded by the UAV captured important moments, such as a blue whale mother-calf pair in apparent nursing behaviour (National Geographic, 2016). It is believed that this was the first time an UAV recorded this behaviour in a baleen whale. The UAV observation also captured one feeding event on video, where the whale comes to the surface and engulfs a large quantity of water and prey, as known as the lunge feeding technique (Oregon State University, 2017; Torres & Klinck, 2016). Finally, an Auckland University of Technology (AUT) student is currently testing the use of an VTOL UAV hexacopter to observe humpback whale (*Megaptera novaeangliae*) behaviour off the Vava'u archipelago in Tonga, where they breed during austral winter months (Fiori). Samples of these aerial observations were published on the AUT Youtube channel (AUTUNI, 2017), showing different behaviours and interactions between the animals.

Clearly UAVs offer distinct advantages in sampling cetaceans and can potentially help reducing bias and improving data strength. Various approaches have been used to collect cetacean behaviour, but there is no scientific literature describing how to use small VTOL UAVs to describe behaviour on bottlenose dolphins, or specific studies accessing disturbance levels on behaviour of a cetacean species. UAVs can become an important ally to boat surveys, especially to study species that inhabit locations requiring logistics for fieldwork, such as bottlenose dolphins off GBI. This study aims at determining how low altitude UAVs can be used for describing behaviour of bottlenose dolphins around GBI, and at looking how this toll can contribute to support conservation and management of bottlenose dolphins.

Chapter Three: Methods



(Photo F. Picinato)

3 Methods

3.1 Study site

Great Barrier Island, herein GBI (36°10'S, 174°23'E; Figure 4) is situated approximately 90 km northeast of Auckland city (36°51'S, 174°46'E) within the Outer Hauraki Gulf and covers an area of 285 km^2. The predominantly rock shoreline is characterised by several sheltered shallow bays and inlets. These waters are usually calm and are influenced by the warm subtropical East Auckland current (EAUC), which brings nutrient-rich oceanic waters into the Gulf resulting in an extremely productive area with high diversity of marine life (Manighetti & Carter, 1999). The study site for this research included all the inshore waters of the west coast of the island, between Miners Head and Ross Bay. This region has been recently identified as a potential hotspot for the bottlenose dolphin (*Tursiops truncatus*) with year-round occurrence and high level of fidelity reported (Dwyer, Clement, Pawley, & Stockin, 2016; Dwyer et al., 2014). Furthermore, most of the area remains uninhabited and marine mammals are not targeted by commercial marine mammal tour operators in this region.

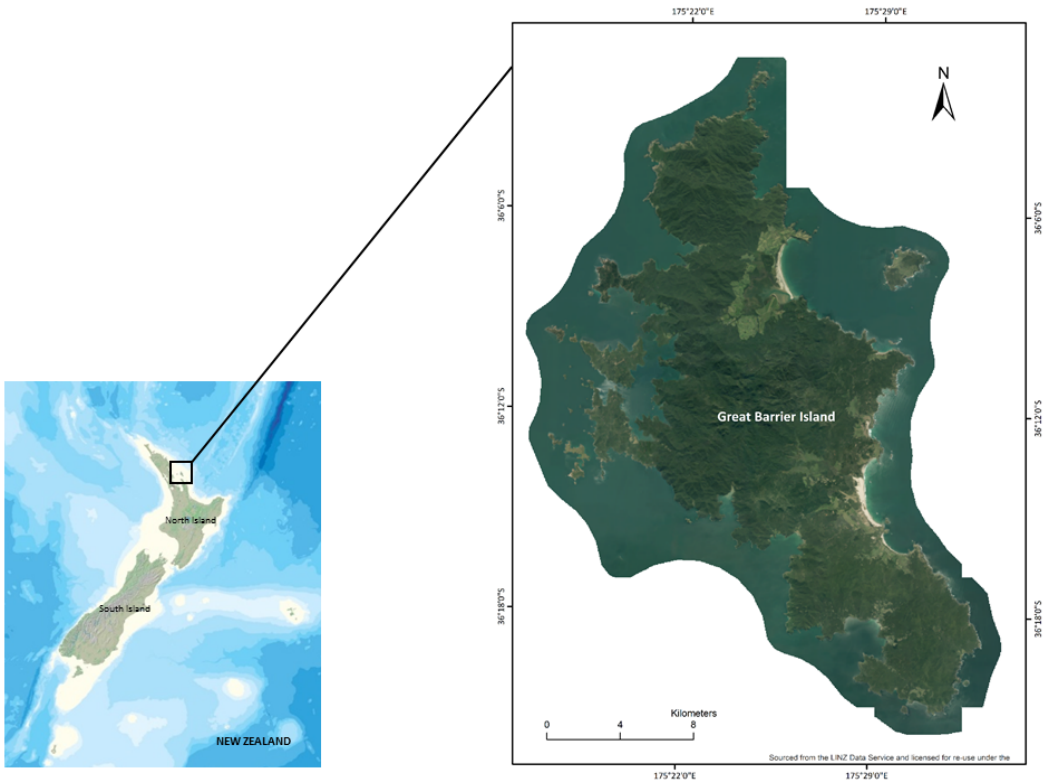


Figure 4: Map of the Great Barrier Island, New Zealand. Map Source: NIWA and LINZ Data Service.

3.2 Platforms & Research Design

Research trips averaging three to five days were conducted to GBI on board the *AUT Sciences* (Figure 5), an Osprey 8.5 m with dual Honda four stroke 150 hp outboard motors equipped with a custom built 1 m x 1 m UAV helipad. Trips were conducted across all austral seasons between July 2015 and March 2017 when sea conditions permitted (Beaufort Sea State 3 or less). Research was conducted following permission granted by the Maritime New Zealand Safe Ship Management system for commercial vessels and by New Zealand Department of Conservation (DOC) for UAV operations over marine mammals.

Figure 5. The Auckland University of Technology research vessel *AUT Sciences.*

3.2.1 Marine Mammal Survey

Non-systematic boat-based surveys were conducted across the west coast of GBI departing from Kaikoura Island (36°11'S, 175°19'E). Daily routes were selected and governed by weather and sea conditions, as well being influenced by the location of the previous sightings of bottlenose dolphins. Surveys were only conducted in conditions of

Beaufort Sea State 3 or less. Effort to find dolphins was made during daylight hours at a cruising speed averaging 10 knots, for periods of 4 to 12 hours.

During each of the surveys two or more experienced observers were present. To detect any sign of cetacean activity, the scan method (Mann, 1999) was employed by the observers using naked eye and/or binoculars (10 X 50 magnification). Blows, splashes, dorsal fins and bird aggregations were used as sighting cues. Once a bottlenose dolphin group was sighted, the vessel approached in accordance with the New Zealand Marine Mammal Protection Regulations (1992). The boat moved at idle speed to minimise the effects on dolphins behaviour (Guerra et al., 2014; Mann, 1999). At 300 m from the group of dolphins, time and GPS location were recorded, as well environmental parameters (weather, Beaufort Sea State, Douglas Sea State and water depth). At this point, the initial behavioural data (predominant behaviour state, group dispersion and group composition) and group size were accessed (see Appendix 3 and 4) using focal group follow with instantaneous scan method (Altmann, 1974; Mann, 1999). All dolphins were scanned left-to-right to ensure inclusion of all individuals and avoid potential biases caused by specific individuals and/or behaviour (Mann, 1999). In order to maintain consistency in the interpretation and reduce observer bias, the same observer (T. Fettermann) assessed behavioural data throughout the study. The boat kept at the no-interaction distance (300 m) from the focal group at all times, unless actively approached by the animals, in which case the engines were either placed in neutral or switched off.

Each dolphin encounter lasted until weather conditions deteriorated and/or the crew were able to maintain visual contact with the focal group without approaching closer than 100 m. The decision to terminate an encounter also included any changes in dolphin's behaviour (e.g. change direction of travel, increasing speed, spatial avoidance of the boat) or when it was necessary to depart back to base due loss of adequate daylight.

Additional field trip logs were filled after each daily survey (e.g. boat log, hours on the water, UAV log and summary of day datasheet). Post field procedures included charge all system batteries, sensor, UAV, transmitter and download the aerial imagery. Finally, data collected during field were manually entered to an Excel spreadsheet.

3.2.2 UAV Operations

Aerial behaviour surveys were conducted using a Vertical Take-Off and Landing (VTOL) Unmanned Aerial Vehicle (UAV) equipped with a high definition camera to collect and record video footage. Flights were conducted for each encounter with bottlenose dolphins from the research vessel, for periods of 10 to 20 minutes depending on aircraft flight endurance. The UAVs used in this research - *SplashDrone*^{TM}, *HexH2O* and *Phantom 4* (Figure 6, see page 31) - are highly dependent of weather, especially the small quadcopters (lifted and propelled by four rotors). Flights were only conducted in fine conditions (Beaufort Sea State 3 or less) with no rain and light to moderate wind (<15 knots). All UAV operations over marine mammals were conducted under marine mammal research permit 499890-MAR issued by New Zealand Department of Conservation (DOC) (see Appendix 6 and 7) and complied with New Zealand Civil Aviation Authority (CAA) regulations.

The UAV was launched from the research vessel at a minimum distance of 100 m from the dolphins, as designated within the permits used to conduct this research. The crew consisted two trained people, the pilot in command to fly the UAV, while a visual observer/operator assistant helped with take-off and landing and collected the dolphin and technical data. From take-off, the UAV ascended vertically to a predetermined height (e.g. 40 m) and then slowly manoeuvred horizontally towards the animals keeping the height locked when flying over them during all flight. The filming lasted around 10 to 20 minutes.

The UAV was subsequently piloted back to the research vessel and landed in the hands of the operation assistant or in the take-off/landing custom built helipad for battery replacement and safety checks. During each flight, the pilot had the responsibility to assess the feasibility and worthiness of each flight. Pre-flights and post-flight procedures were used in accordance with the AUT Operations Manual and manufactures operating flight manual at all the times during field work.

During the 2-year study, three UAVs were used due to technology improvements, feasibility and affordability, as well to fulfil different objectives of the study.

The *SplashDrone*^{TM} designed by FPV Factory, a small battery-powered multirotor aircraft, is connected to a personal view using a DJI Naza-M V2 flight controller (Figure

6a). The device is a quadcopter with a diagonal diameter of 550 mm, body weight of 1750 g, a payload of 750 g and a maximum speed of 12 m/s. The *SplashDrone*^{TM} was controlled with a Spektrum DX9 handset and equipped with a Hero4 GoPro video camera affixed to a gimbal mount to capture either high resolution video or still photos. The *SplashDrone*^{TM} is waterproof, can be controlled from up to 1 km distance in open areas and has a flight endurance of 12 minutes with 70 % consumption of 5200 mAh LiPo battery. This aircraft was used to determine the optimal flight parameters to study bottlenose dolphin behaviour and population ecology (see Objective A, Section 1.2, Chapter 1, pg. 7).

The *HexH2O* from QuadH2O^{TM}, a battery-powered multirotor aircraft connected to a personal view using DJI Naza-M V2 flight controller (Figure 6b). The device is a hexacopter (width 740 mm, height 240 mm, Length 650 mm) with a body weight of 1400 g, but a take-off weight of 4.7 kg when fully loaded (two flight batteries, gimbal and GoPro camera). The maximum speed is 15.5 m/s in a maximum wind speed of 20 knots. The HexH2O was controlled with a Hitec Flash 8 2,4 GHz transmitter and equipped with a Hero4 GoPro Black Edition video camera affixed to a gimbal mount. *HexH2O* is waterproof and equipped with floating devices, which makes it able to land and take-off from the water surface and manoeuvre while floating in calm water. It can be controlled from up to 1 km in open areas and has a flight endurance of approximately 25 minutes. The *HexH2O* was used to collect behavioural data to investigate how low altitude VTOL UAV are in describing behaviour patterns and habitat use (see Objective B, Section 1.2, Chapter 1, pg. 7) and to compare results with boat-based method (see Objective C, Section 1.2, Chapter 1, pg. 7).

The *Phantom 4* from DJI, a small battery-powered multirotor aircraft connected to a personal view using a the DJI GO mobile app (Figure 6c). The device is a quadcopter with a diagonal diameter of 350 mm, body weight of 1380 g including battery and propellers. The maximum speed is 20 m/s in a maximum wind speed of 20 knots. The *Phantom 4* was controlled with a DJI remote controller and equipped with they own video camera affixed to a gimbal mount to capture either high resolution video or still photos. It can be controlled from up to 5 km in open areas and has a flight endurance of approximately 25 minutes. Again, this aircraft was used to collect behavioural data to investigate how low altitude VTOL UAV are in describing behaviour patterns and habitat use (see

Objective B, Section 1.2, Chapter 1, pg. 7) and to compare results with boat-based method (see Objective C, Section 1.2, Chapter 1, pg. 7).

(a)

(b)

(c)

Figure 6. **(a)** Splashdrone (SwellPro, Shenzhen, China); **(b)** HexH2OTM (XtremeVision360, Worthing, UK); **(c)** Phantom 4 (DJI Shenzhen, China).

3.3 Data Collection

3.3.1 UAV Flight Parameters

To determine the optimal flight parameters of the aerial survey to study bottlenose dolphin behaviour and population ecology without causing disturbance or harm to the animals, “test flights” and “disturbance flights” were performed in the field at the beginning of this research.

Firstly, three flights of the *SplashDrone* were conducted to locate and determine the optimal flight parameters including the altitude, duration of flight and image quality. The cameras used during the study do not have different levels of focus or the ability to zoom in, for this reason the altitude has great importance. Have to be able to see all or the majority of the group, and the images need to have a good resolution to be able to identify age class, count individuals and determine behaviour. Three predetermined heights were tested: 10 m, 25 m and 40 m (Figure 7). Aerial video footage was acquired in different settings to determine the minimum quality resolution required and the most adequate to study bottlenose dolphins.

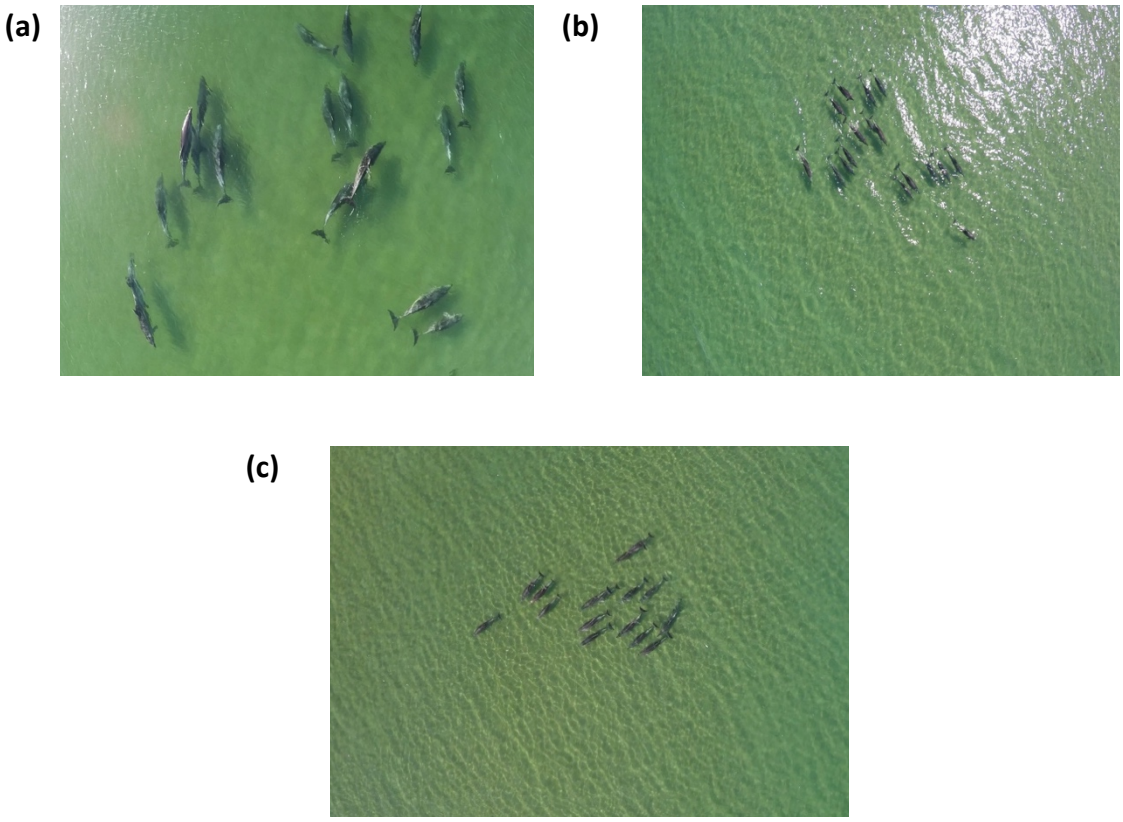


Figure 7: Bottlenose dolphins photographed in Great Barrier Island, New Zealand during flights at **(a)** 10 m, **(b**) 25 m, and **(c)** 40 m of altitude.

Secondly, 25 flights of the *SplashDrone* were performed to investigate the potential disturbance levels on behaviour caused by VTOL UAVs to bottlenose dolphins. To do this, short-term behavioural responses of resting free-ranging bottlenose dolphins were assessed. Three predetermined heights were tested: 10 m, 25 m and 40 m. For this, the vessel sat at anchor for 30 mins before flying commenced to allow dolphins to habituate to the presence of the vessel and any responses to engine noise to subside. Before and while the UAV was flown above the dolphins, surface behavioural and group reorientation events were assessed continuously via one-minute interval scan sampling by an experienced observer on board the research vessel (see Appendix 5). The predominant behaviour state was also assessed every one-minute via scan sampling method to ensure the group was resting throughout the tests. When evident, the observer annotated whether a surface event was repeated multiple times by the same individual. Group reorientation event was considered when the majority of the group changed swim direction of 90° or more with respect to the heading direction. Data were collected for 10 minutes prior to UAV launch (control), and during the 10 minutes exposure to aircraft (impact). Thirty-minute breaks between each test was taken to allow any responses of the animals to the UAV to subside. The aerial surveys were conducted in locations with similar geomorphological characteristics (sandy bays, within a maximum depths of 15 m) and similar environmental conditions to reduce the number of factors to be considered in the analysis.

To measure and record behavioural observations, focal group follow with instantaneous scan sampling was used (Altmann, 1974; Mann, 1999). The main behaviour was defined as the behavioural state in which more than 50% of the animals were involved during the instantaneous sample (Mann, 1999). All dolphins were scanned from left-to-right to ensure inclusion of all individuals and avoid potential biases caused by specific individuals and/or behaviour (Mann, 1999). Secondary behaviour was defined as the behavioural state in which the rest of the animals from the group (< 50 % of the animals) were involved during the instantaneous sample (e.g. 70% of the animals were resting, but 30 % of the group were doing something else, like socialising. In this case, main behaviour was resting and secondary was socialising). Five mutually exclusive and cumulatively inclusive categories of behavioural state were defined from previous

studies on bottlenose dolphins (Table 1) (Constantine, 2002; Lusseau, 2006a; Shane et al., 1986).

Table 1. Definitions of behavioural states recorded for bottlenose dolphins (*Tursiops truncatus*) in the Great Barrier Island, New Zealand

Behavioural State	**Definition**
Socialising	Dolphins observed chasing, copulating and/or engaged in any other physical contact with other dolphin, such as rubbing and touching (excluding mother-calf pairs). Aerial behavioural events such as horizontal and vertical jumps may occur.
Milling	Dolphins exhibited non-directional movements, with frequent changes in bearing prevented dolphins from making headway in any specific direction. Most of the time appears to be transition behaviour between behavioural states.
Foraging	Dolphins involved in any effort to pursue, capture and/or consume prey. Diving for long periods of time, showing repeated unsynchronised dives in different directions in a determined location, exhibiting behaviour such as fluke out dives.
Resting	Dolphins observed in a tight group, engaged moving slowly and in a constant direction. Surfacing are generally more predictable, often synchronous than observed in other behavioural states.
Travelling	Dolphins engaged in persistent, directional movement making noticeable headway along a specific compass bearing. Group space varies and individuals swim with short and relatively constant dive intervals.

Behavioural events were defined as a series of body movement that could be unambiguously identified as a unit and could be observed every time they occurred (Lusseau, 2006a). They are also referred to as events of short durations such as discrete movements (for example: chin slap and side float). In this study, five exclusive behaviours events were recorded following definitions from previous studies on bottlenose dolphins (Table 2) (Lusseau, 2006a, 2006b; Schneider, 1999).

Table 2. Definitions of behaviour events recorded for bottlenose dolphins (*Tursiops truncatus*) in the Great Barrier Island, New Zealand

Behavioural Events	**Definition**
Side Float	Dolphin floats on side position at the water surface. Side flipper is visible and one eye is clear of the water.
Spy Hop	Dolphin orientates vertically with body partially out of the water. Both eyes are clear of the water.
Tail Slap (lobtailing)	Dolphin lifts its tail clear of the water and slaps it on the water surface. Dolphin tends to remain horizontal to the water surface.
Chin Slap (head slap)	Dolphin raises its head clear of the water and slaps it on the water surface.
Breach	Dolphin jump completely out of the water (or almost completely) and land breaking through the surface of the water (mostly on its side, or its back) creating a loud noise and a big splash.

Group was defined as any number of dolphins observed in association, travelling or moving in the same direction and engaged in the same or similar behaviour (Shane, 1990a), considering that some animals could be involved in different activities, even though they are in close association (Mann, Connor, Tyack, et al., 2000). During this research individuals located within 100 m radius were considered to be part of the same group (Wilson, Thompson, & Hammond, 1993). Group size was recorded in categories to the nearest five animals as the minimum and maximum number of dolphins believed to be in the group, unless all individuals in the group were readily identifiable and the observers agreed on an exact number.

Group dispersion or cohesion was recorded as tight, moderate, loose or sub-group (Table 3) (Shane, 1990a).

Table 3. Group dispersion categories recorded for bottlenose dolphins (*Tursiops truncatus*) in the Great Barrier Island, New Zealand

Group Dispersion	**Definition**
Tight	Less than one body length between individuals.
Moderate	Between one and five body lengths between individuals.
Loose	More than five body lengths between individuals.
Sub-group	Dolphins are divided in two or more groups but act as part of a single pod.

Group composition has been used to describe the group in relation to the age-class. Definitions based from previous studies are provided in Table 4 (Constantine, 2002; Mann, Connor, Tyack, et al., 2000; Mann & Smuts, 1998). These terms are related to biological criteria, such as individual size, presence of foetal folds, folded fins and behaviour. Group compositions was assessed using the presence/absence of adult, juvenile, calf and neonatal age classes.

Table 4. Age-classes categories recorded for bottlenose dolphins (*Tursiops truncatus*) in the Great Barrier Island, New Zealand

Age Class	**Definition**
Neonate	Defined by the presence of visible white dorsoventral with foetal folds on the thorax. Uncoordinated and poor motors skills when surfacing. This stage can last up to 3 months.
Calf	One-half the size of an adult dolphin. Is consistently observed in association with and adult animal, swimming along in 'infant position' (i.e., in contact under the mother). Calves were thought to be up to 3-4 years of age.
Juvenile	Two thirds the size of an adult. Is often observed in association to an adult, swimming close to the mother, but never as in 'infant position'.
Adult	All large (i.e., 3.0-3.5m in length) and fully grown dolphins.

***Note,** sub-adults were not considered in the present study since the sexual maturity could not be ascertained by total body length (TBL) or behaviour alone.

3.3.2 Behavioural patterns

To investigate the use of a lightweight low altitude UAV to describe behaviour patterns (see Objective B, Section 1.2, Chapter 1, pg. 7) and compare with boat-based traditional method (see Objective C, Section 1.2, Chapter 1, pg. 7), aerial surveys were conducted to collect footage of bottlenose dolphins. Flights were performed using either *HexH2O* or *Phantom 4* (Figure 6 see page 31). The UAV was launched from the research vessel at a minimum distance of 100 m from the dolphins, ascended to 40 meters of altitude and was then manoeuvred horizontally towards the group at the same altitude. Time and GPS location were recorded at the beginning and end of each flight. Group size and environmental parameters were recorded prior to UAV launch. Dolphin behavioural data (i.e., behavioural state and behavioural events), group composition and group dispersion were assessed and recorded continuously via one-minute interval scan sampling by the operation assistant during the flight. The filming lasted approximately 20 minutes and the UAV was piloted back to the research vessel for landing, battery change and safety checks.

3.4 Data Analysis

3.4.1 UAV Flight Parameters

To find the optimal flight parameters, the altitude and image quality were assessed during the first research trip. The video imagery recorded off the Hero4 GoPro was reviewed using a laptop. Simply a playback of video at normal speed was enough to determine that the configuration of 2.7K-25FPS-Medium FOV at 40 m altitude gave excellent resolution video images to observe bottlenose dolphins. From there was chosen the 40 m to conduct the behavioural flights.

To assess the UAV disturbance level for bottlenose dolphin, the data collected before UAV launch (control) and during the exposure (impact) were entered into a spreadsheet. Nominal independent variables were numerically coded (e.g., weather, Beaufort Sea State). Statistical analysis was conducted using the statistical analysis and graphics software R version 3.4.3 (R Development Core Team, 2017).

A Generalized linear mixed effects model (GLMM) with negative binomial error distribution and log link (glmmADMB) (Skaug, Fournier, Bolker, Magnusson, & Nielsen, 2016) was used to model for the number of reorientation events. The main effects of

presence/absence of the UAV at different altitudes (UAVALT), time of the day (TOD), Beaufort Sea State (BSS), weather (W, sunny vs. cloudy), group size (GS) and the interaction between BSS and UAVALT. To account for the repeated observations on the same group, we included group identity as random term. Potential collinearity issues were assessed using generalized variance inflation factors (GVIF = $VIF^{[1/(2*df)]}$), which were compared to their collinearity thresholds ($10^{[1/(2*df)]}$) (R package car) (Fox & Weisberg, 2011). All GVIFs were below their collinearity thresholds.

GLMMs with a binomial distribution and logit link (R package *lme4*) (Bates, Maechler, Bolker, & Walker, 2015) were generated for the side-floats, tail-slaps, spy-hops and chin slaps. A two-column matrix holding the number of successes (number of animals in a group exhibiting behavioural events) and failures (number of animals per group not showing a behavioural action) was provided as response variable (Venables & Ripley, 2002). These binomial GLMMs contained UAVALT, TOD, BSS, W and the interaction between BSS and UAVALT. The tail-slap, spy-hop and chin-slap models showed inflated standard errors of the parameter estimates, suggesting separation issues. Remodeling those variables using a Bayesian GLMM with a weak prior resolved the separation issues (R package *blme*) (Chung, Rabe-Hesketh, Dorie, Gelman, & Liu, 2013). Assessing the significance of the explanatory variables followed a backwards selection procedure (Zuur, Leno, Walker, Saveliev, & Smith, 2009). Post-hoc analyses were performed using a multiple comparison procedure based on Tukey contrasts (R package *lsmeans*) (Lenth, 2016). The Benjamini and Hochberg (1995) method was used to adjust *P*-values for multiple testing (R package *multcomp*) (Hothorn, Bretz, & Westfall, 2008).

3.4.2 Behaviour patterns

ArcGIS version 10.5 (ESRI, Redlands, California, USA) software was used to plot bottlenose dolphin sightings, around GBI and to create a map of the conducted flights. The New Zealand Transverse Mercator (NZTM2000) projection was used for the GIS analysis.

The aerial video imagery recorded was reviewed in two stages. The first review was performed to get the accurate number of the group size for each of the encounters. The review and counts of the video was simply a playback of the video at normal speed, but also enlarging, enhancing and looking at each image to maximise detection for counting

the animals. At least two independent people made blind count with the same method using high resolution monitors. Group size were also defined as small (1-20), medium (21-50) and big (51-70) based on the accurate group size from the UAV analysis. Group age-class were examined and recorded.

The second review, comprised in a detailed review of the video imagery. The main behavioural state (defined as the behaviour in which more than 50% of the animals were involved), group composition and dispersion were assessed via one-minute interval scan sampling and recorded in a point sampling spreadsheet (same one used during the field to collect behavioural data – see Appendix 5).

To assess behavioural patterns of the samples, data were examined generating proportions for the five main behaviour states. To better understand the activity budget of bottlenose dolphins during this research, the proportion of time spent for each main behavioural state and secondary behavioural were calculated. Furthermore, the activity budget in relation to the season were calculated. Seasons were based on austral seasons (Winter = June-August, Spring = September-November, Summer = December-February and Autumn = March-May).

Interactions between dolphins-boat, dolphins-recreational users (i.e. swimmers, stand up paddleboards and kayakers) and dolphins-other species (i.e. sea birds, fishes and sharks) were recorded during the aerial review. Each encounter was carefully analysed and behavioural data recorded (i.e. behavioural state, changes in behaviour, change in direction, dive, and aerial reaction). Interaction was defined as an encounter between one or more dolphins and any of the category mentioned at a distance equal or less than 3 meters.

3.4.3 UAV- and Boat-based methods comparison

Results from the UAV sensor were compared with boat-based data. The first comparison was the group size for each of the encounters. Boat-based estimation and UAV-derived counts were considered linked - i.e., for each encounter, flights were performed immediately after the group size had been estimated from the boat, so analyses treated these as paired samples. The two samples being compared were not random samples from two distributions, but different detection methods to find the same sightings. The normality and equality of variances between boat-based and UAV-derived counts was

assessed using a Lavene's test and Shapiro Wil. Tests revealed a normally distributed dataset. Parametric test Paired Samples T-test was used to compare difference in variance of the residuals from the models for group size between boat-based estimation and UAV-derived counts.

Behavioural data collected via one-minute interval scan sampling from boat (when the UAV was flying over the animals) and from the UAV sensor were plotted into the same spreadsheet for comparison. The main behavioural state, secondary behaviour and group dispersion were compared using percentage of agreement and disagreement between methods. To assess if behavioural state were affected by the method, Pearson Chi-Square test was performed. Data were tested for normality using a Levene's test and Shapiro Wilk Parametric test was used in the present analysis since the data were normally distributed.

Statistical analysis was carried out using IBM SPSS Statistics 23 software and significance was assumed at P = 0.05 level.

Chapter Four: Results

4 Results

Between July 2015 and March 2017, six field trips averaging three days were conducted to the GBI across all austral seasons. A total of 20 days of boat-based surveys were made onboard of the AUT Sciences, resulting in a total on-effort time of 186.2 hours. Bottlenose dolphins were sighted during 90 % of surveys (n = 18), resulting in a total of 25 independent encounters (Figure 8), with 88.2 total hours spent with the animals. UAV operations were conducted during 88.9% (n = 16) of the sighting days, resulting in a total of 71 aerial surveys (16.6 hrs) over the dolphins. The surveys lasted around 10 minutes (mean = 14 minutes, max = 20 minutes). Most of the aerial surveys occurred during the summer months due to weather conditions; for this reason, summer had the highest number of flights (Table 5). The number of flights was the same in autumn and spring, with winter having the lowest number.

Table 5: Number of independent encounters and UAV flight effort based on austral seasons at Great Barrier Island (GBI).

Austral Seasons	**No. of independent encounters**	**No. of UAV flights**	**Hours of flights**
Summer	11	27	6.7
Autumn	5	17	5.1
Winter	3	10	1.6
Spring	6	17	3.2
Total	**25**	**71**	**16.6**

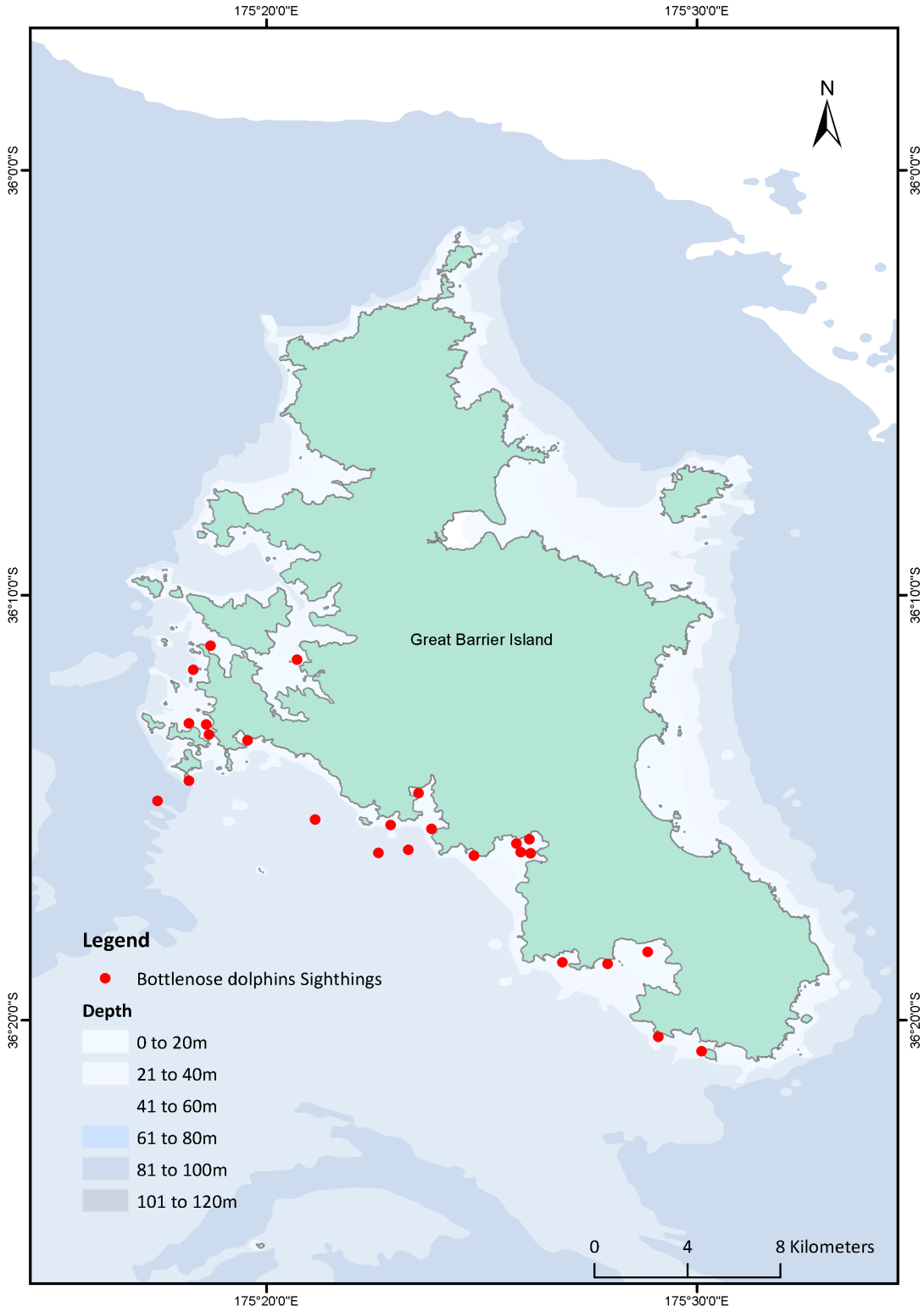


Figure 8: Bottlenose dolphins sightings at the Great Barrier Island (GBI), New Zealand between July 2015 and March 2017.

4.1 UAV Flight Parameters

To determine the optimal flight parameters for studying dolphin behaviour and population ecology, it was necessary to carry out test flights to find the ideal height, environmental conditions including wind speed, lighting and battery life. A total of a minimum of 10 hours of in land flights were conducted for equipment recognition and choice of the ideal parameters that would be used for data collection. In this case, the main environmental and sea conditions determined for the aerial surveys were: a) not to exceed the distance of 1 km from the pilot or until the aircraft could be in line-of-sight (typically < 500 m); b) fly in maximum wind speed of 15 knots (preferably < 10 knots), and c) fly in a maximum Beaufort Sea State 3. Subsequently, two flights during the first survey were conducted over animals in resting behavioural state to find the ideal altitude, and to test the sharpness and quality of the video captured by the UAV. From these tests, it was determined the optimal height is 40 m with the camera pointing straight down attached to a gimbal. It was observed that at 40 m the UAV could have a visual range of most or all animals present in the group (Figure 9). Furthermore, it was determined the minimum resolution required was 2.7K-25FPS-Medium FOV when using a GoPro Hero 4.

Figure 9: Bottlenose dolphins photographed at Great Barrier Island (GBI), New Zealand during the “test flights” at 40 m of altitude.

4.1.1 Assessment of UAV disturbance levels

Free-ranging bottlenose dolphins were exposed to a lightweight VTOL UAV (SwellPro Splashdrone) flying for ten minutes at a fixed altitude over the animals in resting behavioural state. Twenty-five flights were conducted on seven independent groups resting in sheltered bays off the South-West side of GBI, between July 2015 to December 2016. All UAV operations took place in light wind conditions (max wind speed of 10 knots and Beaufort Sea State 1-2). A total of 23 UAV flights at the altitude of 10 m (n = 7), 25 m (n = 7) and 40 m (n = 9) were analysed. Two additional flights at 10 m were further discarded from the analysis as dolphins changed behaviour and were subsequently displaced from the area before completion of the impact flight.

The results on the lowest AIC model show that flight altitude had a significant effect on reorientation events. Two-fold increase in group reorientation events was observed when operating at 10 m of altitude, but no significant effect at higher operation altitudes (Figure 10,Table 6). In contrast, the individual-based behavioural responses remained largely unaffected by the presence of the UAV regardless of the operating altitude, apart from the tail-slaps which showed a 4.5-fold increase in response to the UAV flying at 10 m altitude (Figure 11, Table 6)). Side-floats were statistically more frequent in the morning and on cloudy days (Figure 11 insets, Table 6). Chin-slaps occurred more often when the Beaufort seas state was 1 compared to state 2 and they were also observed more frequently on overcast compared to sunny days (Figure 11 insets, Table 6).

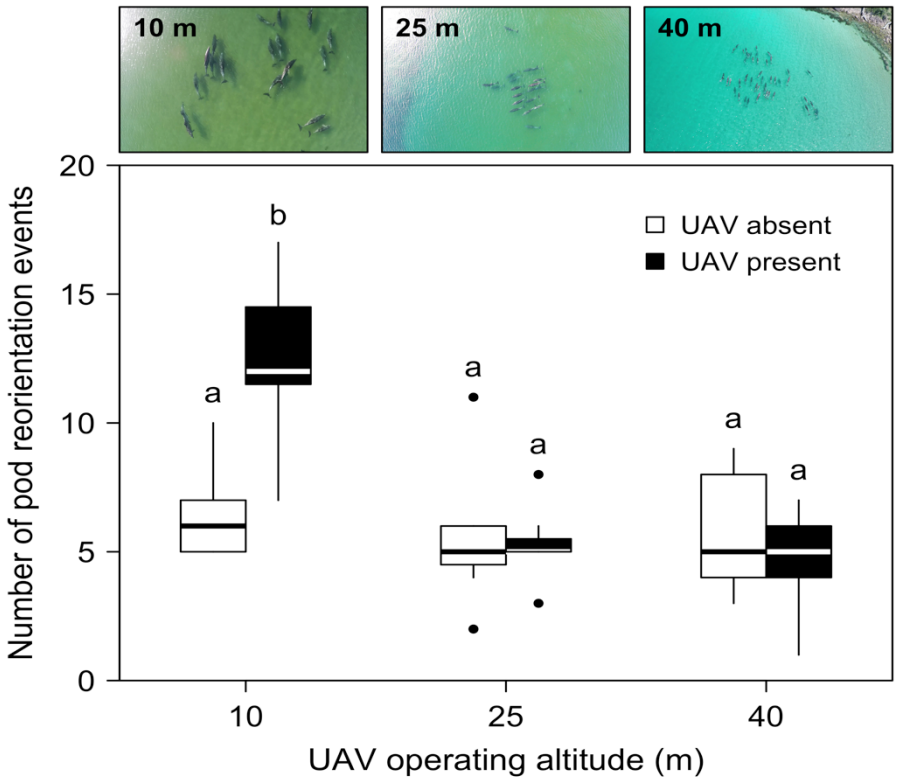


Figure 10: Number of group (pod) reorientation events as a function of unmanned aerial vehicle (UAV) absence or presence at 10, 25, and 40 m operating altitude. Different lower-case letters indicate statistically significant differences at α = 0.05 (multiple comparison procedure using Tukey contrasts). Black filled circles indicate outliers (first quartile - 1.58 × interquartile range or third quartile + 1.58 × interquartile range). Bottlenose dolphins were photographed during UAV disturbance tests around Great Barrier Island, New Zealand.

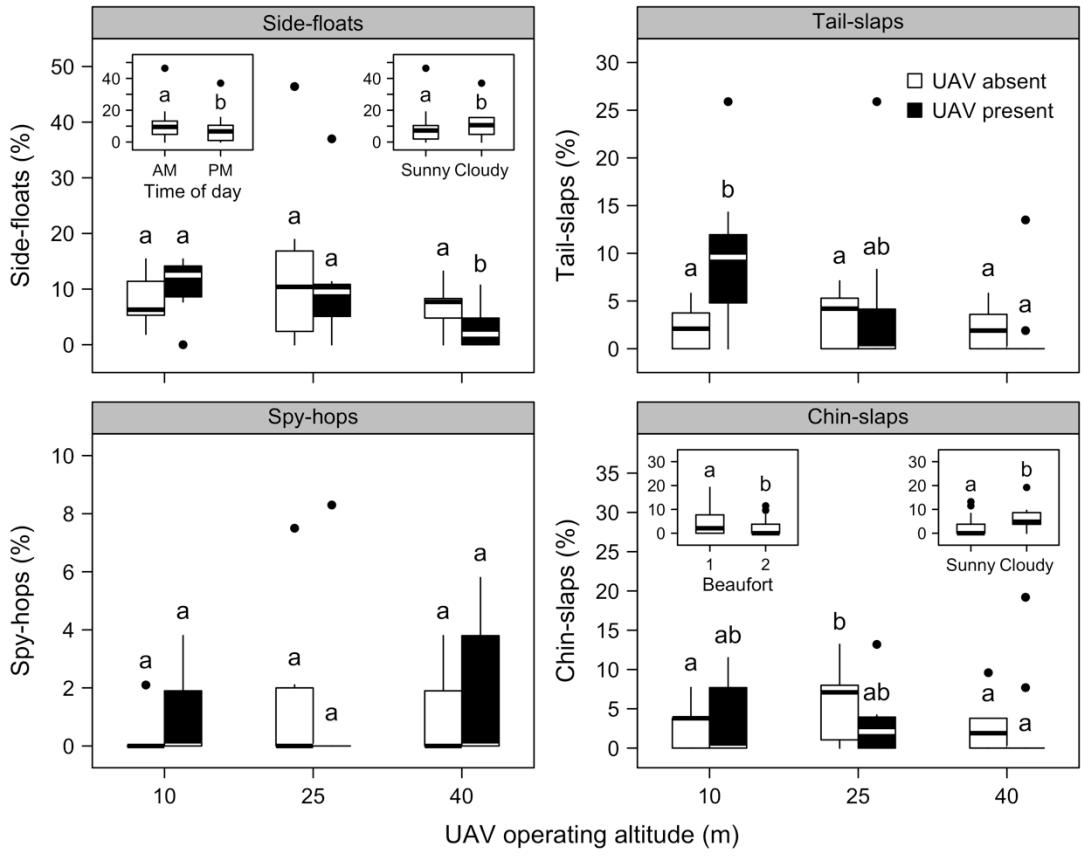


Figure 11: Behavioural responses of bottlenose dolphins (*Tursiops truncatus*) to the presence of an unmanned aerial vehicle (UAV) at 10, 25 and 40 m operating altitude. The behavioural events are expressed as the proportion of animals in groups showing this type of behaviour (n = 5 groups). Inset plots share the same y-axis title with the surrounding plot and show additional statistically significant predictors, if applicable. Different lower-case letters indicate statistically significant differences at $\alpha = 0.05$ (multiple comparison procedure using Tukey contrasts; insets: generalized linear mixed effects model output). Black filled circles indicate outliers (first quartile - 1.58 $\times$ interquartile range or third quartile + 1.58 $\times$ interquartile range).

Table 6: Results from backward selections performed on generalized linear mixed effects models (GLMM) for bottlenose dolphin behavioural events. The first column shows the fixed term of the GLMMs (UAVALT = combined factor of UAV absence/presence and operating altitude, TOD = time of day, BSS = Beaufort Sea State, W = weather, GS = group size). Bold fixed terms indicate the best GLMM specification as judged by the AIC and likelihood ratio tests. AIC = Akaike Information Criterion, *L* = likelihood ratio statistic, *df* = degrees of freedom, *P* = *P*-value for the comparison between full and reduced models. Grey cells indicate the full models of each round of the backwards selection process. Blank cells (*L*, *df* and *P* columns) are associated with the original full model or a newly structured full model resulting from previous model comparisons. Note that for the spy-hops data none of the tested explanatory variables was statistically significant at the end of the backwards selection.

Model	AIC	*L*	*df*	*P*	
Reorientation events					
UAVALT + TOD + BSS + W + PS + UAVALT × BSS	229.5				
UAVALT + BSS + W + GS + UAVALT × BSS	229.6	2.06	1	0.151	
UAVALT + TOD + BSS + GS + UAVALT × BSS	227.8	0.22	1	0.639	
UAVALT + TOD + BSS + W + UAVALT × BSS	227.8	0.24	1	0.624	
UAVALT + TOD + BSS + W + GS	220.5	0.98	5	0.964	
UAVALT + BSS	217.7				
BSS	242.9	35.2	5	< 0.001	***
UAVALT	**216.1**	0.42	1	0.518	
Side-floats					
UAVALT + TOD + BSS + W + UAVALT × BSS	229.7				
UAVALT + BSS + W + UAVALT × BSS	237.6	9.88	1	0.002	**
UAVALT + TOD + BSS + UAVALT × BSS	237.1	9.36	1	0.002	**
UAVALT + TOD + BSS + W	229.1	9.33	5	0.097	
TOD + BSS + W	238.6	19.50	5	0.002	**
UAVALT + BSS + W	244.3	17.30	1	< 0.001	***
UAVALT + TOD + BSS	238.1	11.06	1	< 0.001	***
UAVALT + TOD + W	**228.6**	1.55	1	0.212	
TOD + W	239.3	20.65	5	< 0.001	***
UAVALT + W	242.5	15.87	1	< 0.001	***
UAVALT + TOD	236.5	9.88	1	0.002	**
Tail-slaps					
UAVALT + TOD + BSS + W + UAVALT × BSS	172.8				
UAVALT + BSS + W + UAVALT × BSS	173.0	2.19	1	0.139	
UAVALT + TOD + BSS + UAVALT × BSS	174.1	3.31	1	0.069	
UAVALT + TOD + BSS + W	172.8	9.97	5	0.076	
UAVALT + BSS	178.5				
BSS	190.4	21.87	5	< 0.001	***
UAVALT	**176.6**	0.13	1	0.721	

Spy-hops

UAVALT + TOD + BSS + W + UAVALT × BSS	107.9				
UAVALT + BSS + W + UAVALT × BSS	109.8	3.91	1	0.048	*
UAVALT + TOD + BSS + UAVALT × BSS	106.6	0.73	1	0.394	
UAVALT + TOD + BSS + W	104.8	6.91	5	0.228	
UAVALT + TOD + BSS	103.7				
UAVALT + BSS	104.8	3.15	1	0.076	
UAVALT + TOD	103.0	1.31	1	0.253	
TOD + BSS	98.0	4.37	5	0.497	

Chin-slaps

UAVALT + TOD + BSS + W + UAVALT × BSS	157.9				
UAVALT + BSS + W + UAVALT × BSS	156.8	0.93	1	0.335	
UAVALT + TOD + BSS + UAVALT × BSS	162.3	6.76	1	0.009	**
UAVALT + TOD + BSS + W	156.3	8.43	5	0.134	
UAVALT + BSS + W	**155.1**				
UAVALT + BSS	162.9	9.82	1	0.002	**
UAVALT + W	160.9	7.79	1	0.005	**
BSS + W	162.5	17.36	5	0.004	**

4.2 Behaviour Patterns

Aerial surveys consisted of 16.6 hours of footage recorded on 16 days from July 2015 to March 2017. A total of 71 flights were conducted successfully over 21 independent groups of bottlenose dolphins encountered of the GBI (Figure 12).

Environmental data were collected for all of the 21 encounters. Results showed that the surface temperature ranged from 14.1 to 24° C (mean = 19.2, ± SE = 0.68) and depth ranged from 5.2 to 50.8 m (mean = 20.9, ± SE = 2.65). Sightings occurred in all seasons during the study, and the distribution of each dolphin groups throughout the GBI by season is shown in (Figure 13).

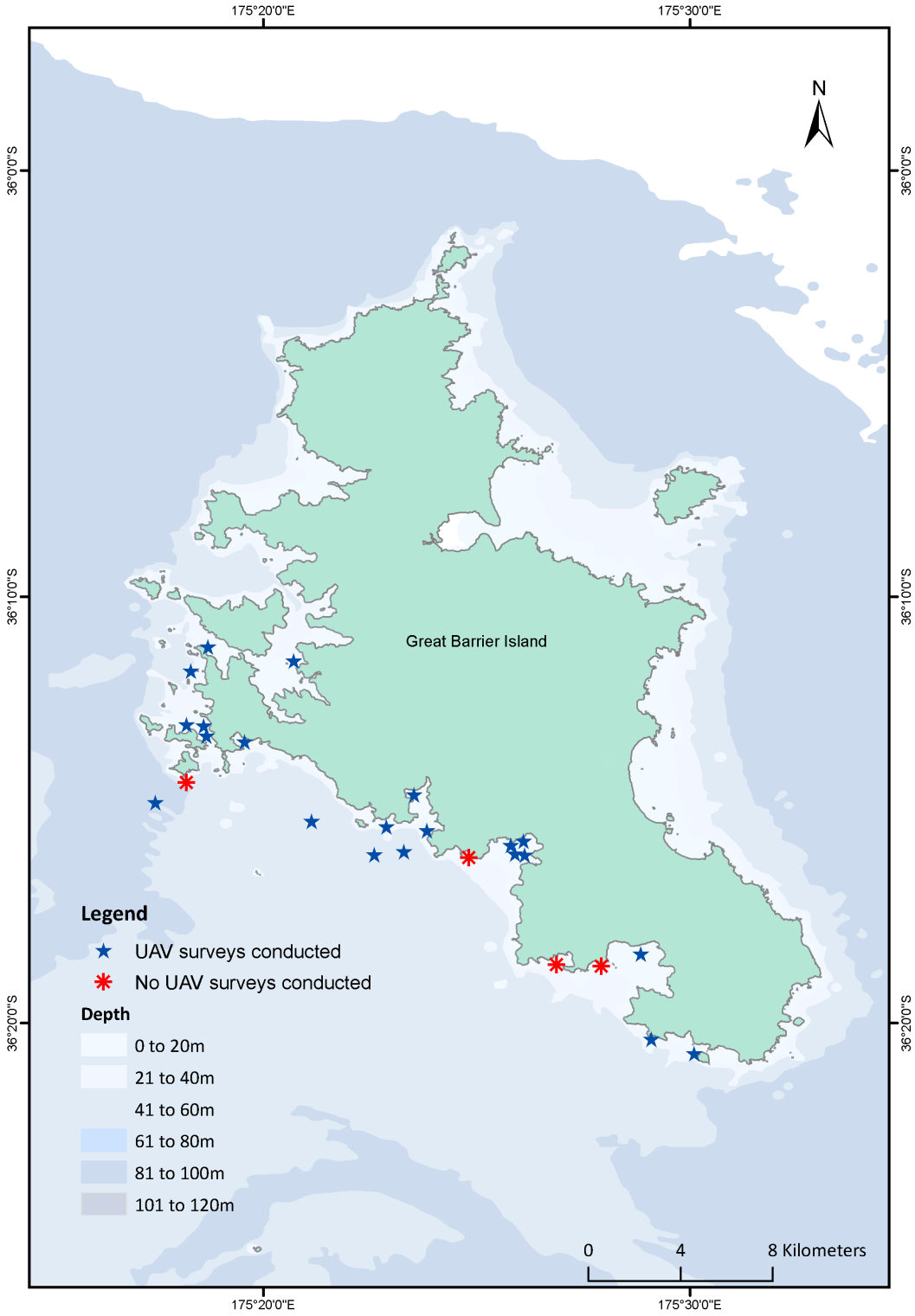


Figure 12: Bottlenose dolphins sightings at the Great Barrier Island (GBI), New Zealand between July 2015 and March 2017, displaying where UAV surveys were conducted.

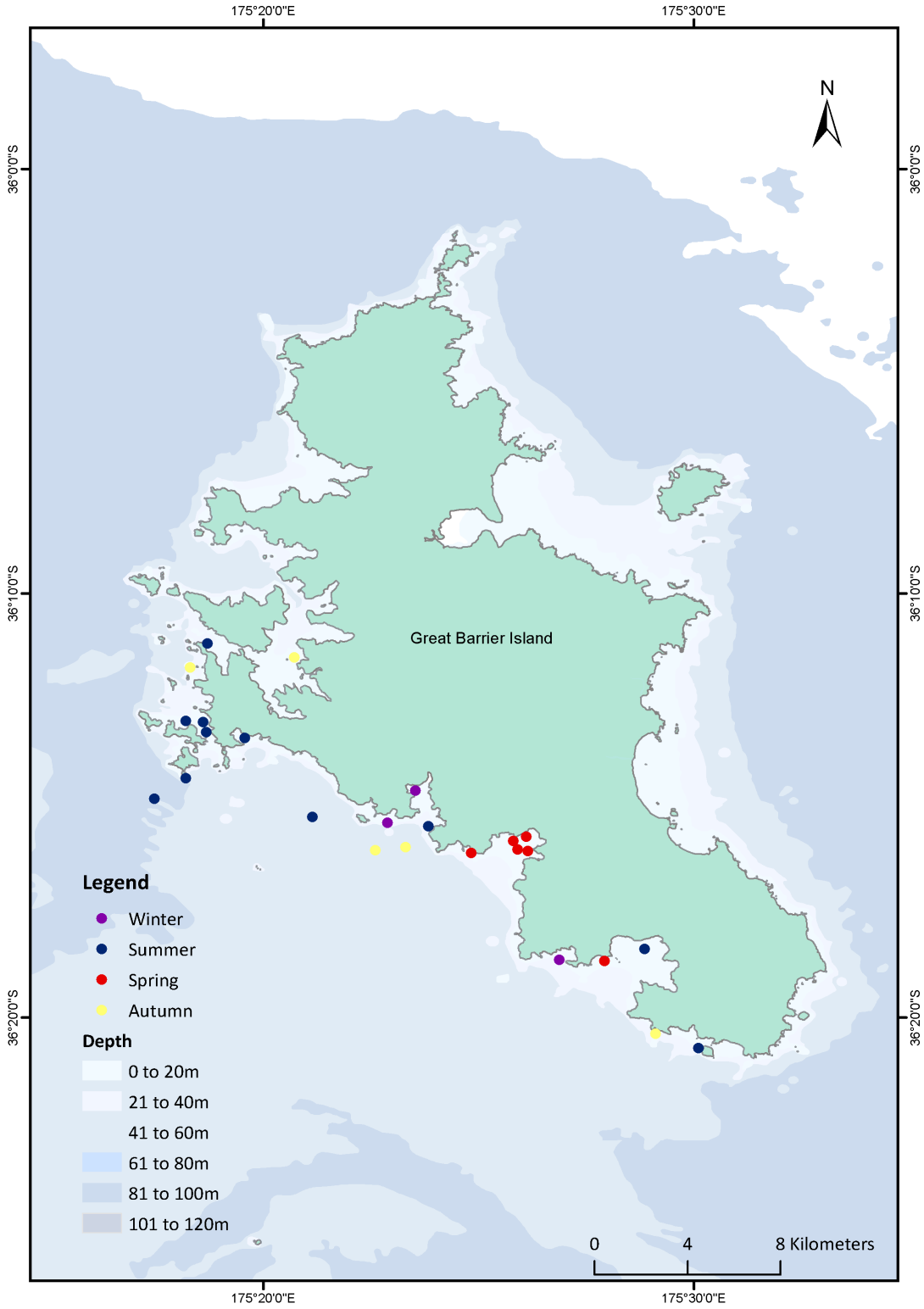


Figure 13: Bottlenose dolphin sightings at the Great Barrier Island, New Zealand (GBI), New Zealand from July 2015 to March 2017 displayed by season (winter = purple, summer = blue, spring = red, and autumn = yellow).

4.2.1 Group Size and Composition

Group size and composition were examined for 21 independent groups encountered between July 2015 and March 2017. A total of 16.6 hours of aerial footage recorded were reviewed on a high-resolution monitor by two independent marine mammal experienced people. Group size ranged from 6 to 66 individuals (mean = 37.4, median = 41, SD = 19.16 ± SE = 4.18, n = 21). Groups that consisted of < 50 individuals had the highest sightings comprising 62 % (n = 13), while groups that consisted of > 50 individuals were observed on 38 % (n = 8) of the sightings (Figure 14). The most frequently observed group size involved 51-55 animals, which was observed in 23.8 % of dolphins encounters (n = 5), and 6-10 animals observed in 14.3 % of dolphins encounters (n = 3) (Figure 14 & Figure 15). On 20 of January of 2016, a total of 86 individuals were recorded at GBI in two independent groups of 21 and 65 dolphins, separated by a distance of 21.5 km.

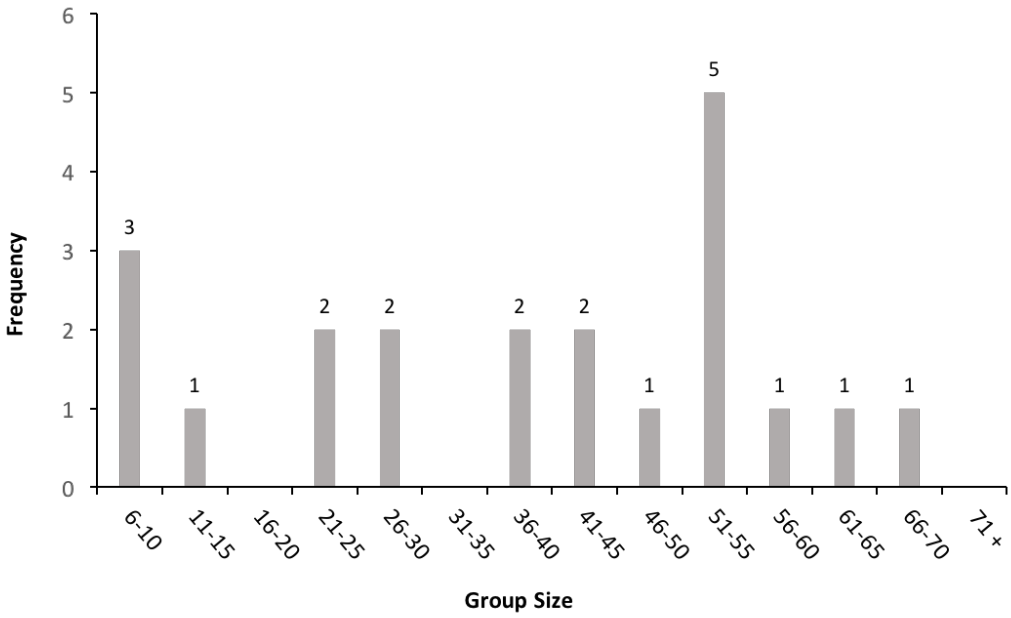


Figure 14: Estimated group size based on accurate number from UAV aerial observations for counts between July 2015 and March 2017 ranged from 6 to 66 individuals (mean = 37.4, median = 41, SD = 19.16, n = 21), with most of groups encountered containing less than 50 dolphins.

Based on the defined group size criteria, the percentage of group sizes encountered during this study was 19% (n = 4) small (1-20 dolphins), 43% (n = 9) medium (21-50 dolphins) and 38% (n = 8) big (51-70 dolphins).

(a) **(b)**

Figure 15: Bottlenose dolphins photographed at Great Barrier Island (GBI), New Zealand during this study at 40 m of altitude illustrating **(a)** small and **(b)** big size groups.

Out of the 21 groups of bottlenose dolphins observed, neonates and calves were observed in 85.7 % (n = 18) of encounters (Figure 16). They comprise the majority of the sightings compared to 14.3 % (n = 3) in absence of calves and neonates. Groups containing adults and juveniles represented 9.5 % (n = 2), and adults only 4.8% (n = 1). All adults only and adults and juveniles groups were observed in small groups, containing between 6 and 11 dolphins.

Overall, calves and neonates were present across all austral seasons and absent during three encounters over the summer months. For this reason, no significant pattern could be observed. Furthermore, statistical analysis could not be conducted to test differences between group sizes between seasons due to limited data.

Figure 16: Bottlenose dolphins photographed at Great Barrier Island (GBI), New Zealand during this study at 40 m of altitude illustrating group composition.

4.2.2 Behaviour

Behaviour patterns were examined for 18 independent groups encountered between July 2015 and March 2017. A total of 41 flights were conducted comprising 8.45 hours of aerial video observations recorded. Most surveys occurred during the summer and autumn months due to weather conditions; for this reason, they have the highest number of flights (Table 7).

Table 7: Number of independent encounters and UAV flight effort based on austral seasons at Great Barrier Island (GBI).

Austral Seasons	**No. of independent encounters**	**No. of UAV flights**	**Flights (Hrs)**
Summer	9	17	3.4
Autumn	6	12	2.9
Winter	2	9	1.7
Spring	1	3	0.5
Total	**18**	**41**	**8.5**

Behavioural State

Overall, the main behavioural states observed were travelling (43.9 %, n = 18) and resting (43.9 %, n = 18), while milling (7.3 %, n = 3), socialising (2.4 %, n = 1) and foraging (2.4 %, n = 1) were the least frequent. (Figure 17).

(a)

(b)

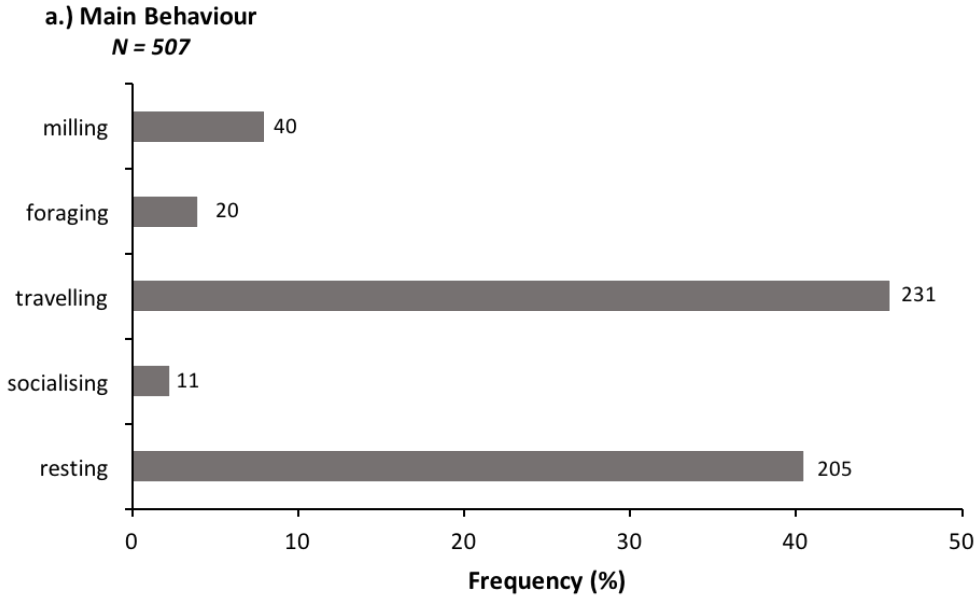
(c)

Figure 17: Bottlenose dolphins photographed at Great Barrier Island (GBI), New Zealand during this study at 40 m of altitude illustrating **(a)** travelling, **(b)** resting and **(c)** socialising behavioural state.

Activity Budgets

Activity budgets were analysed via aerial survey for 18 independent groups of bottlenose dolphins. Out of a total of 8.5 hours of observation (n = 507), travelling (n = 231, 45.6 %, = 3.8 hrs) and resting (n = 205, 40.4 %, = 3.4 hrs) accounted for the majority of activity budget, while milling (n = 40, 7.9 %, = 0.7 hr), foraging (n = 20, 3.9 %, = 0.3 hr) and socialising (n = 11, 2.2 %, = 0.2 hr) were less frequently observed (Figure 18a).

A secondary behaviour was observed for 3.8 hours (n = 229, 45.2 %) of the total observations. Resting (n = 76, 33.2 %, = 1.3 hr), travelling (n = 65, 28.4 %, = 1.1 hr) and socialising (n = 65, 28.4 %, = 1.1 hr) were the most recorded, while foraging (n = 12, 5.2 %, = 0.2 hr) and milling (n = 11, 4.8 %, = 0.2 hr) were less frequently recorded (Figure 18b).



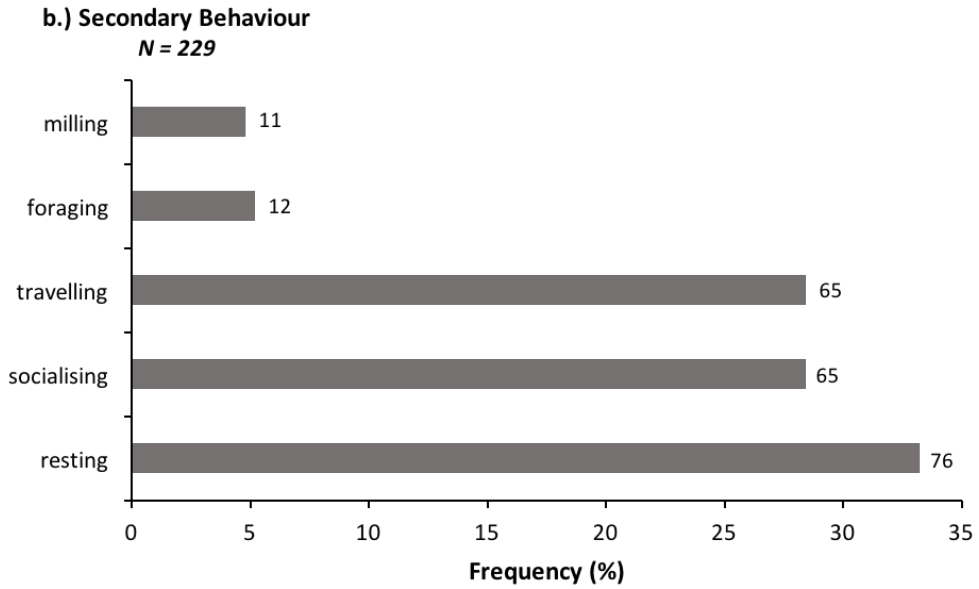
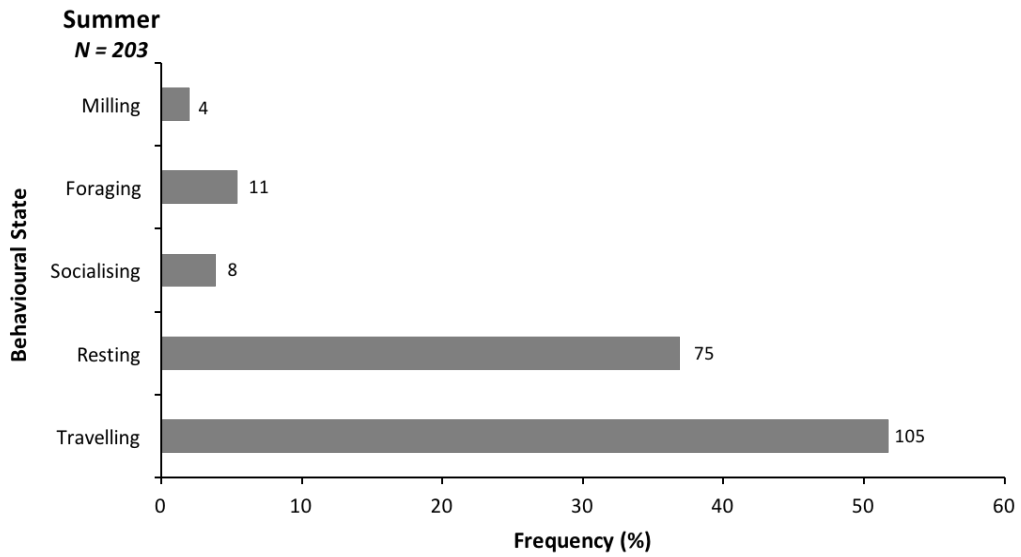


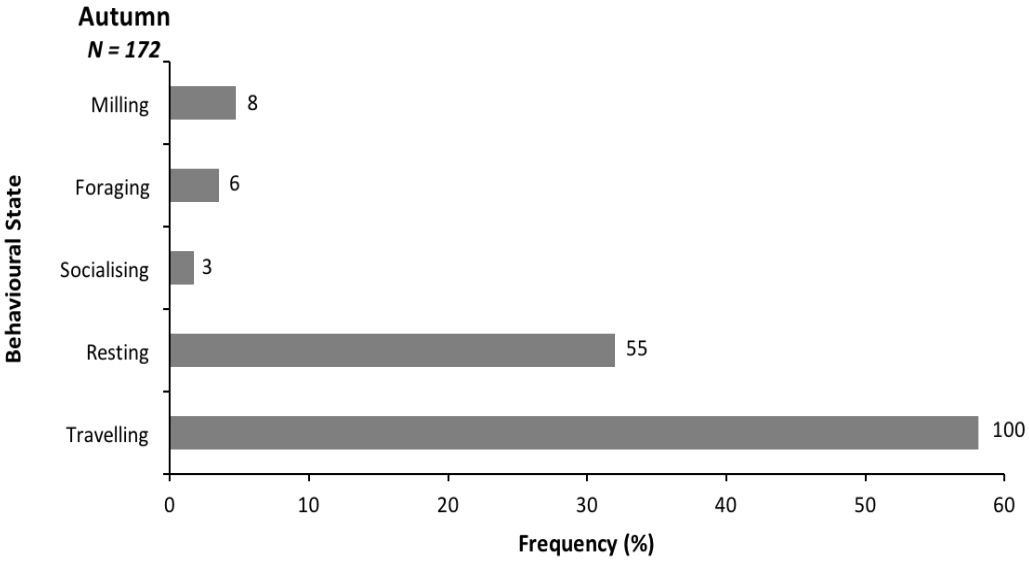
Figure 18: Bottlenose dolphin activity budgets at the Great Barrier Island (GBI). Activity states are represented by the number of observations. Behavioural states were assessed via one-minute interval scan sampling during the aerial surveys.

Summer and autumn months have the highest number of flights (n = 29, = 6.3 hrs) (see Table 7) due to weather conditions. Activity budgets were analysed for 15 independent groups of bottlenose dolphins and results showed that dolphins spent the majority of their time travelling (51.7 % in summer and 58.1 % in autumn) and resting (36.9 % in summer and 32 % in autumn) (Figure 19a and b). Winter and spring season months have the lowest number of flights (n = 12, = 2.2 hrs). Activity budgets were analysed for three independent groups of bottlenose dolphins and results showed that dolphins rested the majority of their time (52.5 % in winter and 71 % in spring), followed by milling (21.8 % in winter and 19.4 % in spring) (Figure 19c and d).

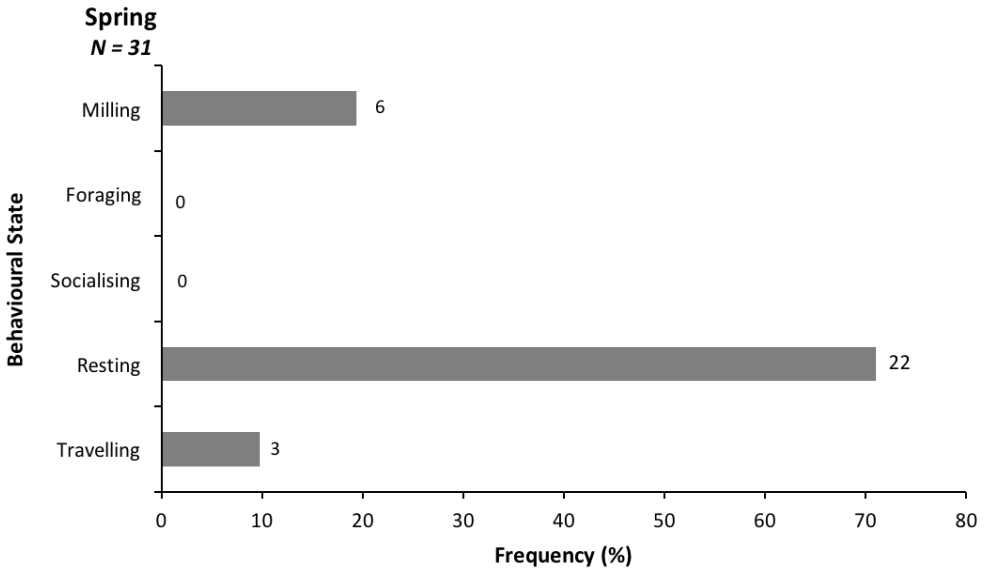
(a)


Summer
N = 203
Milling
Foraging
Socialising
Resting
Travelling
4
11
8
75
105
Behavioural State
0
10
20
30
40
50
60
Frequency (%)

(b)


Autumn
N = 172
Milling
Foraging
Socialising
Resting
Travelling
8
6
3
55
100
Behavioural State
0
10
20
30
40
50
60
Frequency (%)

(c)


Spring
N = 31
Milling
Foraging
Socialising
Resting
Travelling
6
0
0
22
3
Behavioural State
0
10
20
30
40
50
60
70
80
Frequency (%)

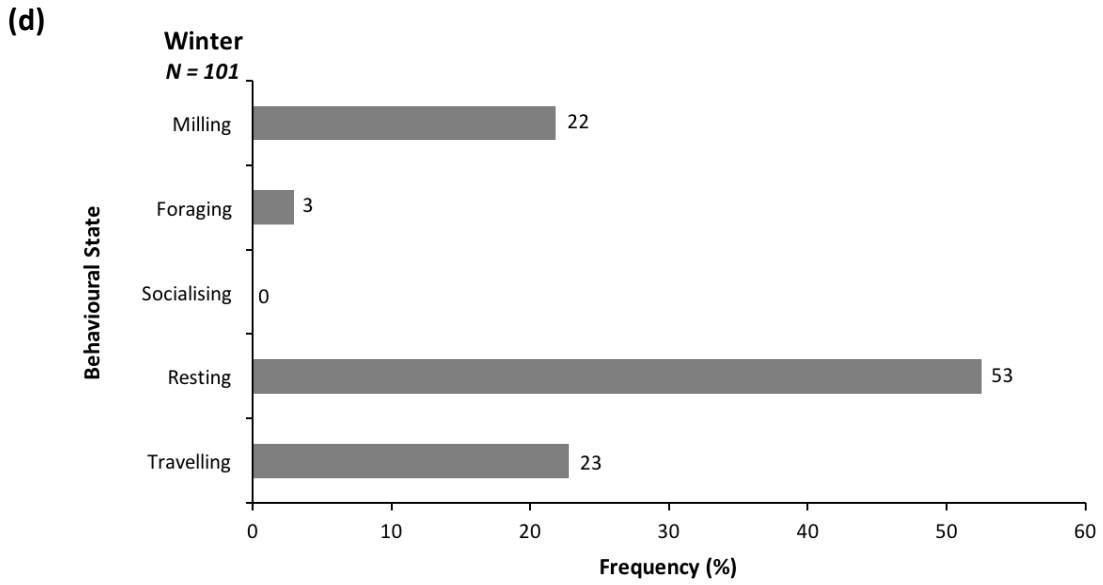


Figure 19: Bottlenose dolphin activity budgets by season for the Great Barrier Island (GBI). Activity states are represented by percentages. Behavioural states were assessed via one-minute interval scan sampling during the aerial surveys. Total of 8.5 hours of observation.

Overall, dolphins rested less in summer and autumn than in winter and spring, and travelled more in summer and autumn than in winter and spring.

4.2.3 Interactions

Interactions were examined for 21 independent groups encountered between July 2015 and March 2017. A total of 16.6 hours of aerial footage recorded was reviewed on high-resolution monitor. Interactions between dolphins-boat, dolphins-recreational user (i.e. swimmers, stand up paddleboarders – SUPs, and kayakers) and dolphins-other species (i.e. fishes, sharks and birds) were reported.

During the aerial surveys different interactions were observed between dolphins and boats. On one occasion, a group of six dolphins was travelling at constant speed when a powerboat at a high speed drove over the group (in breach of the marine mammal act). The animals quickly dove and swam away. In this case, the UAV completely lost track of the group and the dolphins involved were likely to have exhibited a behavioural change as a result of that encounter. Later, the same group of six dolphins was recorded interacting with another powerboat. This time, the boat drove past in a constant speed and dolphins responded to the presence of the vessel bowriding for a few seconds. In

fact, this time the water was much clearer and shallower, and animals remained close to the surface, making it easier for the UAV to keep track of the animals (Figure 20).

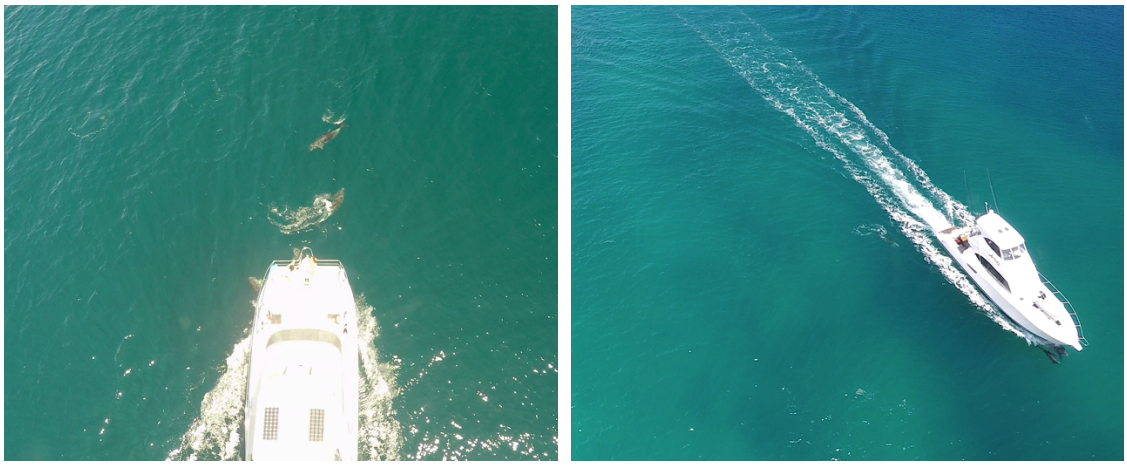


Figure 20: Bottlenose dolphins photographed at 40 m of altitude at Great Barrier Island (GBI), New Zealand during an interaction with powerboats.

Interaction between dolphins and stationary boats were also observed during the surveys. During the summer months the presence of private boats intensifies around GBI waters, and those vessels normally use the sheltered bays to spend the day or stay overnight. Occasionally, UAV operations recorded dolphins cruising along next to those boats, where they just passed by with some degree of curiosity but did not stay long or wanted to interact.

On 20 of January of 2016, a group of dolphins was observed being surrounded by a total of four swimmers, two SUPs carrying two people each, and three kayaks. The encounter took place close to one of the most popular bays in the southwest of GBI on a weekend day. The group consisted of 18 adults, one neonate, one calf and one juvenile. During the aerial observations dolphins exhibited strong reaction towards swimmers, SUPs and kayaks. Every time the recreational users tried to approach the animals, the group changed direction, and most of the time combined with an increase of speed (Figure 21).

Figure 21: Bottlenose dolphins photographed at 40 m of altitude at Great Barrier Island (GBI), New Zealand during an interaction with recreational users, including swimmers, stand up paddleboarders and kayakers.

Interactions between dolphins and other species were also observed in the present study. A school of fish was recorded on video on one occasion when a group of six dolphins was travelling around the coastline. The dolphins were recorded to swimming past the school in 2 to 3 meters of distance, but no interaction or behavioural change was observed. Furthermore, during few encounters, juveniles of hammerhead sharks (*Sphyrna zygaena*) were observed using and sharing the same area as the dolphins. This usually was recorded when dolphins were in shallow and sheltered bays. Again, dolphins showed no reaction to the sharks presence, even when in resting behavioural state. These encounters were only registered with big groups of dolphins. On one occasion, the UAV registered a group of dolphins chasing stingray (sp unknown). This encounter was in shallow waters close to an oyster farm. Birds interactions, including with shearwaters (*Puffinus* spp.) and Australasian gannets (*Morus serrator*), were observed during one encounter, where a big group of dolphins seemed to be foraging. Aerial surveys were conducted over these animals in deeper waters (~30m) off the west side of the GBI. During the survey, dolphins performed long dives, showed surface chasing behaviour and most of the time the birds were close by and also performing dives, indication of foraging.

Furthermore, additional behaviours observed during the footage analysis were for example: social-rubbing between individuals, dolphins chasing each other underwater,

social interaction between calves and juveniles, underwater bubbles, individuals playing with seaweed, nursing and copulation attempts.

4.2.4 Opportunistic UAV observation

During the field trip conducted in January of 2016, three opportunistic flights of 20 minutes were conducted over Bryde's whales (*Balaenoptera brydei*), during three different encounters. During those observations, feeding behaviours were recorded by the UAV, where a series of coordinated lunge events and bubble blowing within a slow circle swimming under the surface were seen (Figure 22a). In addition, an adult whale was observed feeding, briefly joined by a young calf (Figure 22b). It is unique footage and is considered to be the first time the feeding behaviour of a Bryde's whales has been recorded by an UAV (AUTUNI, 2016; *Drone records rare whale footage in the Hauraki Gulf*, 2016).

(a) **(b)**

Figure 22: Bryde's whales photographed at 40 m of altitude at Great Barrier Island (GBI), New Zealand. Feeding behaviour event recorded by **(a)** adult and **(b)** mother and with calf.

4.3 UAV- and Boat-based methods comparison

4.3.1 Group Size and Composition

Group size was successfully examined for 21 independent groups encountered between July 2015 and March 2017 (Figure 23). A paired-samples t-test showed a significance difference between count from the boat (M = 29.6, SD = 14.74) and the UAV (M = 37.4, SD = 19.16) methods; t (20) = 3.399, p=0.003. The mean difference was 7.81 (SD = 10.53).

Comparative boxplots of the group size according to the method used shows that the UAV-based survey resulted in higher bottlenose dolphin counts (Figure 24). Overall, UAV-based counts were higher (71.4 %, n = 15) than the traditional boat-based surveys (19 %, n = 4), supporting the hypothesis that UAV-based surveys can be more precise. On two occasions, UAV- and boat-based surveys had the same count, which occurred in small groups of 6 individuals.

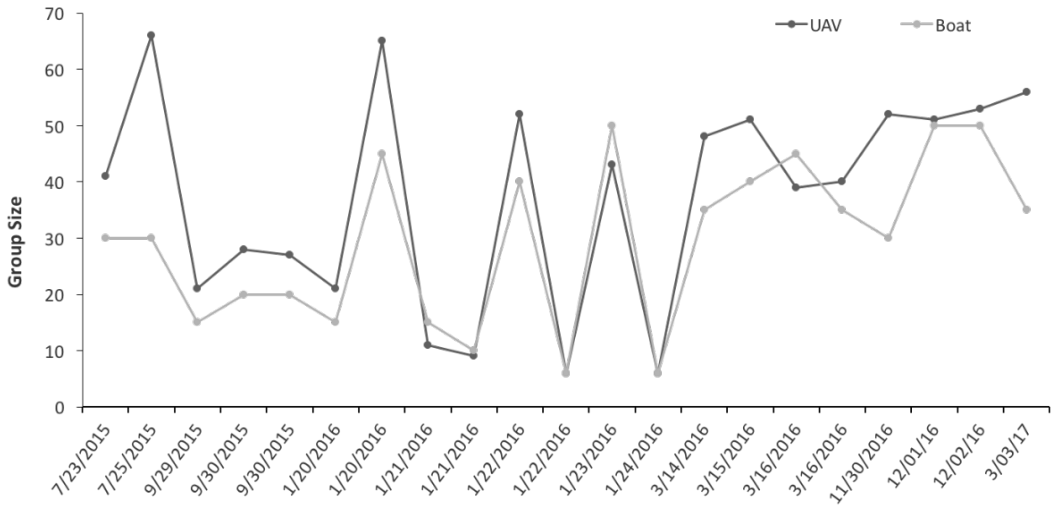


Figure 23: UAV-based counts and boat-based traditional counts for 21 independent bottlenose dolphin encounters between July 2015 and March 2017 at Great Barrier Island (GBI).

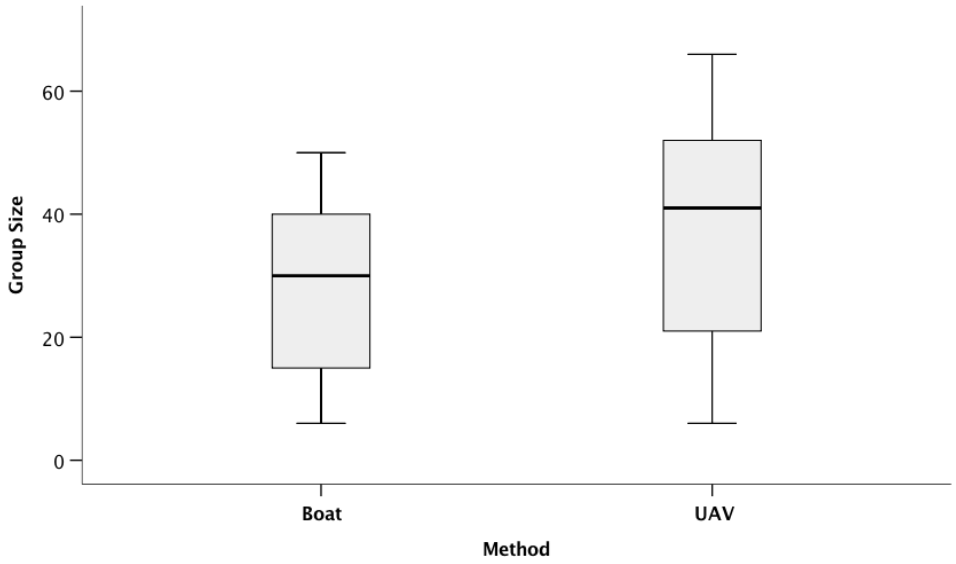


Figure 24: Mean of UAV-based counts and boat-based traditional counts for 21 independent bottlenose dolphin encounters between July 2015 and March 2017 at Great Barrier Island (GBI).

UAV-based data provided the opportunity to verify the age-classes of bottlenose dolphins, however during this research only presence and absence of immature animals were collected from the boat. For this reason, comparison of the numbers of immature dolphins was not possible. Due to limited data, statistical analysis could not be conducted to test differences between methods.

4.3.2 Behaviour

Behaviour patterns between boat- and UAV-based surveys were examined for 13 independent groups encountered between July 2015 and December 2016. A total of 30 flights were conducted comprising 5.9 hours of aerial video and boat behavioural observations (n = 354). Most aerial surveys occurred during the summer months due to the optimal weather conditions (Table 8).

Table 8: Number of aerial surveys (UAV flights) by austral seasons at Great Barrier Island (GBI) for behaviour patterns comparison between boat-based and UAV-based surveys.

Austral Seasons	**No. of independent encounters**	**No. of UAV flights**	**Flights (Hrs)**
Summer	7	15	3.1
Autumn	3	3	0.6
Winter	2	9	1.7
Spring	1	3	0.5
Total	**13**	**30**	**5.9**

The results showed that in 73.7 % (n = 261, 4.4 hrs) of the time there was no difference in behavioural state recorded between methods. However, the behavioural state differed 26.3 % (n = 93, 1.6 hrs) of the time, showing different behaviour recorded between boat and UAV methods.

Overall, resting and travelling where the most frequently behavioural states recorded. Out of a total of 5.9 hours (n = 354) of aerial and boat observations, resting (boat: n = 199, 56.2 % = 3.5 hrs and UAV: n = 169, 47.7 % = 2.8 hrs) and travelling (boat: n = 87, 24.6 % = 1.5 hr and UAV: n = 135, 38.1 % = 2.3 hrs) accounted for the majority of the

behaviours observed, while milling, foraging and socialising were less frequent (Figure 25).

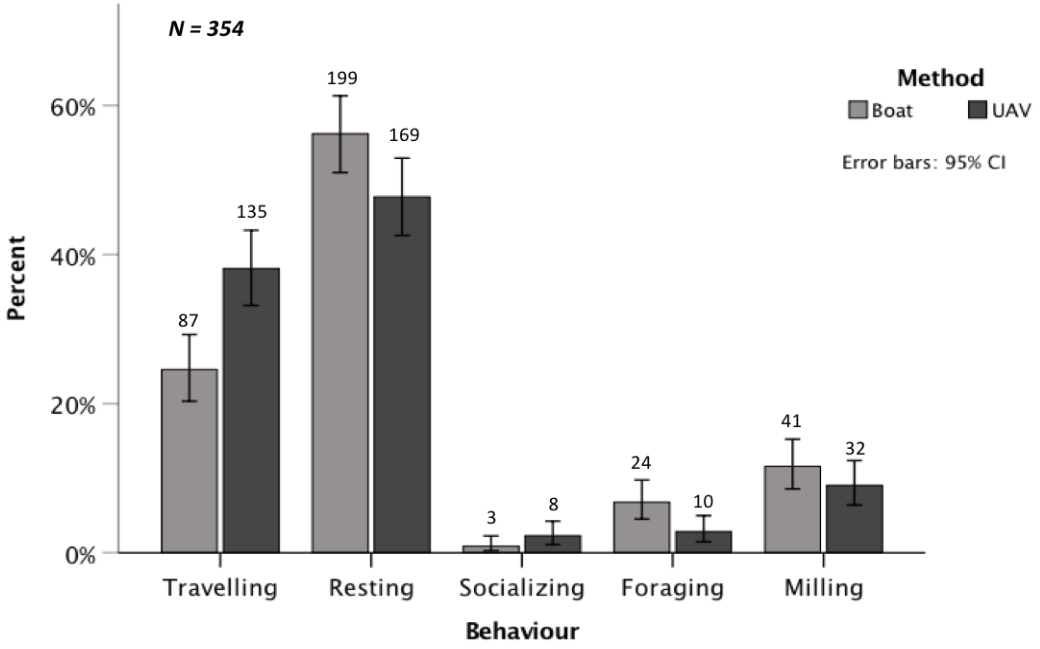


Figure 25: A comparison of activity budget for bottlenose dolphin groups by standard boat-based and UAV-based surveys for the Great Barrier Island (GBI). Activity states are represented by percentages. Behavioural states were assessed via one-minute interval scan sampling during both surveys. Total of 4.22 hours of observation (n = 354).

These observations were tested statistically by comparing the percentage of occurrence of the behavioural state against the method used to collect the data. The Pearson Chi-Square test revealed that the behavioural state recorded varied significantly with the type of method used ($\chi 2$ (4) = 21.97, p = 0.000). The results showed a significant difference in travelling ($\chi 2$ (1) = 15.11, p = 0.000), resting ($\chi 2$ (1) = 5.09, p = 0.003) and foraging ($\chi 2$ (1) = 6.05, p = 0.018) behaviour between boat and UAV (Figure 25). There was significantly more travelling, and less resting and less foraging detected by the UAV than the boat. No significant difference was detected for the other behavioural states.

Group dispersion between boat- and UAV-based surveys were also examined. Results showed that in 53.7% (n = 190, 3.2 hrs) of the time was no difference in group dispersion between methods. However, the group dispersion differed in 46.3 % (n = 164, 2.7 hrs)

of the time, showing a different dispersion observed between boat and UAV methods. Overall, the results showed that the UAV detected more loose and sub-groups than boat-based observations (Figure 26).

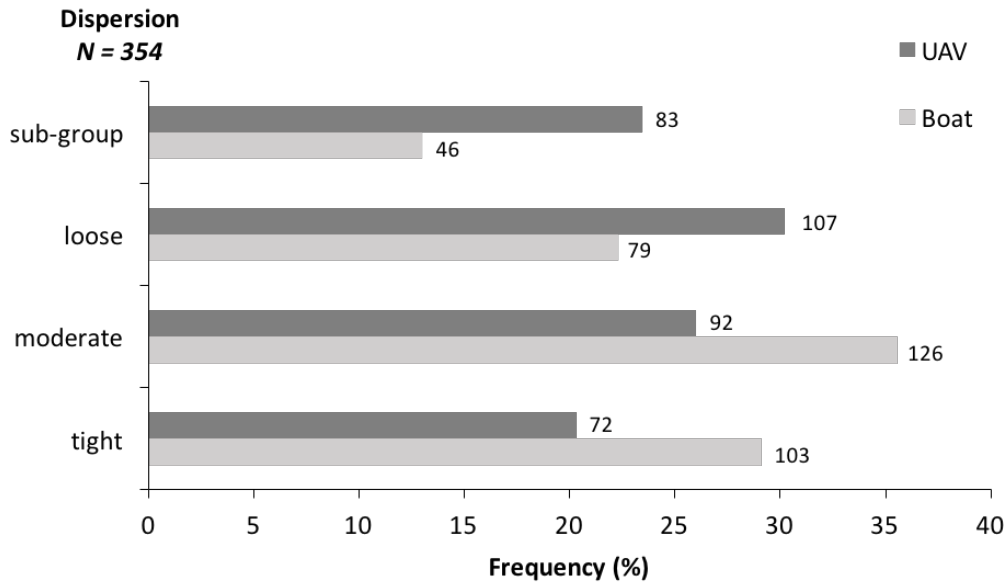


Figure 26: A comparison of group dispersion for bottlenose dolphin groups by standard boat-based and UAV-based surveys for the Great Barrier Island (GBI). Dispersions are represented by percentages. Pod dispersion were assessed via one-minute interval scan sampling during both surveys. Total of 4.2 hours of observation.

Chapter Five: Discussion

5 Discussion

Introducing a new technology for data collection always requires careful analysis, particularly in terms of maintaining the efficiency and accuracy of the data. It is also most important to understand if the novel equipment brings advantages compared to traditional methods or not. Aerial views provide biologists with profound advantages viewing animals in open habitats, and as UAVs fly at lower altitudes than other aircraft and satellites, they can provide a more localised and detailed biological information at a spatial extent (Jones, Pearlstine, & Percival, 2006). UAVs are not "one size fits all" highlight Jones (2003). Time aloft and image resolution need to be considered to fit the different applications, and the aircraft required for wildlife studies need to be easy to use, preferably electrically powered, portable and operable by one or two people (Jones, 2003). Goebel *et al*. (2015) believe that electric VTOLS are among the most promising tools for ecological applications and technology. They represent a valuable platform that can potentially complement and enhance many ongoing conservation programs (Koh & Wich, 2012). However, different UAV configurations produce different sound profiles and these may produce undesirable reactions in the animals of interest. In fact, the effect of the UAVs on the behavioural and physiological responses of the target species is extremely important in early stages of the study and should be addressed and assessed. In this thesis, the focus was on preliminary data that was gathered to assess whether UAVs are useful to study bottlenose dolphin behaviour. The main objectives were to determine the optimal parameters to study behaviour and population ecology safely, in a non-invasive way; investigate how UAVs can be used in describing behaviour, how they compare to conventional boat survey methods; and how they can contribute to support conservation and management of the species.

5.1 Do low altitude UAVs represent a non-invasive tool to study dolphin behaviour?

During this research, short-term behavioural responses of bottlenose dolphins to a small lightweight VTOL UAV (*Splashdrone*) flying at three different altitudes were quantified. The results showed that flying at 10 m elicits a quantifiable response from resting animals. That is, the number of group reorientation and tail slap events strongly increased between controls and flights. Disruptions in resting behaviour were also

observed during two flights at 10 m altitude, where dolphins initially changed behaviour followed by displacement from the area. In contrast, it was observed that when the UAV was flying at 25 m or higher, it had no significant effect on dolphin's behaviour.

Surface behavioural events (e.g. tail slap, side float, spy hop, chin slap) and swimming patterns (e.g. bearing consistency, dive time) are widely used by researchers to quantify short term responses of delphinids to either acoustic or visual disturbance sources (Erbe, 2012). For example, the increase in numbers of directional changes can be due to horizontal avoidance and has been reported for bottlenose dolphins (Constantine et al., 2004; Lemon et al., 2006; Lusseau, 2006a; S. M. Nowacek, Wells, & Solow, 2001) and killer whales (*Orcinus orca*) (Williams, Trites, & Bain, 2002) exposed to powerboats. The increase in frequency of aggressive behaviours, such as tail slap and chin slap, can represent a response to disturbance (Southall et al., 2007), whereas side floating and spy hopping might indicate an attempt to visualize the noise source (Lusseau, 2006b; Shane, 1990b). The results presented in this study suggest that bottlenose dolphins noted and reacted to the aircraft flying at 10 m altitude, increasing the number of reorientation and tail slaps events.

Noise produced by manned aircraft flying at low altitude elicit strong behavioural responses in several species of cetaceans (Patenaude et al., 2002; Smultea et al., 2008; Wursig et al., 1998). While the literature detailing about potential disturbance caused by UAVs on cetaceans is scarce (Smith et al. 2016), recent studies documented that pinnipeds can change their behaviour in the presence of lightweight VTOL UAVs flying at 30m and below (Fritz, 2012; Pomeroy et al., 2015). Meanwhile, Durban et al. (2015) did not observe evidence of behavioural responses in killer whales (*Orcinus orca*) exposed to a VTOL UAV flying at 35m altitude. In a less recent study, several species of baleen whales and sperm whales (*Physeter microcephalus*) have been approached by VTOL UAV flying lower than 10 m altitude and no reaction of the targeted animals was noted (Acevedo-Whitehouse et al., 2010). However, these prior observations were not focussed on the detection of behavioural responses, and were dedicated designed to experimentally assess and quantify the responses levels of animals to different flight altitudes.

Splashdrone UAV flying at 10 m produce noise levels between 91 and 97 dB re μPa root mean square (rms) [mean of 95 dB re 1 μPa (rms)] at 1m depth (Christiansen, Rojano-Doñate, et al., 2016). It is believed that odontocetes like bottlenose dolphins are able to hear these acoustic stimuli, although Christiansen *et al.* (2016) suggests that the effect is likely to be small, even when the animals are close to the surface. However, bottlenose dolphins are highly active at the surface, and are able to hear airborne noise, as well as any other marine mammal (Southall et al., 2007). Therefore, it is important to also consider also the airborne noise levels (@ 1 m of 80 dB re 20 μPa), in particular as they are significantly higher than the underwater correspondent (Christiansen, Rojano-Doñate, et al., 2016). Furthermore, bottlenose dolphins have been documented to avoid the shade of helium-filled tethered balloons used for aerial surveys (Nowacek, Tyack, & Wells, 2001a). The *Splashdrone* is considerably smaller in size than the balloons, and, therefore casts a smaller shadow on the water surface. However, one dolphin was observed to perform a side float just after the aircraft shadow cast past over his head when flying at 10 m altitude. This event could have been in response to the UAV shadow cast over its body, though this cannot be confirmed (Figure 27).

Figure 27: Side float sequence cropped from the aerial video captured by the Splashdrone at 10 m of altitude. Note: the shadow of the UAV on top of his head (a) just before performing side float (b-e).

As discussed prior, some cetacean species apparently react strongly to aircraft, while others appear less affected. Nevertheless, an experimental assessment of cetacean behavioural responses to UAVs is not always practicable and there may be many confounding variables. The potential effect of UAVs on marine mammals may depend on the behavioural state of the animals at the time, as well as environmental factors (sea state, wind speed and geomorphology) and the presence and type of other anthropogenic activities nearby (Smith et al., 2016). While environmental factors can modulate the acoustic stimuli received by cetacea (Erbe, Reichmuth, Cunningham, Lucke, & Dooling, 2016), this survey was carefully designed to minimise the potential effects of independent variables during the tests. In this case, the *Splashdrone* was flown in a maximum wind speed of 10 knots with a maximum Beaufort Sea State of 2, in similar habitats. Furthermore, the surveys were only conducted over resting animals, without any type of human activity taking place nearby, while the research vessel maintained a minimum distance of 100 m away with its engines off.

Results from this study suggest that *Splashdrone* or similar to this UAV should conservatively only be flown at over 10 m for bottlenose dolphins. This strengthens the argument that further research on potential impact of UAVs on marine mammals is required to avoid the risk of harassment for the targeted animals (Fiori et al., 2017; Smith et al., 2016). Precautionary research approaches are preferred, with and the assessment of disturbance levels recommended to be conducted during early conceptual stages of study design (Hodgson & Koh, 2016).

5.2 Have the low altitude remote sensing UAVs been effective to collect behavioural data and habitat use of bottlenose dolphins around GBI?

This study assessed the capability and potential of UAVs to collect high-quality imagery during surveys of large groups of bottlenose dolphins off GBI. The objective was to see how effective low altitude UAVs are to describe behavioural patterns and habitat use. Until now, low altitude UAVs have been successfully tested for a number of marine mammal research applications, but most of the studies have been conducted on big cetaceans such as humpback (*Megaptera novaeangliae*), bowhead (*Balaena mysticetus),* and blue whales (*Balaenoptera musculus*), whereas studies on small cetaceans such as delphinidae are still very scarce. In fact, UAV use to study bottlenose dolphin behaviour has previously been undescribed.

This study found that a height of 40 m was the ideal altitude to observe the large groups of dolphins off GBI. The images recorded at 2.7K at 25 frames per second with a medium angle window, using a GoPro Hero 4, was sufficiently detailed to count the group, identify age classes, as well as to observe behaviour patterns and interactions. However, when surveying small groups or groups that were tightly together, lower altitudes such as 25 m could safely be used for this population (Fettermann et al., 2018).

The video review of each survey took 30 minutes, which is not much time considering that the method provided the opportunity for counting all individuals and categorizing them carefully. The group size was successfully obtained for all 21 independent encounters of bottlenose dolphins surveyed during this study, and results showed that the UAV platform was able to give a precise number. This supports the hypothesis that UAV based surveys can be precise and even more accurate than other methods, such as ground or boat-based surveys. Hodgson *et al.* (2016) reported that UAV-derived counts were significantly different - in this case larger - to the ground counts during his study on birds. It is believed that the perspective of UAV imagery reduces likelihood of missed counts due to, for example, topography and/or individuals obscuring the counting person's line of sight (Hodgson et al., 2016). Goebel *et al.* (2015) also reported having more accurate UAV-derived counts than grounds counts when studying seabirds and pinnipeds in Antarctic. The UAV images allowed them to accurately count gentoo penguins (*Pygoscelis papua*) and chinstrap penguins (*Pygoscelis antartica*) nests and chicks, as well as to distinguish pups from adults in a species level, and detect tagged animals. The advantage of having permanent data, as are the images obtained by the UAV survey, is that it gives the opportunity to inspect the data carefully multiple times. In this study, all age classes were also successfully detected. The images obtained gave not only the opportunity to identify the presence of immature individuals, but also to count and gather a precise number of neonates, calves and juveniles for each group. Furthermore, the benefit of having a permanent dataset that can be reviewed multiple times is that it gives the opportunity to get diverse post-processing data, such as animal size, body shape and nutritive conditions, among others.

In this study, behaviour patterns were examined for 18 independent groups, and the results showed that the five behavioural states (socialising, milling, foraging, resting and

travelling) were successfully detected and described. In addition, secondary behaviour was also successfully detected during the aerial surveys.

It has previously been demonstrated that overhead video can provide continuous footage of dolphins throughout the water column, even if the animals are sometimes not visible from the vessel (Nowacek, 1999). In fact, video footage can help observe and record behaviour of individuals in environments where sampling is difficult, and thereby gather more detailed and complete behavioural data. This method has been successfully used in previous studies, for example, to study foraging behaviour of bottlenose dolphins (Nowacek, Tyack, et al., 2001b) and to document movement patterns and behaviour of Puget Sound killer whales (*Orcinus orca*) (Nowacek, Lange, Wells, & Tyack, 1995) using a helium-filled aerostat balloon, and to record behaviour of male bottlenose dolphins (*Tursiops truncatus*) using an airplane (Rohr et al., 1998). Mann (1999) states that conducting separate "video" follows of different individuals captured on the same tape is equivalent to multiple focal-individual follows, provided simultaneous behaviours are accounted for in statistical analysis. The amount of time spent in the post-analysis can be considered time consuming, but it gives the opportunity to carefully measure behaviour, including all individuals, as the aerial survey has the ability to track all the animals even when they are below the water surface.

Again, the ability to track the animals when underwater, especially in places with clear water, brings a third dimension to the data collection. The advantage in angle perspective gives the ability to quantify and characterise behaviours that can sometimes not be seen from the research vessel, for example, dolphins chasing each other underwater, or dolphins being in physical contact, such as rubbing and touching, playing with seaweed or other objects, copulating, nursing, or feeding events, amongst many others. In fact, it can provide a tool to access rare or undescribed behaviours. During this research, I was able to opportunistically film Bryde's whales feeding off GBI. The aerial survey images gave the opportunity to observe feeding behaviours performed by an adult individual and a mother and calf pair. This is unique footage and it was considered to be the first time filmed by a UAV. Similar events have recently been captured by scientists around the globe, such as one of rare blue whale feeding (Oregon State University, 2017) and nursing (National Geographic, 2016) off New Zealand waters.

Furthermore, the UAV data gives an opportunity to analyse in a fine scale, and the footage creates a permanent database, where information can be accessed and reviewed multiple times. Even if behaviour is not the main focus of a study, such as the ones conducted by Durban *et al.* (2015), Koski *et al.* (2015), Christiansen *et al.* (2016) and Durban *et al.* (2016), the UAV imagery has great potential to be used to link with behaviour changes, due to the high quality information collected during those surveys.

Additionally, encounters between dolphins and boats, dolphins and recreational users, such as stand-up paddleboarders, kayakers and swimmers, and with other species, such as seabirds and sharks, were successfully observed during this research. The encounters between dolphins and boats, and dolphins and recreational users were mostly observed during the summer months, where their presence intensifies around GBI waters due the warm weather and summer holidays. UAV surveys were conducted over a few of these events and results indicated that the imagery obtained can help to have a better understanding of the dolphin behavioural responses during those interactions. In this study, dolphins showed strong avoidance and changes in behaviour with increased levels of human disturbance. Results from the interactions recorded that dolphins clearly exhibited horizontal avoidance when exposed to stand-up paddleboards, kayaks and swimmers. This is consistent with diverse previous studies, where bottlenose dolphins were reported to show a sensitization and an increase of avoidance levels with prolonged exposure to swimmers (Constantine, 2001), and to turnaround and change behaviour when interacting with kayakers and others recreational users (Fandel, Bearzi, & Cook, 2015; Lusseau, 2006a). Until now, our understanding of dolphin behaviour responses to those human activities has been based on studies conducted by boat, although it is clear that low altitude UAVs can give an opportunity to gather a better perspective on those interactions, especially knowing that power boats can also elicit a behavioural response (Constantine et al., 2004; Lemon et al., 2006; Lusseau, 2006a; Nowacek, Wells, et al., 2001). Finally, UAVs can record interactions between other species that, most of the time, cannot be seen from the boat, like the ones described during my study with sharks and schooling fish.

5.3 How do low altitude remote sensing UAV surveys compare to boat surveys?

In this section, only data collected during this research were included in the analysis and discussion for both methods.

Results from this study showed that the dolphin count from UAV-derived surveys was significantly different to the boat-derived counts. Overall, UAV-derived surveys resulted in higher bottlenose dolphins counts than the traditional boat-based surveys, supporting the hypothesis that UAV based surveys can improve boat-base accuracy. This is consistent with prior observations reported by Hodgson *et al.* (2016), where UAV-derived counts were significantly higher compared to the ground counts obtained during his study on birds. It is believed that the perspective of UAV imagery reduces the likelihood of missed counts due to, for example, topography and/or individuals obscuring the counter's line of sight (Hodgson et al., 2016). Having this additional tool and image system on board of the research vessel allows correction of boat-based counts, as well as giving the opportunity to verify the categorization of the target species, especially when studying large groups such as the bottlenose dolphins off the GBI. The images obtained also allow carefully inspection and potentially eliminate errors.

Adame *et al.* (2017) reported that counts and categorization from the UAV show a smaller amount of errors compared to boat-based ones. Their study conducted on California sea lions suggested that boat-based surveys failed more in categorization of animals than UAV-surveys, especially when the number of animals increased. This can clearly underestimate abundance and induce a higher categorization uncertainty. Boat-derived dolphin group sizes are usually recorded using minimum, best and maximum estimate counts of animals observed surfacing at any one time. In addition, photo-identification is usually carried out and can help confirming or amending counts if needed. However, not all individuals in a group are always photographed and consequently group size cannot always be verified. The number of neonates, calves and juveniles are also estimated visually from the boat, usually using minimum, best and maximum counts, and they are later confirmed or amended by photo-identification. The UAV-imagery obtained during this study provided the opportunity to carefully verify the age-classes of bottlenose dolphins, and with the advantage of analysing the imagery

multiple times gave the opportunity to ask for expert guidance when some individuals could be difficult to categorise. Unfortunately, only the presence and absence of immature animals were collected from the boat during this research, and for this reason, a comparison between methods could not be conducted.

A total of 30 surveys were conducted from boat and UAV at the same time, for behaviour activity comparison. The results demonstrated that the behavioural state recorded between methods differed 26.3% of the time. It is clear that the aerial perspective from the UAV allows the observer to ensure the entire group is surveyed whereas the perspective from the boat can make it difficult, and human error by the observer can contribute to a significant variation. Behaviour studies on cetaceans can present some difficulties, especially because these animals are only partially visible and for a short period of time (Tayler & Saayman, 1972). In fact, some species can spend 95% of their time below the water surface (Leatherwood & Evans, 1979) and behaviour observations from the boat perspective can sometimes be affected, and observer bias can be mixed with availability bias (Mann, 1999; Mann, Connor, Tyack, et al., 2000). Hodgson *et al*. (2017) argue that aerial behaviour observation from the UAV provides a more accurate assessment of availability than methods currently available (including land- or boat-based focal follows) because it provides a direct measure of availability, minimizing assumptions about what portions of the dive cycle would be visible from the air, and it does not affect the cetacean behaviour. Furthermore, in some cases boat observations can influence the nature of the observations and cause bias due the fact that many species of marine mammals are either attracted by or avoid vessels.

During this study, the UAV method detected significantly more travelling and less resting and foraging than the boat method. As discussed previously, the perspective from the boat can make it difficult and be negatively affected sometimes, especially when observing reasonable large groups of dolphins. It is true that large groups can be easier to find and keep track of, but they also require more challenging settings for minimizing observational bias (Mann, Connor, Tyack, et al., 2000). In fact, some behaviours are difficult to identify and easy to confuse, for example travelling and foraging, which sometimes is obvious, but sometimes is ambiguous (Mann, Connor, Tyack, et al., 2000). Bias from group sampling can happen for diverse reasons, for example; the observer's attention can naturally be drawn to certain events, such as socialising; the visibility of

the group members can change depending on their activity; and group activity may be easy to determine if members of the group are doing the same thing, but difficult to determine if some animals are doing different things (Mann, Connor, Tyack, et al., 2000). Behavioural disagreement during this study varied between foraging - travelling, foraging - socialising, resting - socialising, and resting - travelling (slow travelling) between the boat and UAV, respectively. Again, the UAV showed great benefits and proved to be an essential component for the field work. In fact, having the UAV imagery on screen and in real time on the boat can help improve data collection and potentially reduce many biases.

5.4 Contribution to support conservation and management of bottlenose dolphins

The site selected for this study was based on the importance of the area to the bottlenose dolphin population. This region was recently described as a potential hotspot for the North Island population, with year-round occurrence and a high level of fidelity reported (Dwyer et al., 2014). During this study, it was possible to develop methods using small, vessel-launched multirotor UAVs to directly record aerial video of coastal bottlenose dolphins to describe their group dynamics and behaviour patterns. Dolphins were recorded at GBI during all trips conducted, and the images obtained by the UAV surveys gave a new perspective for studying behaviour of the nationally endangered bottlenose dolphin. The images allowed observation of how they interact, expanding the knowledge about these animals. The goal was to test and improve techniques and methodologies for the use of UAVs in scientific research and use them to optimise field activities, establishing a protocol to carry out for this population. Clearly, the small VTOL UAV proved to be a great complementary tool, and most importantly, it can be the eyes that are missing in the fight for the preservation of New Zealand cetaceans.

Developing and implementing conservation strategies involves a full understanding of the nature of the animals under review and the environment they live in (Barros & Wells, 1998; Rogan, Ingram, Holmes, & O'Flanagan, 2000), and how they change in space and time. Many studies believe that cetacean distribution is related to habitat features, but it sometimes is unclear what the habitat provides. However, behavioural observations can help provide that correlation, and a holistic view is essential. This study provided information about the behaviour and ecology of bottlenose dolphins around GBI,

collected from a new perspective, from which detailed information could be extracted. It clearly produced positive results and demonstrated the power of the UAV to be employed on behaviour ecology research. Furthermore, it can help with future implications and management measures for GBI.

5.5 Limitations

In order to use the unmanned aerial system in the marine environment, supervised training over land is required before one can start flying over sea. Some countries, like Australia and the United of the States of America, require a full pilot certification, the whole process of which can take months and requires extensive administration. Until now, New Zealand is one of the few countries that allows flying of UAVs without certification, and for this reason I was able to conduct the aerial surveys after the relevant in house training provided by AUT. However, a certified pilot was present at all the times during this research, complying with AUT UAV laboratory requirements. In addition, an official research permit from the Department of Conservation was granted to conduct UAV operations over marine mammals. Again, this has been the bigger limitation for studies in other countries, as it can be very difficult to obtain permits.

Small UAVs, such the ones used in this study, are strongly dependent on weather and sea conditions. The weather during this study was relatively calm and dry, with low wind speed and minimal or no precipitation. The risks to have the aircraft exposed to some of those conditions can prevent the operation or roll into a technical problem. During this study, the UAVs were not able to fly over four of the encounters, mainly due to increased wind speed or precipitation beyond a Beaufort Sea State of 3.

Previous studies highlight the limitation on short flight endurance and the limited area or range for aerial surveys. During this study, flight endurance was concluded to be linked with the number of batteries available for each aircraft. Flight endurance can limit long duration observations, which can be an issue especially for behavioural studies. The batteries usually need to be replaced every 20 minutes, for this reason, the ability to recharge the batteries on board and have as many as possible are highly recommended. It was found during this study that the hexacopter was the least favourite aircraft on board due their big size and the time consuming to recharge the batteries.

Consequently, this aircraft was mainly used as a backup, whereas the Splashdrone and the Phantom 4 were carried as the primary aircraft.

Another potential limitation of the UAVs involves the processing of the large amount of data generated by the aerial surveys, which requires a substantial time investment for data organization and processing. In behavioural analysis, the time it takes can vary depending how many times the imagery has to be reviewed. During this study, each video (approximately 10 minutes) took around 20 to 30 minutes to be analysed. This is not much considering the amount of information collected. However, this should be carefully considered at the beginning of a study.

The ability to find dolphins can be a potential limitation during this type of study, especially considering that the west coastline of the GBI is a relatively large area. It would take approximately 55 km to cover the area by boat, not including driving into each of the bays. Since there are no dolphin watch vessels operating on these waters to help with locating dolphins groups, it was essential to have GBI Marine Radio and other vessels around the island to help report when dolphins were observed. During this study, dolphins were successfully sighted 80% (n = 18) of the 20 on-effort days.

Finally, the biggest limitations during this study were due to weather and sea conditions, which prevented having more trips to the GBI. Out of the 24 months' window, field work was only possible over 6 months, as trips were established to be conducted only under conditions of Beaufort Sea State 3 or less and wind speed under 15 knots.

Chapter Six: Conclusion

6 Conclusion

6.1 Introduction

This thesis is the first dedicated study to investigate the use of lightweight low altitude unmanned aerial vehicle (UAV) on any marine mammal sp. in New Zealand waters. The study provides important insights into the use of UAV around the nationally endangered bottlenose dolphins off Great Barrier Island (GBI). The main objectives were to investigate if this novel tool represents a non-invasive platform to study dolphin behaviour, and if can improve data collection, fill gaps and/or strength data compared with traditional boat-based methods. This final chapter highlights the findings with regards to this approach and evaluates the importance of this study to practical applications and how contribute to support conservation and management of the species. Finally, recommendations for future research are addressed.

6.2 Summary of research findings

Bottlenose dolphins were regularly encountered off the west coast of GBI during this research across all austral seasons. UAV operations were successfully conducted, with the highest number of flights occurred during the summer months due the optimal weather conditions.

Flight parameters including the optimal height and camera settings were tested during the two first flights on field and results determined an optimal altitude of 40 m combined with a minimum resolution of 2.7K-25FPS-Medium FOV when using a GoPro hero 4.

To assess the potential risk of disturbance to these animals caused by the UAV, short term behavioural responses of resting animals were assessed to the UAV flown at 10 m, 25 m and 40 m altitude. All operations took place in light wind conditions (max wind speed of 10 knots, Beaufort Sea State 1-2). Results showed that the UAV altitude had a significant effect on dolphins reorientation and tail slap events. The number of directional changes and the frequency of tail slap events increased significantly between controls and flights (impact) when the UAV flown at 10 m over the dolphins. In addition, disruption in resting behaviour were observed during two flights at 10 m altitude. In

contrast, no significant differences were detected when the aircraft flown at 25 m and 40 m altitude.

Group size and composition were examined from the aerial footage recorded for 21 independent groups encountered. Group size ranged from 6 to 66 individuals (mean = 37.42, median = 41), whereas the most frequently observed group size encountered contained between 51 to 55 individuals. On one day, a total of 86 dolphins were recorded during two independent groups separated by a distance of 21.5 km. Calves and neonates were present in the majority of the groups across all austral seasons.

Activity budget were analysed from the aerial footage and results showed that dolphins were travelling and resting most of the time. Seasonal variation in activity budget showed bottlenose dolphins travel more in summer and autumn, and rest more in winter and spring.

Interactions between dolphins and boats, recreational users and other species were successfully observed during the aerial surveys. Bottlenose dolphins were recorded to change behaviour and swim away when approached by a high-speed powerboat, and bowride for some time when approached by a constant speed powerboat. In addition, dolphins exhibited strong horizontal reaction when exposed to swimmers, stand up paddleboards and kayaks.

Group size, group dispersion and behavioural data were successfully compared between UAV and boat-based methods. The UAV-based group size was significantly higher than the boat-based survey. Furthermore, the UAV detected more loose and subgroups than boat-based observations. The behavioural state recorded also showed difference with the type of method used. The UAV-based detected significantly more travelling, and less resting and foraging that the boat.

6.3 Significance and contribution of research findings

This study contributes to a better understanding of how low altitude UAV can be used around bottlenose dolphins off GBI. In addition, it provides information on a topic never investigated before in these waters and for this species, and in which our knowledge has been restricted. More specifically, this study created a methodological framework to analyse bottlenose dolphins behaviour patterns in a multidimensional and macro

holistic perspective. At the behavioural and ecological aspect, this study is a valuable contribution to strengthen data collection in the field and analysis. My results support the use of a lightweight low altitude UAV around bottlenose dolphins off GBI and show that: 1) it can be used for surveys over short duration and range; 2) represents a non-invasive platform when flying at 25 m altitude or higher; and 3) it can be safely and efficiently deployed from a small boat and quick have a position above the dolphins. It also represents a valuable contribution for other cetacean's researches and regulatory bodies to help shape guidelines and avoid animal harassment.

It is extremely important to share results between scientists and resources managers as they struggle to respond escalating threats to marine and terrestrial resources. The environment conditions combined with dolphins fast movements are challenging factors when observing free-ranging dolphins. To this date, there is no scientific publications describing the use of UAV in small delphinids or dedicated studies in behaviour for small cetaceans. Recently, researchers from Duke University Marine Laboratory (USA), travelled to Scotland to fly an hexacopter over groups of bottlenose dolphins. They managed to obtain clear images in order to take body measurements, and believe that the UAV techniques it will be useful to study bottlenose dolphins health (http://sites.nicholas.duke.edu/uas/dolphin-photogrammetry/).

Disruptions in resting behaviour were observed while assessing the potential disturbance towards to the UAV. During a couple of aerial surveys at 10 m altitude dolphins initially changed behaviour and were subsequently displaced from the area before completion of the impact flight. This can have a significant impact on the population, where the UAV noise can disturb and interrupt biologically significant behaviours (i.e. resting) which may carry energetic costs and affect individual fitness. Short-term effects (i.e. reduction in fitness) can potentially lead to long term population consequences (Filby et al., 2014; Lundquist et al., 2012; Peters, Parra, Skuza, & Möller, 2012; Tezanos-Pinto & Baker, 2012). For this reason, aerial surveys need to be conducted without risk of harassment to the animals.

It is clear then that the use of UAVs for marine mammal research can improve data quality and has a great potential to collect behavioural data from an advantageous perspective in non-invasive way. Finally, this study strongly recommends that the UAV

survey methods should therefore be regarded as complementary rather than competing approaches. Furthermore, the results suggest that *Splashdrone* or a similar aircraft should conservatively only be flown at over 10 m for bottlenose dolphins and that further research on the potential impact of UAVs on wildlife (Ditmer et al., 2015; Vas et al., 2015) and marine mammals (Fiori et al., 2017; Smith et al., 2016) is required to avoid the risk of harassment. Precautionary research approaches are preferred and the assessment of disturbance levels should be conducted during the early conceptual stages of study design (Hodgson & Koh, 2016). Finally, knowledge gained from disturbance assessments will provide invaluable guidance for the regulation of recreational and commercial use of UAVs around wildlife.

6.4 Future Research

This thesis has provided and introduced a valuable background information to the use of UAV for behaviour study off bottlenose dolphins off GBI. It was the first to assess approaches to any marine mammal in New Zealand and the first to assess impact of drone itself on dolphin behaviour. With this, I conclude and strongly recommend for future research projects incorporate the use of a lightweight low altitude UAV to support and/or supplement the boat data collection and analysis. I believe that this novel tool can fill gaps and strength data without causing disruptions, or harassment of the animals. From management perspective, I believe that the UAV surveys can help with future implications and managements of the GBI.

However, careful consideration of how risks might influence population is necessary when choosing the UAV platform for field. Is recommended to have a precautionary approach and disturbance levels should be assessed during early stages of the study design, especially if the UAV need to be flown over the animals in low altitudes. Researchers have an obligation to evaluate their impacts on the target species to minimise any possible adverse effects that can may cause. Future research should further identify the threshold at which disturbance occurs (i.e. between 10 and 25 m) and also identify how this differs during different behavioural states other than resting. (Fettermann et al., 2018).

The size and type of the aircraft for future research should be taken in consideration to make sure it can be operated safely from the research vessel. In this case, where

operations were conducted from a small vessel (= 8.5m), lightweight vertical take-off and landing (VTOL) UAV is highly recommended. The VTOL provide great stability and it is highly manoeuvrable. They are easy to carry, easy to use, and can be launched and retrieved by hand.

Sensors are another factor that need to be taken in consideration prior the study, as the camera is the key component of a UAV and has to be selected carefully. It is important to have high quality image resolution, as well the presence of gimbal for reduce vibration effects and to improve image quality and clarity. Furthermore, the first person view (FPV) is essential, where the video camera is mounted on the UAV and video is transmitted in real live time to the pilot. This helps track the animals easily and always the pilot to feel as though they are on-board instead of looking at the aircraft.

For bottlenose dolphins off GBI, long term studies should be encouraged to continue in the area, and further investigation to the entire coastline of GBI should be undertaken and not only the western side. Future research should continue to collect data throughout the year and UAV platform should be incorporated to optimise field activities. Commercial tourism should not be allowed to target marine mammals in this region and public educational program and management measure should be implemented to ensure that bottlenose dolphins remain undisturbed by the growing number and diversity of anthropogenic presence in the bay, especially during the summer months.

In conclusion, hopefully this thesis can inspire future research and contribute to help refine future planning efforts and to inform decisions for future operational use of UAV around dolphins in New Zealand waters.

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Appendix 1: Copyright permission letter

Ticiana Fettermann de Oliveira
MScCandidate / +64 21 075 3427
New Zealand Institute of Applied Ecology /Auckland University of Technology

24/ November/ 2017

Thomas Allen Jefferson, Ph.D.

Dear Thomas Allen Jefferson,

My name is Ticiana Fettermann, I am a masters student at Institute of Applied Ecology, and am writing a thesis on Unmanned aerial vehicle (UAV) remote sensing of behaviour and habitat use of the nationally endangered bottlenose dolphin (*Tursiops truncatus*) off Great Barrier Island, New Zealand for *Master of Science*. A print copy of this thesis when completed will be deposited in the University Library, and a digital copy will also be made available online via the University's digital repository ScholarlyCommons@AUT.

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Distribution map of bottlenose dolphins on page 238.

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Yours sincerely,

Ticiana Fettermann

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Date: 24 November 2017

Appendix 2: Summary of UAV studies on Marine Mammal research relevant for this thesis.

Subject / Aim of the Study	Location / Specie	UAV Class/ Model	Source
Surveys of Manatees	Florida, USA / Manatees	LASE - FolBat	Jones, Pearlstine, and Percival (2006)
Collection of blow (exhaled breath condensate) of large whales and dolphins	Baja California, Mexico/ Cetacean (large whales and dolphins)	VTOL – Aquacopter	Acevedo-Whitehouse et al. (2010)
Surveys of Marine Mammals – Dugong and whales	Moreton Bay, Australia/ Dugongs and humpback whales	LALE - ScanEagle	Hodgson, Noad, Marsh, Lanyon, and Kniest (2010) Hodgson, Kelly, and Peel (2013) Hodgson et al. (2017)
Survey, abundance estimation and photogrammetry of Seals	Antarctica / Seals	VTOL - Quadcopter	Perryman, Goebel, Ash, LeRoi, and Gardner (2014) Goebel et al. (2015)
Photogrammetry – Body condition of Seals	Scotland / Harbour Seals	VTOL – Quadcopter and Hexacopter	Schick et al. (2014)
Photogrammetry – photo identification of Killer whales	Vancouver Island, Canada / Killer whales	VTOL – Hexacopter APH-22	Durban et al. (2015)
Photogrammetry – re-identification of Bowhead whales	Nuvatu, Canada / Bowhead whales	LASE – TD100-E	Koski et al. (2015)
Survey of Seals at Bearing Sea	Bering Sea / Seals	LALE - ScanEagle	Moreland, Cameron, Angliss, and Boveng (2015)
Survey and photogrammetry – photo identification and measurements of Seals	UK / Harbour Seals	VTOL - Quadcopter	Pomeroy et al. (2015)
Survey and photo-identification of Sea Lions	Alaska / Steller Sea lions	VTOL - Hexacopter	Sweeney et al. (2015)
Photogrammetry – body condition of Humpback whales	Exmouth Gulf, Australia / Humpback whales	VTOL – Quadcopter Splasdrone	Christiansen, Dujon, et al. (2016)
Photogrammetry - body condition of Blue Whales	Gul of Concorvado & Gulf of Ancud - Chile	VTOL – Hexacopter APH-22	Durban et al. (2016)
Survey (counts and age-class) of California Sea Lions	Espiritu Santo, Archipelago, Mexico / Sea Lions	VTOL – Quadcopter	Adame et al. (2017)
Photogrammetry – body condition of large whales	New Zealand's subantarctic Auckland Islands / southern right whales	VTOL – Quadcopter DJI Inspire 1 Pro (I1P) and Splashdrone & Hexacopter APH-22	Dawson et al. (2017)

[VTOL] Vertical Take-Off and Landing, [LALE] Low Altitude Long Endurance, [LASE] Low Altitude Short Endurance

Appendix 3: Initial sighting sheet for data collection.

2015/16/17 Great Barrier Bottlenose Dolphin UAV Research

Date _____ **Survey No** _____ **Encounter No**_____

Encounter Start Time _____ **Latitude & Longitude** _____

Finish Time_____ **Latitude & Longitude** _____

Weather Sunny Overcast Showers Rain Hail Fog **Cloud Cover**_____%

Beaufort 0 1 2 3 4 5 6 **Douglas Sea Scale** 0 1 2 3 4 5 6 7 8 9

Visibility Excellent Very good Good Fair Poor Unaccpt **Tide State**_____

Water depth _____m **SST** _____•C **No Vessel present** _____

Dolphins Data

Group size 1-5 5-10 10-15 15-20 20-25 25-30 35-50 >50

Dispersion tight mod loose sub-group

Group Composition Adults Juvenile Calves Neonate

Behavioral Data **State** Travelling Foraging Socializing Resting Milling

NOTES:

Appendix 4: Environmental parameters Guide Scale used in this study

List of Definitions used to record Environmental Parameteres
2015/16/17 Great Barrier Bottlenose Dolphin UAV Research

Environmental parameter		Definition
WEATHER	Sunny	Predominantly sunny, no/few clouds
	Ovecast	Cloud/ grey, no visible sun
	Showers	Light rain and limited visibility
	Rain	Heavy/ continuous rain and dark skies
	Hail	Hail showers/ storms
	Fog	Fog conditions/poor visibilty
CLOUD COVER	**%**	Determine the % of how much of the sky is covered by Clouds. 100% the entire sky is covered, 0% there isnt clouds.
BEAUFORT Sea State (force)	0	Flat, smooth and mirror-like, calm wind (0-1kt)
	1	Light ripple and light airs (1-3ktns)
	2	Small wavelets, not breaking, light breeze (4-6ktns)
	3	Large wavelets, scattered whitecaps gentle breeze (7-10ktns)
	4	Small waves, frequent whitecaps, moderate breeze (11- 16ktns)
	5	Moderate waves with many whitecaps (17-21ktns)
	6	Long waves, all whitecaps, some spray, strong breeze (22-27ktns)
DOUGLAS Sea Scale (height waves and swell)	0	No wave, calm glassy, no swell
	1	0-0.1m wave, calm rippled, very low swell (short and low wave)
	2	0.1-0.5m wave, smooth, low swell (long and low wave)
	3	0.5-1.25m wave, slight, light swell (short and moderate wave)
	4	1.25-2.5m wave, moderate, moderate swell (average moderate wave)
	5	2.5-4m wave, rough, moderate rough swell (long moderate wave)
	6	4-6m wave, very rough, rough swell (short heavy wave)
VISIBILITY	Excellent	Surface water calm with no sun glare, witohut any environmental factors impeding ability to sight the animals (visibility >5km)
	Very Good	Slight uneven conditions, or chop on water, but still very easy to sight the animals (visibility >5km)
	Good	Light chop with scattered whitecaps, swell (2-4m) or some glare, still can see the animals fairly easily
	Fair	Choppy waves, frequent whitecaps, low-light conditions (overcast, dawn, dusk), swell 4-6m, some animals likely to be missed
	Poor	Numerous whitecaps, sun glare or haze in >50% of study area, or swell >6m, rainy, foggy, very hard to sight animals, many likely to be missed

Appendix 5: Focal group follow datasheet used in this study

Scan Sampling Data Collection sheet - 2015/16/17 Great Barrier Bottlenose Dolphin UAV Research

Date:_____ Time of Launch_____ Encounter#_____ Flight#_____ Altitude_____m Pilot_____

Latitude & Longitude: _____ Weather:_____ Cloud Coverage %:_____ UAV Model_____

Beaufort:_____ Douglas Sea State:_____ Water Visibility:_____m Group Composition: adults juvenile calves neonate

S= social **M** =milling
F=foraging **R**=resting
T=travelling
SG=sub grouped
T=tight **M**=moderate
L=loose

Time	Main Behaviour	Group Dispersion	Secondary Behaviour	%	Group Direction Changes	Side Float	Tail Slap	Spy Hop	Breach	Chin Slap	Notes
1	S M F R T	SG T M L	S M F R T								
2	S M F R T	SG T M L	S M F R T								
3	S M F R T	SG T M L	S M F R T								
4	S M F R T	SG T M L	S M F R T								
5	S M F R T	SG T M L	S M F R T								
6	S M F R T	SG T M L	S M F R T								
7	S M F R T	SG T M L	S M F R T								
8	S M F R T	SG T M L	S M F R T								
9	S M F R T	SG T M L	S M F R T								
10	S M F R T	SG T M L	S M F R T								
11	S M F R T	SG T M L	S M F R T								
12	S M F R T	SG T M L	S M F R T								
13	S M F R T	SG T M L	S M F R T								
14	S M F R T	SG T M L	S M F R T								
15	S M F R T	SG T M L	S M F R T								
16	S M F R T	SG T M L	S M F R T								
17	S M F R T	SG T M L	S M F R T								
18	S M F R T	SG T M L	S M F R T								
19	S M F R T	SG T M L	S M F R T								
20	S M F R T	SG T M L	S M F R T								
21	S M F R T	SG T M L	S M F R T								
22	S M F R T	SG T M L	S M F R T								
23	S M F R T	SG T M L	S M F R T								
24	S M F R T	SG T M L	S M F R T								
25	S M F R T	SG T M L	S M F R T								
26	S M F R T	SG T M L	S M F R T								
27	S M F R T	SG T M L	S M F R T								
28	S M F R T	SG T M L	S M F R T								
29	S M F R T	SG T M L	S M F R T								
30	S M F R T	SG T M L	S M F R T								

Appendix 6: Marine mammal research permit 499890-MAR issued by New Zealand Department of Conservation (DOC)

Department of Conservation
Te Papa Atawhai

49989-MAR

MARINE MAMMALS PROTECTION ACT 1978

PERMIT TO TAKE MARINE MAMMALS

PURSUANT to sections 5, 6 and 7 of the Marine Mammals Protection Act 1978:

Auckland University of Technology
("the Permittee")

is **HEREBY AUTHORISED** within New Zealand Fisheries Waters at the following locations:

1. Great Barrier Island

To undertake research using an unmanned aerial vehicle (UAV) on the following species:

1. Bottlenose dolphin (*Tursiops truncatus*)
2. Common dolphin (*Delphinus delphis*)
3. Bryde's whale (*Balaenoptera edeni/brydei sp.)*
4. Killer whale (*Orcinus orca)*
5. Short-finned pilot whale (*Globicephala macrorhynchus*)
6. Southern right whale (*Eubalaena australis*)
7. Humpback whale (*Megaptera novaeangliae*)
8. False killer whale (*Pseudorca crassidens*)

Using the following methods for the purpose of aerial behaviour surveys:

1. Approach the species listed above closer than 150m above sea level
2. Approach the species listed above up to 20m above sea level

This Permit is **SUBJECT TO** the following conditions:

1. The permittee must undertake all work in accordance with the research project description set out in the application attached in **Schedule 1**, except where otherwise stipulated in the following permit conditions.

2. At least one of the following listed participants, nominee as per Condition 3 or a marine mammal officer (under the Marine Mammals Protection Act 1978), must be present at all times during activity undertaken under the authority of this permit:
   a. **Barbara Bollard Breen**
   b. **Ticiana Fettermann de Oliveira**
   c. **Lorenzo Fiori**

3. The permittee may use a nominee under the authority of this permit only where the nominee:
   a. Has been trained in the use of the correct operating technique;
   b. Is aware of the conditions of this permit, and;
   c. Has provided evidence of his/her relevant experience to the Director-General[1] and on the basis of this has been approved prior to the work occurring.

4. Any nominee must carry a letter from the Director-General and the Permittee when conducting work under the authority of this permit to identify themselves as an approved nominee as per clause 3 of this permit.

[1] **Director-General** includes a Department of Conservation Manager with delegated authority from the nearest Department of Conservation Office

5. If a marine mammal or group of marine mammals shows obvious signs of alarm, agitation or disturbance from a UAV, altitude is to be increased. If reactions persist after the altitude is increased contact is to be abandoned for the remainder of that day.

6. The permittee is responsible for the health and safety of persons involved in the work carried out under the authority of this permit and shall indemnify the Minister and the Crown against all and any action, claim injury damage and loss, which may arise in any manner whatsoever from the issue of this permit.

7. The permittee must inform the Director-General of the intention to operate under the authority of this permit. Where possible at least twenty (20) working days notice is to be given prior to any work being undertaken.

8. Prior to any work commencing under the authority of this permit the Director-General may require that the permittee contact commercial marine mammal tourism operators to inform them of the research intentions and/or develop an operational protocol to minimise any conflict between parties.

9. Any costs associated with required consultation beyond Department of Conservation staff time and travel will be borne by the permittee.

10. The Director-General may nominate an observer and require that this observer be present while activities conducted under the authority of this permit occur.

11. The permittee must suspend and review the sampling being undertaken should unexpected adverse reactions from a marine mammal be detected.

12. The permittee must conduct activities under the permit in such a way as to minimise disturbance to marine mammals as much as possible, without compromising the intended outcomes of the research as outlined in the permit application in **Schedule 1**.

13. The permittee must provide to the Director-General an annual report of all activities carried out under the authority of this permit, at the end of each financial year (30th June), using the standard annual report form. In addition to this the permittee must keep a full log of the reactions of the animals sampled, included pre-sampling and post-sampling behaviour. This log will be submitted as an appendix to the aforementioned annual report.

14. The permittee must provide a copy of any data sets, research findings, reports and published papers resulting from the research undertaken under the authority of this permit, to the Director-General within one year of having completed the particular research project or within a year from the expiry date of this permit, whichever is sooner. The Director-General retains authority to use the data set for scientific purposes, in consultation with the permittee.

15. The permittee must send results to the Director-General as soon as possible if the results have an implication for the management of individuals and/or populations. Such results would be used for management purposes and not for publication in scientific journals.

16. This permit does not allow the permittee to undertake commercial marine mammal tour operations or to charge scientists or other persons to work on projects relating to the permit.

Term of this Permit

17. This permit may be suspended, amended, restricted or revoked at any time.

18. This permit is not transferable and is valid from the date of signing up to and including 31 July 2017, unless sooner suspended, amended, restricted or revoked.

Dated at Auckland this 21 day of June 2016

.....
Nicholas Turoa

Acting Operations Manager
Great Barrier Island
acting under delegated authority from the Minister of Conservation and the Director-General of Conservation

Appendix 7: Extension of the Marine mammal research permit 499890-MAR issued by New Zealand Department of Conservation (DOC)

Department of Conservation
Te Papa Atawhai

49989-MAR

MARINE MAMMALS PROTECTION ACT 1978

PERMIT TO TAKE MARINE MAMMALS

PURSUANT to sections 5, 6 and 7 of the Marine Mammals Protection Act 1978:

Auckland University of Technology
("the Permittee")

is **HEREBY AUTHORISED** within New Zealand Fisheries Waters at the following locations:

1. Great Barrier Island

To undertake research using an unmanned aerial vehicle (UAV) on the following species:

1. Bottlenose dolphin (*Tursiops truncatus*)
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3. Bryde's whale (*Balaenoptera edeni/brydei sp.)*
4. Killer whale (*Orcinus orca)*
5. Short-finned pilot whale (*Globicephala macrorhynchus*)
6. Southern right whale (*Eubalaena australis*)
7. Humpback whale (*Megaptera novaeangliae*)
8. False killer whale (*Pseudorca crassidens*)

Using the following methods for the purpose of aerial behaviour surveys:

1. Approach the species listed above closer than 150m above sea level

This Permit is **SUBJECT TO** the following conditions:

1. The permittee must undertake all work in accordance with the research project description set out in the application attached in **Schedule 1**, except where otherwise stipulated in the following permit conditions.

2. The permittee must conduct activities under the permit in such a way as to minimise disturbance to marine mammals as much as possible, without compromising the intended outcomes of the research as outlined in the permit application in **Schedule 1**.

3. At least one of the following listed participants, nominee as per condition 4 or a marine mammal officer (under the Marine Mammals Protection Act 1978), must be present at all times during activity undertaken under the authority of this permit:
   a. **Barbara Bollard Breen**
   b. **Ticiana Fettermann de Oliveira**
   c. **Lorenzo Fiori**

4. The permittee may use a nominee under the authority of this permit only where the nominee:
   a. Has been trained in the use of the correct operating technique;
   b. Is aware of the conditions of this permit, and;
   c. Has provided evidence of his/her relevant experience to the Director-General[1] and on the basis of this has been approved prior to the work occurring.

[1] **Director-General** includes a Department of Conservation Manager with delegated authority from the nearest Department of Conservation Office

5. Any nominee must carry a letter from the Director-General and the permittee when conducting work under the authority of this permit to identify themselves as an approved nominee as per condition 4 of this permit.

6. This permit authorises the use of a UAV to 20m above sea level

7. If a marine mammal or group of marine mammals shows obvious signs of alarm, agitation or disturbance from a UAV, altitude is to be increased. If reactions persist after the altitude is increased contact is to be abandoned for the remainder of that day.

8. The permittee is responsible for the health and safety of persons involved in the work carried out under the authority of this permit and shall indemnify the Minister and the Crown against all and any action, claim injury damage and loss, which may arise in any manner whatsoever from the issue of this permit.

9. The permittee must inform the Director-General of the intention to operate under the authority of this permit. Where possible at least twenty (20) working days notice is to be given prior to any work being undertaken.

10. Prior to any work commencing under the authority of this permit the Director-General may require that the permittee contact commercial marine mammal tourism operators to inform them of the research intentions and/or develop an operational protocol to minimise any conflict between parties.

11. Any costs associated with required consultation beyond Department of Conservation staff time and travel will be borne by the permittee.

12. The Director-General may nominate an observer and require that this observer be present while activities conducted under the authority of this permit occur.

13. The permittee must provide to the Director-General an annual report of all activities carried out under the authority of this permit, at the end of each financial year (30th June), using the standard annual report form. In addition to this the permittee must keep a full log of the reactions of the animals sampled, included pre-sampling and post-sampling behaviour. This log will be submitted as an appendix to the aforementioned annual report.

14. The permittee must provide a copy of any data sets, research findings, reports and published papers resulting from the research undertaken under the authority of this permit, to the Director-General within one year of having completed the particular research project or within a year from the expiry date of this permit, whichever is sooner. The Director-General retains authority to use the data set for scientific purposes, in consultation with the permittee.

15. The permittee must send results to the Director-General as soon as possible if the results have an implication for the management of individuals and/or populations. Such results would be used for management purposes and not for publication in scientific journals.

16. This permit does not allow the permittee to undertake commercial marine mammal tour operations or to charge scientists or other persons to work on projects relating to the permit.

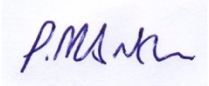
Term of this Permit

17. This permit may be suspended, amended, restricted or revoked at any time.

18. This permit is not transferable and is valid from the date of signing up to and including 31 December 2017, unless sooner suspended, amended, restricted or revoked.

19. This permit replaces the permit dated 21 June 2016.

Dated at Auckland this 24th day of May 2017



Paul McArthur
Operations Manager
Great Barrier
acting under delegated authority from the Minister of Conservation and the Director-General of Conservation