

# **New Zealand fur seal (*Arctocephalus forsteri*) pup behaviour and an assessment of novel non-invasive population survey methods.**

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A thesis submitted in partial fulfilment of the requirements for the  
Degree of Master of Biological Sciences in the University of Canterbury.

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## Abstract

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Recent earthquakes in the Kaikoura region have devastated the East coast of New Zealand, causing landslides and sea bed rise which has completely altered the landscape of the Ohau Point seal colony and highlighted the immediate application of this research. The aim of this study was to quantify New Zealand fur seal pup (*Arctocephalus forsteri*) behaviour and to develop a non-invasive population sampling method, using Unmanned Aerial Vehicle and thermal imaging technology. I found that ontogenetic change in behaviour occurs in NZ fur seal pups over the first five months of life. In particular, grooming and mock fighting behaviours decreased overtime, whilst swimming and resting remained constant. Additionally, UAV population survey methods were found to cause minor disturbance, whilst detecting 27% of the pups in the colony, in a fraction of the time required to conduct traditional methods. Thermal imagery further enhanced these results, yielding greater detection than photographic images during the cooler periods of the day (morning and evening). This thesis will discuss the initial and immediate applications of this technology for pinniped surveys. It is rare that an ecological study has immediate application such as this one. The results from this study can provide baseline data for future behavioural analysis, as well as, provides a heightened appreciation for pup 'play' habitat. Given the recent earthquakes, the potential is great for immediate application of UAV and thermal imaging for remote sampling of coastal marine species.

## Chapter One – Introduction

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Coastal marine mammals, in particular Pinnipedia, are vulnerable to human interaction and are in many ways intimately linked to human's changeable social practices and infrastructure, as well as fiscal variability and anthropogenic change (Bester & Van Jaarsveld, 1997; Erlandson & Rick, 2008). This intimate linkage of mammal population dynamics with human-based changeability means that these populations are in a perpetual state of change with respect to being labelled as in need of conservation or in need of management due to interactions with primary industries, and sometimes both simultaneously (Wickens, 1995).

The challenge for scientists is to keep pace with the changes in coastal marine mammal populations; to understand the vulnerabilities and needs of these populations (Ceballos, Ehrlich, Soberón, Salazar, & Fay, 2005). Generally, the science can be compartmentalised into behavioural studies and population measures, both of which are currently lacking in data and as yet don't adequately address the vulnerability or need for expansion of many populations (Harcourt, 2001). Many studies recognise the most vulnerable stage of population growth to be the production and development of young (pups) (Bester, 2014; Bradshaw, Davis, Lalas, & Harcourt, 2000), but there are few studies that provide insight to ontogenetic development of behaviours and growth parameters, nor an effective non-invasive method of monitoring this vulnerable stage over time (Baylis *et al.*, 2005; Bowen, 1991a). It is only through understanding and developing such studies that science can aim to keep pace with the conservation and management aims of a changeable human population.

### Background to Pinniped Populations

In the last 50 years, pinniped populations worldwide have experienced significant changes in abundance. In the Southern Hemisphere, The New Zealand fur seal (*Arctocephalus forsteri*) and Antarctic fur seal (*Arctocephalus gazella*) populations have increased, whilst

southern elephant seal (*Mirounga leonina*) populations have suffered declines (Boyd, Arnbom, & Fedak, 1994; Goldsworthy, Bulman, He, Larcome, & Littan, 2003; Guinet, Jouventin, & Weimerskirch, 1999; Lallas & Bradshaw, 2001; Smith, 2005; Smith, 1989; Trillmich, 1990; Trites & Donnelly, 2003). In the Northern Hemisphere, the Steller sea lion (*Eumetopias jubatus*), northern fur seal (*Callorhinus ursinus*) and harbour seal (*Phoca vitulina richardst*) populations decreased in the Gulf of Alaska and Bering Sea but increased between California and southeast Alaska (Bigg, 1988; Ferrero & Brix, 2000; Gerber & Hilborn, 2001; Olesiuk, Bigg, & Ellis, 1990; Pitcher, 1990; Trites, 1992). These declines have been attributed to predation, disease and nutritional stress, higher pup mortality, altered blood chemistry and changes in behaviour, but these causes are hard to scientifically validate (Bigg, 1988; Ferrero & Brix, 2000; Gerber & Hilborn, 2001; Olesiuk *et al.*, 1990; Pitcher, 1990; Trites, 1992). Similarly, the Pacific walrus (*Odobenus rosmarus divergens*) suffered declines in the 1950's followed by rapid population growth until they declined again in 1989. This later population decline has been attributed to high harvest pressure from 1980 onwards as they were overharvested for commercial purposes (Fay, Eberhardt, Kelly, Burns, & Quakenbush, 1997). The sealing industry originated around 1610, as Dutch sailors hunted African seals (*Arctocephalus pusillus*) for both oil and hides. It was not until the late 1700s that it became a commercial enterprise and in 1755 American whaling ships started harvesting oil from elephant seals living on the Falkland Islands (Busch, 1987). Sealing reached Australia in 1788 when the Port Jackson settlement was established, and it extended to New Zealand in the late 1800 to early 1900s (Smith, 2002). Whilst most sealing has been banned for conservation reasons, seals are still hunted in Canada, Namibia, Greenland, Iceland, Norway and Russia for commercial purposes. They are also hunted in Finland and Sweden for reducing fisheries competition, but these industries have come under great scrutiny by veterinary experts due to inhumane practices in slaughters. For example, The Canadian seal hunt is the world's largest commercial slaughter of marine mammals, during which seals are inhumanely clubbed (Butterworth & Richardson, 2013; Wegge, 2013). The hunting of marine mammals is becoming less common practice worldwide, however, recovery from such exploitation warrants further study, more frequent surveys of pup productivity and in some cases the establishment of conservation practices.

## Pup Importance

Annual pup productivity acts as an important indicator for the size, health and growth of a pinniped (seal, sea lion and walrus) population (Berkson & DeMaster, 1985; Lalas & Harcourt, 1995; Shaughnessy, Gales, Dennis, & Goldsworthy, 1994; Taylor, Barton, Wilson, Thomas, & Karl, 1995). Pup productivity and health can also be used as an indirect indicator of colony status, such as maternal investment and resource availability, and the overall health of the colony, among others. Population decline was identified through pup productivity in the Steller sea lions, *Eumatopias jubatus* (Sease & Gudmundson, 2002), and the Hawaiian monk seals, *Monachus schauinslandi* (Baker & Johanos, 2004), and has been used to estimate the sustainable level of fisheries bycatch for the New Zealand sea lions, *Phocarctos hookeri* (Breen & Kim, 2006; Breen, Hilborn, Maunder, & Kim, 2003) and the post-sealing recolonisation stage for *A. forsteri* (Bradshaw, Lalas, & Thompson, 2000; Lalas & Bradshaw, 2001).

Pinniped pups are highly vulnerable during their first year due to aggressive mating behaviour of males and during periods of low food availability. The NZ fur seal (*Arctocephalus forsteri*) has a relatively high first year mortality and this critical period is the optimum time to assess the colony. A study conducted on *A. forsteri* pups showed a mortality rate of 20% in the first 50 days and 40% in the first 300 days, and 70% of the first 50-day mortality was attributed to starvation and physical damage (Mattlin, 1978). Alternative evidences attributes pup mortality to stillbirth, suffocation, road kill and drowning (Baird, 2011; Boren, Morrissey, & Gemmell, 2008). Another example of the harsh nature of a pinniped colony is shown in the Antarctic fur seal *Arctocephalus gazelle* from South Georgia, USA, where pup mortality rate was recorded as 17-31%. The mortality was attributed to high population density; starvation, as mothers were unable to form bonds with their pups due to bull disturbance; and to injury when pups were trampled by bulls, accidentally bitten by their mothers during birth, or when attempting to feed from other females than their mother (Doidge, Croxall, & Baker, 1984). Similar dangers exist for New Zealand fur seal pups when exposed to human disturbance which can cause stampedes (Boren, 2005).

A more contentious and prominent example is New Zealand's only endemic and, threatened, pinniped *Phocarctos hookeri*. The strong decline in pup production from 1988-2009 for *P. hookeri*, has been directly linked to low numbers of females returning to breeding areas (Robertson & Chilvers, 2011), with associated hypotheses including disease, predation, dispersal/migration, climate change and anthropogenic impacts (Robertson & Chilvers, 2011). Robertson and Chilvers (2011) in particular conclude that anthropogenic impacts from direct competition with fisheries for resources and fisheries related bi-catch (arrow squid fisheries), as well as nutrient stress and decreased reproductive output have the most substantial effect. However, recent evidence has not supported this conclusion, as arrow squid only comprises 20% of NZ sea lions diet and survival and breeding rates were low during high years of arrow squid (Meynier, Mackenzie, Duignan, Chilvers, & Morel, 2009). Regardless of interpretation, nutritional stress is evident in NZ sea lions which may be caused by competition with other fisheries such as Hoki and Red Cod. It is important to consider that fish stocks are affected by other impacts such as climate and therefore, it is dangerous to assume that fisheries are the sole cause of decline.

New Zealand government agencies, The Department of Conservation (DOC) and Ministry for Primary Industries (MPI), have collaborated in designing a sea lion threat management plan which takes into account anthropogenic causes of sea lion mortality, such as; mortality in fishing gear, indirect effects of fishing, subsistence hunting and poaching, pollution and marine debris and habitat alteration. Natural causes such as climate variation, predation, disease and parasites, toxic bloom events, genetic diversity and behaviour have also been incorporated into this threat management plan. Conservation efforts such as the MPI and DOC sea lion management plan such as these could benefit from novel, cost effective methods of population sampling over large areas in place of expensive and time consuming physical searching. New technology such as UAV's (Unmanned Aerial Vehicles) and thermal imagery provide the opportunity to develop a non-invasive sampling method for measuring pup productivity, health and condition through aerial photography and video.



## Traditional Pup Counting Methods

Pup productivity is traditionally measured using mark recapture techniques (Boren, 2005; Gales, Haberley, & Collins, 2000; Lallas & Harcourt, 1995), where at least half of the colonies pups are marked in some way. There are multiple methods of tagging, some for long term and others for short term studies. Long term methods include hot and cold branding, coded tags, scarring (toe or fin clipping) and external numbered tags (attached to ears, flippers etc.) (Merrick, Loughlin, Antonelis, & Hill, 1994; Merrick, Calkins, & Loughlin, 1996; Murray & Fuller, 2000). Toe clipping and iron branding have been shown to decrease the lifespan of the animals due to the exposure of tissue to infection (Pavone & Boonstra, 1985). A study on the ringed seal (*Phoca hispida*) stated that the branding did not cause any visible stress; however, the authors did not present any data regarding the seals stress levels to support this claim (Smith, 1973). Short term methods for identification include hair dye, paint and electronic devices such as radio/satellite tags (Walker, Trites, Haulena, & Weary, 2012). These methods could alter seal pup behaviour by reduced swimming speeds, hindering movement, or by increasing pup mortality through infection (Pavone & Boonstra, 1985). All of these methods require catching the pups, which can induce fear and anxiety, especially if they are experiencing pain (Mellor, Beausoleil, & Stafford, 2004). A study where Weddell seals (*Leptonychotes weddellii*) were captured showed that they suffered high stress, indicated by increased cortisol levels, which could be dampened by administering diazepam (Harcourt, Turner, Hall, Waas, & Hindell, 2010). However, most studies do not use drugs to calm fur seals as it is considered an unnecessary expense and potentially dangerous; for example, an anaesthetised seal may attempt to swim away and could drown. The following day, a thorough walk-through count is conducted and the number of marked and unmarked pups is recorded. Pup productivity measures only require very short term marking techniques, such as the application of non-toxic paint or a small haircut to the forehead (< a week), as they are only needed for identifying previously counted pups. Marking pups requires restraint, and can be easily paired with simple and fast morphometric measures (Mass, girth and length). These morphometric measures allow the additional analysis of colony health, maternal investment and food source abundance. Hands on techniques such as these also allow the measure of pup mortality by recording the number of dead pups

found during the count. Whilst these methods provide information necessary for assessing colony health, growth and expansion, they are invasive and are best conducted when pups are mobile; however, this also happens to be during their period of greatest mortality.

## UAV Surveying

Unmanned Aerial Vehicle aerial samples are increasingly used in monitoring of animals for surveying purposes. For example, UAV surveys have been used to observe Alaskan seals, as well as elephants (*Loxodonta africana*), black headed gull (*Chroicocephalus ridibundus*) alligators (*Alligator mississippiensis*), bison (*Bison bison*), deer (*Cervus elaphus*) and orangutan (*Pongo abelii*) (Francesc *et al.*, 2012; Israel, 2011b; Jones IV, Pearlstine, & Percival, 2006; Koh & Wich, 2012; N.O.A.A, 2011; Vermeulen, Lejeune, Lisein, Sawadogo, & Bouché, 2013; Wilkinson, Dewitt, Watts, Mohamed, & Burgess, 2009). Aerial photography from aeroplanes has also been used extensively in the past to observe seals and walrus from hard to reach areas, but for fur seal monitoring, this would not be cost effective or accurate, due to the natural camouflage of wet fur seals on the rocks and the high flight height (Hills & Gilbert, 1994; Kirkwood *et al.*, 2010).

Aerial surveys and photography have successfully been used to visualise seal colonies, but were unable to distinguish pups from the habitat (Baker, Jensz, Cawthorn, & Cunningham, 2010), making them ineffective for monitoring. Elephant surveys have also been conducted successfully in Burkina Faso (West Africa) from a height of 100 m without disturbance, and limited only by a flight time of 45 minutes (Vermeulen *et al.*, 2013). However, calves were harder to count than the adults, reinforcing the issue observed with pup identification. This inability to accurately detect pups reduces the efficacy of the survey as important measures are lost, such as individual size, colour and habitat associations (Baker *et al.*, 2010). Recent advancements in technology and the subsequent improvements in photographic equipment may provide the opportunity for better results in the future. In addition, a more mobile UAV, such as a quad-copter may reduce the inflexible flight path associated with fixed-wing technology. A quad copter is able to fly low and take close-up, high resolution photos,

potentially nullifying the pup identification issue, however, it may cause disturbance to the seals and is unable to fly in windy conditions. Aerial surveys are not limited to photographic imagery, recent development in small thermal imagers have allowed the use of infrared for aerial detection of various surface temperatures.

## **Thermal Imagery**

Thermal or infrared imagery is a rapidly growing industry. Initially confined to just military operations, price drops and adaptations for industrial purposes have resulted in affordable technology that can be applicable in various industries (such as detecting heat loss in homes) and activities (such as hunting pig or deer) (Cilulko, Janiszewski, Bogdaszewski, & Szczygielska, 2013). Thermal imagery technology consists of a detector, a thermal imager and a real time recording device. Radiant energy is converted into an electrical signal by the detector and then processed into a visible image. Infrared cameras are able to detect animals undetectable to the naked eye by detecting the thermal gradient between their surface temperature and their environment (*see chapter four*). Thermal imagery was first utilized for the detection of large mammals by (Addison, 1972; Croon, McCullough, Olson Jr, & Queal, 1968; Graves, Bellis, & Knuth, 1972; McCullough, Olson Jr, & Queal, 1969). Croon *et al.* (1968) and McCullough *et al.* (1969), first used thermal imagery to successfully detect white tailed deer (*Odocoileus virginianus*) in complex forest (Croon *et al.*, 1968; Graves *et al.*, 1972). Thermal imagery has also been used with some success to detect marine mammal populations in open environments (Burn, Webber, & Udevitz, 2006; Duck, Thompson, & Cunningham, 2003). Another study on California big horn sheep used an aeroplane mounted, forward looking infrared radiometer (FLIR) and developed a sightability model with an 89% probability of detection (Bernatas & Nelson, 2004). Since then thermal imagery has been used to successfully detect the diel migration of gray whales (*Eschrichtius robustus*) (Perryman, Donahue, Laake, & Martin, 1999).

Thermal technology may provide the answer to some of the difficulties faced when counting land-based marine mammals that can be found over a wide range of habitats, such as seals camouflaged against or hidden between rocks, or New Zealand sea lions hidden deep in the

bush of Stewart Island. Ohau Point seal colony, located 27 km north of Kaikoura, has a very unique profile that makes it ideal for the testing of UAV and thermal technology. At around 4-5 months of age, NZ fur seal pups will explore the native bush behind the colony, migrating up a freshwater stream to play in a waterfall. This is the only occurrence I am aware of in the world and makes it the ideal habitat to test both thermal and UAV technology over the same species (*Arctocephalus forsteri*) on the complex rocky shore and beneath the dense forest environment.

### **New Zealand Fur Seal – A History**

The New Zealand fur seal (*Arctocephalus forsteri*) lives along the rocky shore of New Zealand and its sub-Antarctic islands, generally south of 40° S (Figure 1.1). *Arctocephalus forsteri* also inhabits the southern and western coasts of Australia and its offshore Macquarie Island, which hosts a substantial breeding colony (Crawley & Wilson, 1976; Shaughnessy, 1999a). During the 1700's to late 1800's the New Zealand fur seal was exploited for meat, oil and skin/fur by early Polynesians and colonizing Europeans in New Zealand and Australia (Lento, Haddon, Chambers, & Baker, 1997; Wynen *et al.*, 2000). Skin cargo details show at least 1,367,000, fur seal skins departing South Australia, New Zealand and their sub-Antarctic islands between 1948 and 1972 (Ling, 1999a). These cargoes contained the fur of *Arctocephalus* spp., as well as two species of sea lion: the Australian sea lion (*Neophoca cinerea*) and the New Zealand sea lion (*Phocarctos hookeri*)(Ling, 1999a).



**Figure 1.1.** Locations of the main New Zealand fur seal rookeries, based on information at <http://www.nabis.govt.nz>. Nelson-Marlborough colonies include those at Stephens Island, Separation Point, and Tonga Island. Sub-Antarctic colonies include Antipodes Islands, Bounty Islands, Campbell Island, Enderby Island, and Snares Islands. Kaikoura colonies include those at Barney's Rock, Lynch's Reef, and Ohau Point (Baird, 2011). Figure reproduced with permission from Baird.

Both Australian (*Arctocephalus pusillus doriferus*) and New Zealand fur seal (*Arctocephalus forsteri*) are considered to be in a state of recolonisation following the introduction of

protective legislature (Goldsworthy *et al.*, 2003; Lalas & Bradshaw, 2001; Smith, 2005; Smith, 1989). It was in 1978 that the NZ fur seal received full protection from poaching and the New Zealand Marine Mammal Protection Act (NZMMPA) was created (Cawthorn, 1985; Mattlin, 1987). The population of *A. forsteri* in New Zealand was last systematically estimated between 30,000 and 50,000 (Wilson, 1981) and most recently was estimated at 200,000 (Harcourt, 2001). The population of *A. forsteri* in Australia was most recently estimated at 40,000 (Gales *et al.*, 2000). Since the NZMMPA was passed, the New Zealand fur seal has recolonized previous areas that were locally extinct and has become well established (Wilson, 1981; Wynen *et al.*, 2000). Recovery has not been as successful for the Australian fur seal (*A. pusillus doriferus*) compared to other fur seal populations (Arnould, Boyd, & Warneke, 2003). Hunting of the Bass Strait population (containing both New Zealand and Australian *Arctocephalus* spp.) continued to supply local markets until 1923 (Warneke & Shaughnessy, 1985). Fisheries, both coastal and offshore, developed substantially during the 1900s, which led to the shooting of seals at land and sea to reduce fisheries competition (Ling, 1999b; Warneke & Shaughnessy, 1985). It was in 1975 that all seals in Australian, Commonwealth and State waters gained protection under the National Parks and Wildlife Conservation Act (Shaughnessy, 1999b). Today, seals are hunted in Canada, Namibia, Greenland, Iceland, Norway and Russia for commercial purposes. They are also hunted in Finland and Sweden for reducing fisheries competition, but these industries have come under great scrutiny by veterinary experts due to inhumane practices in slaughters. For example, The Canadian seal hunt is the world's largest commercial slaughter of marine mammals, during which seals are inhumanely clubbed (Butterworth & Richardson, 2013; Wegge, 2013). Whilst the hunting of marine mammals is becoming less common practice worldwide, recovery from such exploitation warrants more frequent population surveys and in some cases, the establishment of conservation practices.

## ***Arctocephalus forsteri* Life-cycle**

*Arctocephalus forsteri* breeds annually and usually gives birth to a single pup after a 10-month gestation period (Crawley & Wilson, 1976). During the breeding season, seals come ashore to mate after a prolonged period feeding at sea (haul-out). This period begins with the early arrival of the males around October-November as they establish territories and is followed by the breeding female's arrival in late November (Crawley & Wilson, 1976). The peak pupping time is in mid-December shortly after the arrival of the females. The females look after their pups for the next 10 days and have usually obtained another mate before leaving on their first foraging trip. They leave on 3-4 day foraging trips to return and stay for 2-4 days to suckle their pups (Crawley & Wilson, 1976). The foraging trips get longer as the pups grow. The pups also get more mobile and form aggregations while their mothers are foraging. The females will spend most of their time hauled up at the rookery (minus small foraging trips) for approximately 10 months (August-September)(Crawley & Wilson, 1976). After the mating period the males disperse to feed or to find haul-out areas (Crawley & Wilson, 1976). The dispersal of highly competitive breeding males is followed by an influx of sub-adult males from neighbouring areas. At about 10 months old pups are weaned, although timing varies, likely due to environmental conditions: 238-269 days old on Tonga Island, 300 days on Open Bay Island and 337 days in Kaikoura, whilst in Australia the median weaning time is 285 days (Boren, 2005). Prior to pup weaning, pups will spend most of their time swimming, resting, mock-fighting in groups around rock pools and in caves (McNab & Crawley, 1975). Understanding pup development and behaviour is crucial as pups are used for measuring population growth and provide comprehensive information about the colony.

## **New Zealand Fur Seal Pup Behaviour**

Play is characteristic of juvenile mammals and though play behaviour is heavily studied, the function of play still remains elusive (Fagen & Fagen, 1981; Nunes *et al.*, 2004). There are countless theories for why animals play, the main three being practice theory, social bonding and cognitive training (Caro, 1995; Palagi, Cordoni, & Borgognini Tarli, 2004; Spinka, Newberry, & Bekoff, 2001). Practice theory is the idea that play acts as a way of developing strength, motor skills, and finesse that will improve important adult behaviours such as fighting. Social bonding refers to the development of communication skills and increased social cohesion that may occur from playing with juvenile conspecifics. Cognitive training theory suggests that play may have hidden neurological benefits, such as coping with stress. There are many theories posed and argued in current literature, but even the most prominent ones are still yet to be validated by sufficient research (Harcourt, 1991; Palagi *et al.*, 2004; Sharpe, 2005).

Pup behaviour has been particularly well-studied during the period when they are in the presence of their mothers, covering social recognition, mother/pup post birth interactions and pup/bull interactions (Bowen, 1991b; Goldsworthy & Shaughnessy, 1994; Insley, Phillips, & Charrier, 2003; McNab & Crawley, 1975; Phillips, 2003). However, the ontogeny of behaviour in New Zealand fur seals is yet to be quantitatively studied and little is known about their behavioural development and the effect the environment has on pup behaviour.

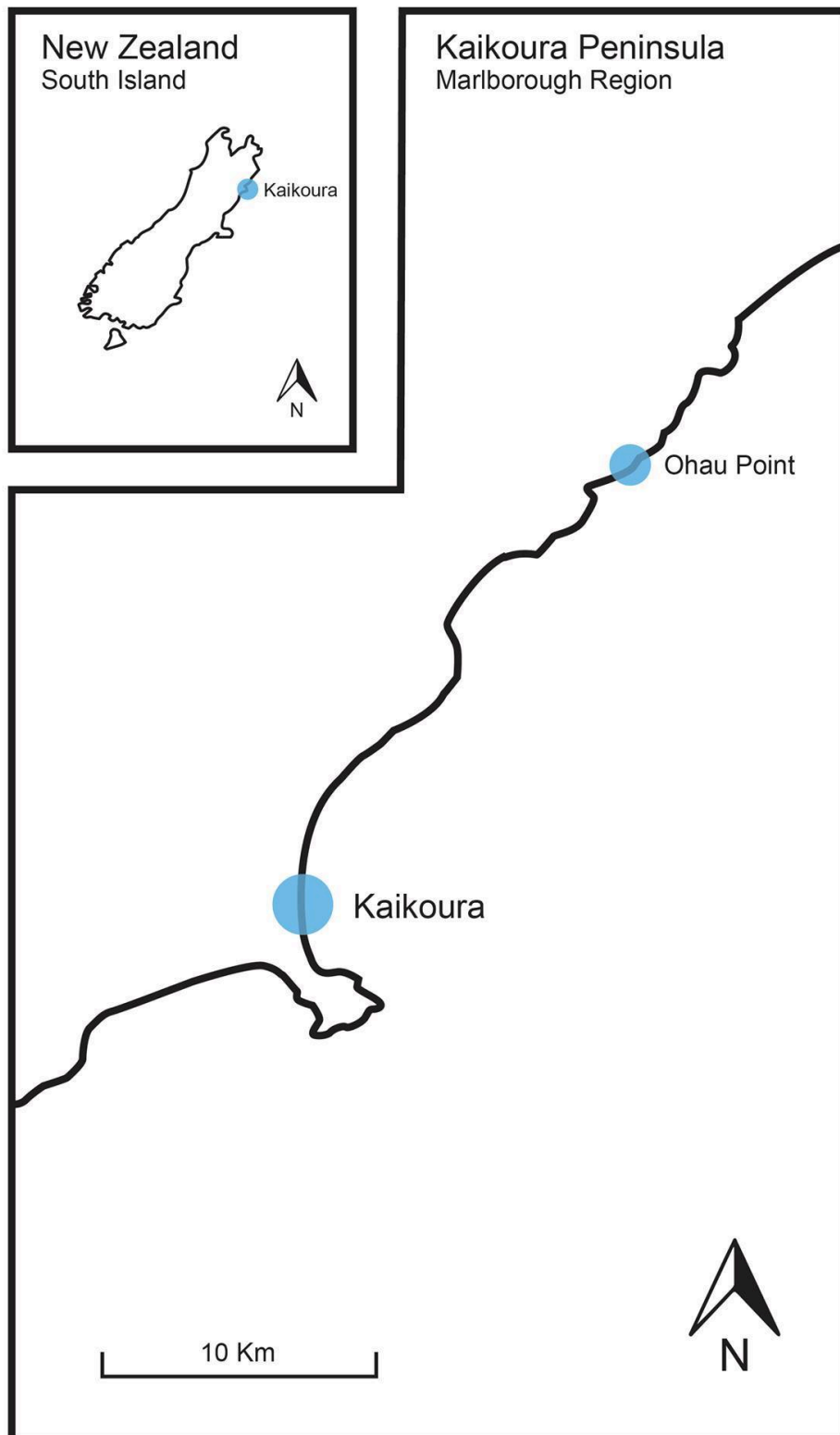
New Zealand fur seal pup behaviour was documented in 1975 by McNab and Crawley, where they observed mother-pup behaviour immediately after birth till they became more independent of their mothers (McNab & Crawley, 1975). Pups form groups “pods” in caves or pools on hot days and at the highest point in stormy weather. Pups also exhibited adult-like behaviours such as grooming and mock-fighting coordination, albeit conducted in an uncoordinated fashion. The function of play for NZ fur seal pups may then support the practice theory, however, previous studies on mock-fighting have had mixed interpretations



of benefits (Caro, 1995; Smith, 1982). The development of behaviour in New Zealand fur seals is crucial for aiding in ecotourism management and the development of novel sampling methods in the future.

### **Ohau Point Colony – Study Population**

In 1958, the peak recorded population estimate for *Arctocephalus forsteri* in Kaikoura, reached a reported population of 200-300 on the peninsula in summer and 800 in winter (Stirling, 1970; Street, 1964). *A. forsteri* formed colonies in three main sites on the coast, Kaikoura Peninsula, Ohau Point and Barney's Rock and these populations have become well established and are growing steadily (Figure 1.2) (Boren, 2005). Another population that is slowly growing is in Horseshoe Bay, Banks peninsula, which was recolonized in 1970 and has become a breeding colony (Wilson, 1981). The Department of Conservation also reported pupping at Te Oka Bay in 1990 (Boren, Muller, & Gemmell, 2006).



**Figure 1.2.** Ohau Point, New Zealand fur seal breeding colony, with Kaikoura for reference (Map created by Lon van Elk).

## Tourism & Sanctuary Implementation

Seal colonies are important to the ecosystem and tourism industry of New Zealand, in particular the seal pup nursery of Ohau point, Kaikoura. The Ohau point seal colony is now under legislative protection as a sanctuary (Kaikōura Marine Management Act 2014) and it is illegal for anyone to enter without a permit. In addition, the Marine Mammal Protection Act 1972, amended 1994, protects seals from harmful interactions with humans. The Department of Conservation (DoC) has introduced signage to the Ohau Point Seal Sanctuary, however, signage has been shown previously to be an ineffective means of regulation in Kaikōura (Acevedo-Gutierrez, Acevedo, Belonovich, & Boren, 2011). This sanctuary covers all of Ohau Point, except for Ohau stream, which has become a famous tourism site where the pups are located during their mothers foraging trips.

Marine mammal ecotourism is becoming a large industry and it usually presents a challenging ecosystem-tourism management paradox. For example, the management of the bottlenose dolphin (*Tursiops* spp.) in Doubtful Sound, New Zealand is problematic, as tour operators are increasing in numbers and having potentially negative impact on the dolphins behaviour, but the tourism rise is good for the local economy (Lusseau & Higham, 2004). Bottlenose dolphins in Shark Bay, Australia have declined since more than one tourism boat is active and this decline has been attributed to displacement of sensitive individuals and to noise pollution (Bejder *et al.*, 2006). Tourism boats also negatively affect killer whales (*Orcinus orca*), as tourism has been considered to be the main cause of abundance declines in the region as orca reduce the predictability of their swimming path and females increase the angle between their dives (Bejder *et al.*, 2006; Williams, Trites, & Bain, 2002). *Arctocephalus forsteri*, Florida manatee (*Trichechus manatus latirostris*) and the Australian sea lion (*Neophoca cinerea*) are also becoming highly commercialised with increasing numbers of visitations and officially monitored seal and manatee swims (Cowling, Kirkwood, Boren, & Scarpaci, 2014; Lovasz, Croft, & Banks, 2008; Sorice, Shafer, & Ditton, 2006). Ecotourism may have some short and long term overall effects; however, if well designed procedures are created and enforced, ecotourism has the potential to safeguard biodiversity and ecosystem function, through tourism funded conservation (Gössling, 1999).

## Thesis Aims

The aim of this study was to assess the behaviour, health, growth and population numbers of the New Zealand fur seal, *Arctocephalus forsteri*, pups living on the Kaikoura coast. This includes a critical analysis of the current methodology for measuring pup productivity, as well as, the use of UAV technology and trial of thermal imagery. It is well known, the currently favoured methods, while necessary, can cause damage and distress to the seals. The lack of non-invasive population sampling methods inspired me to develop a non-invasive, efficient method for seal population observation using UAV technology. UAV's are able to fly above the colony and take bird's eye view photographs, which using image analysis software, can be used to count the seals and measure their physiological characteristics. UAV's are becoming more frequently used and viable due to their decreasing costs and have been successfully used to survey Alaskan ice seals (N.O.A.A, 2011). The data obtained from this section of the study will be compared with past studies to assess pup productivity and condition at slowly growing higher densities (Boren *et al.*, 2006; Boren, 2001, 2005). I will also be conducting a behavioural observation study of seal pup behaviour at Ohau Point. This information will improve our understanding of how pup behaviour develops during their critical period. This study may also aid in ecotourism management and regulation within the local region, where both seal and human populations are expanding (Boren, 2005). The development of this methodology could provide worldwide conservation and commercial sealing organizations, with a potentially highly efficient method of surveying seal pup productivity, over difficult terrain, as it is a reliable proxy of seal colony health and could be used when determining the optimum sustainable population level Vermeulen *et al.* (2013) required in effective sealing management.

The aims of this research were to:

1. Conduct a quantitative assessment of the ontogeny of New Zealand fur seal pup behaviour.
2. Test the efficacy of UAV photography based population surveys of pinnipeds, whilst measuring the disturbance.
3. Test the efficacy of aerial and ground based thermal imagery for pinniped detection on a rocky shore and forest environment.

## Chapter Two - Ontogeny of Fur Seal Pup Behaviour

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### Introduction

Play behaviour is characteristic of juvenile mammals and its pervasiveness may suggest play is a crucial part of their development (Nunes *et al.*, 2004). Burghardt (2005) defines play as being: i. incompletely functional in the context in which it is expressed (this does not mean 'purposeless'); ii. spontaneous and voluntary (done for its own sake); iii. differing from other behaviour in being exaggerated, modified, or occurring precociously; iv. occurring repeatedly but not stereotypic; v. observed in healthy subjects and initiated in a stress-free condition, however, there are exceptions, as play can both cause stress and reduce it.

Despite years of research, the function of play behaviour in non-human animals is still poorly understood (Fagen & Fagen, 1981). There have been multiple hypotheses proposed for the function of play, the majority of which can be broadly categorised as follows: 1) Practice theory: physical training (cardiovascular fitness and musculoskeletal development) or the development/refinement of motor skills (species-specific survival skills) (Caro, 1995); 2) Social bonding theory: to facilitate social cohesion, reduce tension and develop communication skills (Palagi *et al.*, 2004); 3) Cognitive training theory: to promote the development of cognitive skills (Spinka *et al.*, 2001).

Practice theory suggests that the purpose of play is to develop adult fighting or predatory skills and to improve strength and endurance (Caro, 1995). If the function of play is to practice catching or escaping predators, one would expect play to be more common in juveniles than adults and to increase in effectiveness with age through rehearsal (Smith, 1982). Immature chimpanzees exhibit a higher frequency of play than adults, suggesting that play may function as a safe mechanism to conduct personal self-assessment, whilst developing physicality and motor skills (Palagi *et al.*, 2004). Similarly, cheetah cub success at catching each other increases with age, but their ability to catch prey and remain concealed during 'play stalks' does not improve (Caro, 1995). These results suggest that certain motor skills associated with play may improve with 'rehearsal', whilst benefits of others may be non-existent, or just harder to detect.

Social bonding summarises the benefits of social cohesion, reduced tension and development of communication skills obtained from play behaviour (Palagi *et al.*, 2004). Rats kept in isolation from

birth are either more aggressive towards littermates than isolated rats given a daily hour of play-time, or run away from play initiated by a non-isolated littermate (Potegal & Einon, 1989). This response to isolation has been recorded in multiple primate species (including humans) and suggests that play fighting may be crucial in play initiation and communication of intent (Bekoff & Allen, 1998; Pellis & Pellis, 1991; Saunders, Sayer, & Goodale, 1999). Additionally, work on captive chimpanzees suggests that playing and social grooming may act as a method of conflict management (Dunbar & Grooming, 1996). This theory is supported by multiple studies that state that play and social grooming are important in maintaining social cohesion or hierarchy (Palagi *et al.*, 2004); however, a recent study on meerkats concluded that social play did not enhance social cohesion (Sharpe, 2005).

Cognitive training theory identifies the less obvious neurological benefits of play behaviour. This can be understood as improving stress coping ability when faced with unexpected situations (Spinka *et al.*, 2001), possibly by activating the same 'fight or flight' neurochemical pathway as stress (Siviy, 1998). This hypothesis posits that when a juvenile animal plays and experiences stress, its brain changes and it becomes less sensitive to stress hormones, ultimately enabling animals to recover more quickly from a stress-inducing experience and potentially preparing animals for the stress-filled world of adulthood.

There are numerous complications in understanding the function of play. For example, while research has determined the costs and the short term benefits of play (Sharpe, Clutton-Brock, Brotherton, Cameron, & Cherry, 2002), the long term or physiological benefits have proven elusive (Byers & Walker, 1995; Martin & Caro, 1985; Sharpe & Cherry, 2003). Additionally, analysing the behaviour of juvenile animals in relation to their later reproductive success or survival is very difficult (Bekoff & Byers, 1985; Gomendio, 1988), and the functions of play are likely to be affected by variables such as age, sex, dominance relationships, context, habitat and maternal investment (Breuggeman, 1978; Cameron, Linklater, Stafford, & Minot, 2008; Poirier, Bellisari, & Haines, 1978). The function of play may therefore not have a single benefit for all, but has evolved for numerous reasons in multiple species (Coppinger & Smith, 1990), as has been suggested for seals (Arnold & Trillmich, 1985; Bowen, 1991a; Harcourt, 1991).

Burghardt's surplus resource theory (Burghardt, 1988) suggests that play is more likely to occur in species that exhibit long periods of immaturity and parental care. Pinnipeds are born on land with their eyes open and are active within minutes of birth, establishing attraction calls with their mothers and suckling (Lawson & Renouf, 1985; Newby, 1973). Gestation period varies within

pinnipeds; being generally shorter in otariids (~7 – 8 months) and longer in phocids (~11 months) and odobenids (~15 – 16 months) (Riedmann, 1990). Whilst phocids attend their pup for the entirety of their lactation, after the first week, otariids recurringly leave their pups for feeding bouts of up to five days after the first week (Costa & Gentry, 1986). This difference in maternal attendance has led to the relatively non-social behaviour of phocid pups, which tend to only associate with their mother, and, conversely, the highly social behaviour of many otariid neonates (Kovacs & Lavigne, 1986; Rasa, 1971; Reiter, Stinson, & Le Boeuf, 1978; Sullivan, 1982). Weaning time varies within species, but is generally longer in phocids, the shortest period being in the hooded seal, *Cystophora cristata*, at ~8 – 12 days, and the longest being six weeks in the Mediterranean monk seal, *Monachus monachus* (Stirling, 1983). In otariids, the shortest weaning period is approximately four weeks in the Northern fur seal, *Callorhinus ursinus* and the longest period recorded is 1 – 3 years in the Cape fur seal, *Arctocephalus pusillus*, with the average usually occurring between 10 – 12 months, such as in the New Zealand fur seal, (*Arctocephalus forsteri*) (Stirling, 1983). Most phocids are anti-social or do not play with other pups, possibly due to their shorter period of maternal investment, as most pups fast for ~2 weeks after being quickly weaned (Riedman, 1990) and the extremely high costs of allosucking (milk stealing), which can cause fatalities in pups from starvation (Riedman, 1990). Play behaviour may be more prominent in otariid species than phocids, as they are less developed when born, require longer lactation periods, and do not develop independent foraging until much later than phocids. However, among phocids, grey seal neonates, *Halichoerus grypus*, profusely exhibit play in large haul-out groups (Burghardt, 1988; Surviliene, Ruksenas, & Pomeroy, 2016).

Otariid pups will gain mobility within a month of birth and gather in rock pools during their mother's absence (during feeding trips) (Stirling, 1971). This clustering occurs in the Northern fur seal (Bartholomew, 1952), Antarctic fur seal (Bonner, 1968), Steller's sea lion (Gentry, 1970; Gentry, 1975), subantarctic fur seal (*Arctocephalus tropicalis*) (Bester, 1977) and the New Zealand fur seal (McNab & Crawley, 1975; Stirling, 1971). Until weaned, pups will spend the majority of their time playing (mock fighting and swimming), which suggests that despite being energetically taxing and potentially dangerous (Harcourt, 1991), it is a highly beneficial behaviour (Gentry, 1970; Gentry, 1975; Stirling, 1983). The function of otariid play behaviour initially seems to consist of practicing and developing agonistic adult male behaviours and swimming skills (Gentry, 1974; Harcourt *et al.*, 2010). However, there may be multiple benefits of play for otariids (Arnold & Trillmich, 1985; Gentry, 1974; Harcourt, 1991). The highly social nature of otariid neonates makes them an ideal species for the study of play behaviour. Here, I investigate the behaviour (including play) of young



New Zealand fur seal (*Arctocephalus forsteri*) pups, which are well known for their inquisitive and playful behaviours.

New Zealand fur seal populations are rapidly increasing in New Zealand and Australia and are now considered a potential threat to the fishing industry due to fisheries competition (Boren, 2010). Kaikoura, on the East coast of New Zealand, hosts the largest breeding colony of New Zealand fur seals in New Zealand (Boren *et al.*, 2006). This colony is unique, because at approximately 5 – 6 months of age, the pups leave the rocky shore and migrate up a freshwater stream (Ohau Stream) to play. The period prior to this migration (0 – 5 months), is considered the critical period for New Zealand fur seal pup survival (Boren *et al.*, 2006; Mattlin, 1978). Pup mortality during this period has been attributed to nutritional stress, pup abandonment by mothers, and territorial male aggression (Mattlin, 1978). Once mobile, New Zealand fur seals will begin to develop their swimming skills in rock pools but remain averse to moving water until weaned, at around a year of age (McNab & Crawley, 1975). Until weaned, pups spend the majority of their non-feeding time resting, swimming and ‘play fighting’ (Gentry, 1975; Gentry, 1974; Stirling, 1971). Play fighting is defined as activity that does not incur injury, does not involve fighting for a resource, is characterised by frequent role reversals between attacker and defender, and chasing following a fight does not prevent further affiliation (Pellis & Pellis, 2016). Play fighting behaviour in otariids is characteristically like adult male fighting; however, unlike adult fur seals, pups are less coordinated, play fighting is not ritualised, and pups appear to show restraint and do not ‘aim’ to injure their opponent (Gentry, 1974; Harcourt *et al.*, 2010; Stirling, 1971). The prominence of these energetically expensive behaviours during such a critical period for survival inspired this study, the purpose of which was to conduct a quantitative behavioural analysis of New Zealand fur seal pup behaviour in Kaikoura in relation to environmental variables. The primary objective was to identify ontogenetic change in the behaviour of New Zealand fur seal pups, in particular during their first five months of life.

## **Methods**

### **Ohau Point Seal Colony**

I observed New Zealand fur seal pups (*Arctocephalus forsteri*) from January to May 2015, at the Ohau Point seal colony, located 28 km North of Kaikoura, on the East coast of the South Island of New Zealand. The Ohau Point fur seal colony is situated alongside State Highway 1 and spans

approximately 1 km of the coastline. I conducted all observations at the Ohau Point on the 'North Platform', at the northern most third of the Ohau Point seal sanctuary (Boren, 2005). North Platform is characterized by large flat platforms, clusters of large boulders and rocks, small caves, crevices and a reef of bull kelp (*Durvillea* spp.) which buffered wave action. I chose North Platform because it was the ideal site for pup behavioural observations as it could be viewed from a high vantage point with a wide field of view of a large flat platform, has multiple tidal and non-tidal rock pools, had minimal disturbance by tourists, and allowed non-disruptive monitoring of a high number of pups. I observed a total of four pools; two of which (A-pool and Fence-pool) were always present, with the other two present and observed during low tide (Tri-pool and Twin-pool). I sat upon a vantage point atop an 8 m high concrete wall, from which three of the four rock pools were observed. These four rock pools ranged in size, tidal zone and shape, and the availability of these for sampling relied on tidal height and pup occupancy. Pups were considered to be occupying a pool if they were < 2 m from the pools' edge.

Pups in this colony were born from November 26<sup>th</sup>, 2015 to December 29<sup>th</sup>, 2015, with the majority of pups born within a two-week period (median pupping date of 16<sup>th</sup> December), such that month of study correlates well with pup age throughout the colony (Boren, 2005). Observations began in January, when most pups were approximately 18-20 days old and had become mobile (Crawley & Warneke, 1979).

## **Sampling Methods**

Videography of behavioural data was captured using a tripod mounted Panasonic HC-V550M™ video camera. I sampled three days/week for a period of five months (January-May), and the sampling days were chosen using a random number generator. To comprehensively observe seal pup behaviour, I conducted three, one-hour sampling sessions at 7 am, 12 pm and 6 pm. I shifted the 6 pm sampling time to 5 pm during daylight savings due to the decrease of natural light and visibility earlier in the day.

I used instantaneous scan sampling for this study (Altmann, 1974), where a single, or group, of pups in or around a rock pool were filmed for an entire sampling session. I framed the video to the centre of a pool and included approximately 2 m of the area surrounding the pool. At each sampling time I chose the rock pool randomly from those occupied by pups and tidally available. If the pups vacated

the pool within the first 30 min for more than 10 min, I ended the sampling session and I chose another occupied pool to begin the sampling session from the start. Rock temperature was measured using an Onset HOBO™ Data Logger pendant setup, attached to the end of a fishing rod. The pendant was then cast from the vantage point into the study area prior to behavioural video recording. The pendant was protected by a cone-shaped case made from hard plastic mesh and a small parachute to slow the fall. The pendant recorded temperature every 10 s and the mean temperature was calculated from these data. Due to malfunction of the pendant, 12/184 sampling times were lost. Apart from rock temperature, I visually estimated and recorded abiotic factors prior to each session (and, if a dramatic change occurred, during the session). The abiotic factors I recorded were cloud cover (%), tidal phase (high, mid and low), wind strength (very high, high, medium, low, none) and wave action (very high, high, medium, low, none). The latter three variables of ordinal data were converted into a numerical scale for analysis. I used the Metservice tidal chart to determine tidal phase (<http://www.metservice.com/marine-surf/tides/kaikoura>).

I observed all video and scored the frequency of behaviours exhibited using VLC™ video player and at two min intervals recorded the behaviour of each pup as one of four behaviours:

### **Non-play behaviours**

- 1) Resting: lying down with eyes closed or sitting motionless.
- 2) Grooming: scratching fur with flippers and biting at flippers or fur.

### **Play behaviours**

- 3) Swimming: swimming, floating, chasing other pups in water, jumping out of water.
- 4) Mock fighting: biting, growling, lunging or wrestling with other pups (Cassini, Szteren, & Fernández-Juricic, 2004).

### **Lost data, Issues and Resolutions**

On January 1<sup>st</sup>-3<sup>rd</sup>, I caught 120 pups and recorded the morphometric data (60 males and 60 females) which were then tagged with a non-invasive fabric tag that was glued to their fur using a fast setting, two-part epoxy glue. Tags were made of sun-stabilized shade cloth marked with an exterior grade paint pen (numbered 1 – 120 ). I conducted pre-trials to test the sturdiness of the tags, the paint used to label them and the effect of salt water on the paint; however, the tags were

insufficient for long term studies, as only a single tag with its number legible was sighted after a month. Therefore, tags could not be used for identification of behaviours between individuals.

I stored all video data on a new Seagate 4 TB hard drive. Unfortunately, this hard-drive malfunctioned and resulted in loss of random segments of video files. Some of the data were recorded to a back-up, but following a file name change, automatic back-ups ceased. The majority of these videos were successfully analysed, in a few cases frames were frozen and these data points had to be shifted from the two-minute interval sampling mark to within  $\pm 15$  s and, in some cases, 20 min segments of video were lost completely. Additionally, I was unable to conduct sampling on the evening of February 11<sup>th</sup> due to road closure.

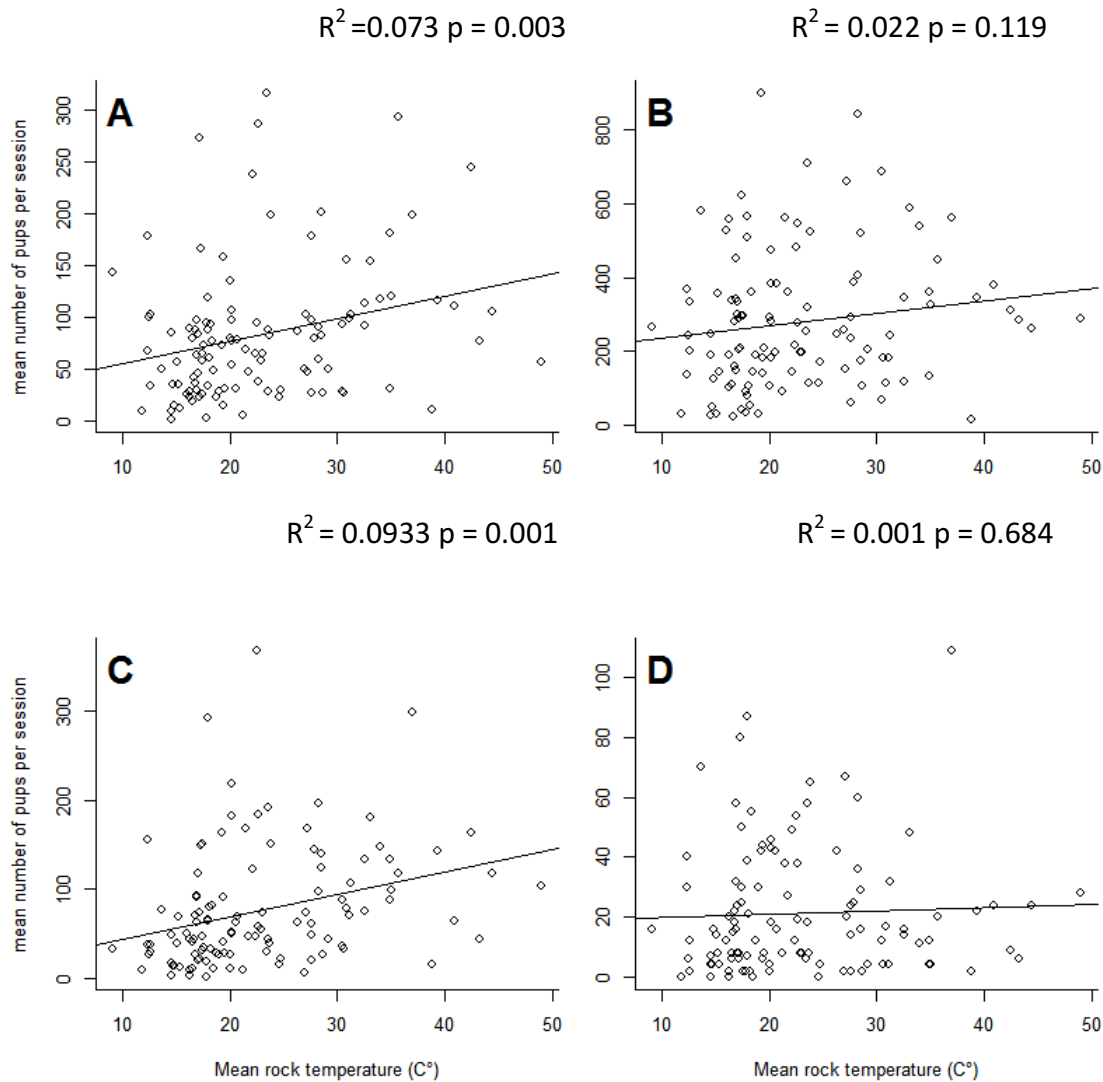
## **Statistical Analysis**

All available data collected from January to May were used for statistical analysis using the Adonis package for the statistical program R version 3.0.3 (R Development Core Team, 2015). All behaviours were initially analysed together as the data were expressed as proportions and therefore were non-independent (an animal not performing one behaviour was invariably performing another). Two primary analyses tested 1) the relationship between the relative frequency of behaviours and time during each month of the study period, and 2) the effect of environmental variables on the relative frequency of behaviours. Normal Q-Q, residuals vs. fitted, scale-location and residuals vs. leverage plots were used to test for normality. As the dataset was not normally distributed, data were analysed using PERMANOVA to account for the multivariate nature of the data, using a Chi-squared matrix to account for proportional data. To determine whether there was a significant change in the proportion of behaviour from the beginning of their critical period and the end, t-tests with unequal variance were conducted for the proportion of behaviour in January to April (Figure 3.3). May was excluded from the latter analysis due to low sample sizes.

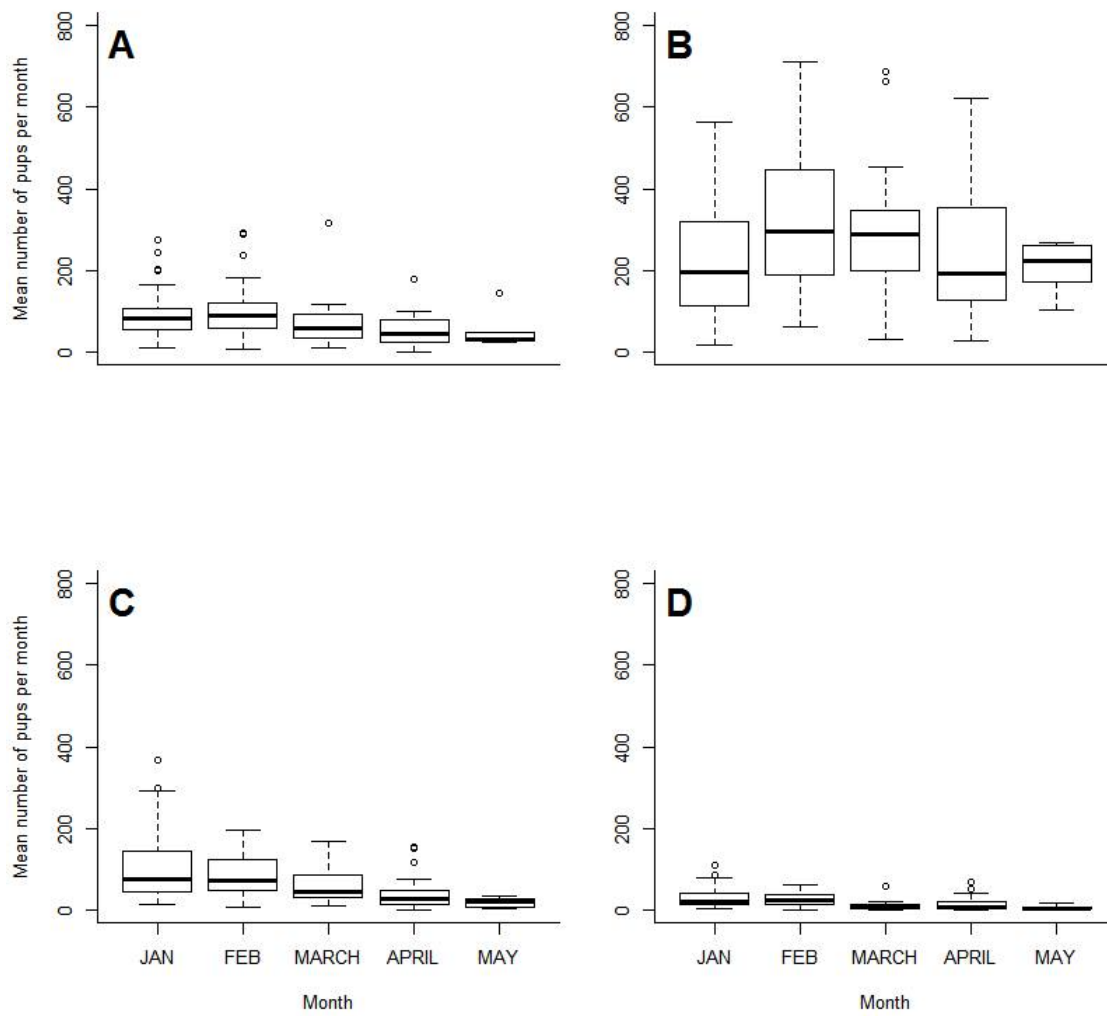
## **Results**

Rock temperature had a significant effect on the overall proportion of seal pup behaviour ( $F_{(1, 111)} = 4.101$ ,  $p = 0.006$ ; Figure 2.1). In particular, there was a significant increase in resting and grooming, but no significant effect on swimming, or fighting (Figure 2.1). There was no significant effect of time

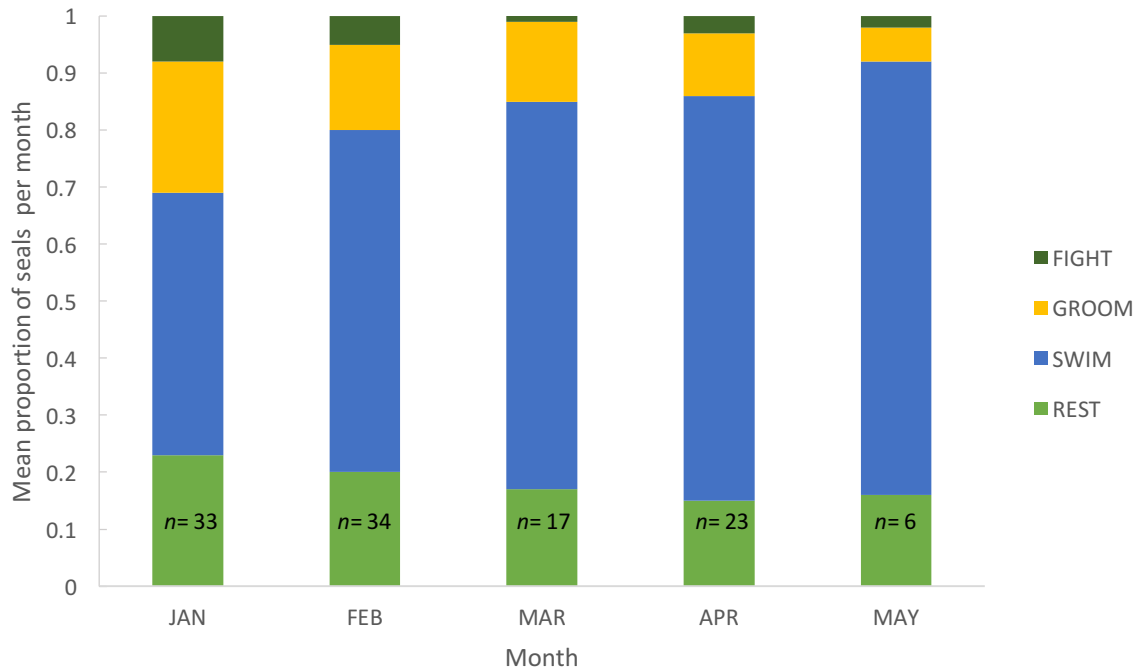
of day, rock pool, tide, cloud cover, wind strength or wave action on overall pup behaviour. Additionally, I found that the overall proportion of pup behaviour changed significantly from January to May ( $F_{(4, 108)} = 2.966$ ,  $p = 0.004$ ; Figure 2.2). There was a significant increase in proportion of swimming ( $t_{(46)} = -6.161$ ,  $p = <0.001$ ), and a significant decrease in grooming ( $t_{(53)} = 6.659$ ,  $p = <0.001$ ), resting ( $t_{(48)} = 2.442$ ,  $p = <0.05$ ) and fighting ( $t_{(45)} = 3.707$ ,  $p = <0.001$ ), from January to April (Figure 2.3).



**Figure 2.1.** The mean number of New Zealand fur seal pups displaying resting (A), swimming (B), grooming (C), fighting (D) behaviours per hour long sampling period versus mean rock temperature (C°). Note the scales on the y-axis vary.



**Figure 2.2.** The median number of New Zealand fur seal pups displaying resting (A), swimming (B), grooming (C), fighting (D) behaviours over 5 months following their birth.



**Figure 2.3.** Mean proportion of seal behaviours per month, over 5 months following birth near Kaikoura, New Zealand, 2015.

## Discussion

### Rock Temperature

Rock temperature had a significant effect on pup behaviour during the first five months of their life. Swimming was expected to increase with increasing rock temperature, as pinnipeds swim during high temperatures to cool down (Beentjes, 2006). I found a visible increase in swimming with increasing rock temperature ( $^{\circ}\text{C}$ ), however, it was statistically non-significant. Fur seals are well-adapted to cold environments, with two-layered fur providing insulation (Liwanag, Berta, Costa, Budge, & Williams, 2012). Otariids use their flippers and axilla for thermoregulation, holding them in the air to reduce cooling in cold water (Bartholomew & Wilke, 1956) and lying with body and limbs extended (sailing) to allow for the maximum surface area of heat loss to prevent overheating (Bartholomew & Wilke, 1956; Bonner, 1968). These seal pups were not observed sailing and require rock pools, shade or caves to cool down in high temperatures, as they do not swim in the ocean until nine months of age (Stirling, 1970). It is possible that the study area, which did not include caves or forest shading found further up shore (and up the Ohau stream), may have underestimated the time spent cooling down by pups.

Play fighting was expected to vary inversely with increasing temperature (to minimise heat production), but temperature appeared to have no effect on this behaviour. However, this may be an artefact of only sampling pup behaviour around rock pools as pups were observed competing for ideal resting spots or cool pools, which may suggest that mock fighting, in these instances, is not playful. Resting increased significantly with rock temperature, suggesting pups either minimise movement and/or swim to prevent overheating. Additionally, there was a significant positive association between grooming and rock temperature. The increase in grooming is likely driven by increasing swimming leading to exposure to potential marine parasites and salt irritation. This was indirectly corroborated by my observations of pups in Ohau stream above the shoreline which suggest that grooming occurs less frequently in a freshwater habitat and that they tend to groom when they have recently been in salt water (O. Gooday, pers. obs.). Nevertheless, it is worth bearing in mind that the relationship between behaviour and rock temperature may have been undetectable, as pup behaviour may depend on other unmeasured factors, such as maternal investment and nutrition (Cameron *et al.*, 2008).

### **Growth, Development & Play**

A significant effect of age (depicted by sampling month period) on pup behaviour was observed, which may suggest ontogenetic development. New Zealand fur seal pups begin swimming within two weeks of birth, but they have an aversion to open/disturbed water until up to one year of age (Stirling, 1971). The termination point of their aversion to water may coincide with their weaning time, when their mothers stop feeding them to initiate at-sea feeding (Stirling, 1970). I found a significant increase in the proportion of swimming behaviour over the first five months of the pup's life. This increase in swimming was coupled with a significant decrease in grooming and mock fighting. Pups may swim in pools to develop their bones / swimming muscles (Renouf & Lawson, 1986), or to relieve tension prior to feeding or their mothers' return (Palagi *et al.*, 2004). Swimming together in rock pools may also serve a social function, such as enhancing social cohesion. Pups form groups prior to migrating up the Ohau stream, as well as when they venture into the ocean for the first time. This suggests that social cohesion, or a form of safety in numbers may be affecting behaviour.



Pups were observed chasing each other, holding their breath underwater/diving, leaping out of the water/breaching, exploring the colony, and playing with objects (sticks or seaweed). Object play has been considered to promote motor development and cognitive skills in juveniles (Nahallage, Leca, & Huffman, 2016). I speculate that it may also function as practice for killing prey, as I frequently observed pups playing with seaweed in an aggressive fashion, waving it around violently and slapping it on the surface of water or rock, identical to a seal ripping apart a squid (pers. obs.). Caro (1995) observed a similar behaviour in cheetahs playing with their food; however, functionality was not shown to increase with rehearsal suggesting that practice theory for this behaviour may be unlikely. Chasing behaviours, breaching (swimming) and exploration of habitat (the rocky shore or migration up Ohau stream) may suggest that play also aids in the development of antipredator behaviours (Harcourt, 1991), honest communication of intent, i.e. understanding a conspecific's intent when chasing you (Dugatkin & Bekoff, 2003), as well as preparing for the unexpected (Spinka *et al.*, 2001).

Spinka *et al.* (2001) proposed the theory that play develops 'flexible kinematic and emotional responses' to situations where individuals experience a loss of control. This theory falls simultaneously within the practice (1) and cognitive theory (3) of play, in that individuals actively seek play in order to create unexpected situations through self-handicapping. Self-handicapping refers to the individual actively putting itself in a situation that is naturally disadvantageous and where play constantly shifts between well-controlled movements and loss of controlled movements. This practice of loss of control over locomotion, position or sensory input can prepare individuals to regain control quickly. The loss of control has also been hypothesised to encourage improvisation of behaviour through alteration of conventional movements (Spinka *et al.*, 2001). For example, seal pups may practice mock-fighting to practice stabilization, following a loss of balance. Similarly, when hunting prey or avoiding predators, seals will use the most efficient means of swimming to escape, but may experience potential collision with obstacles, visual disorientation or unusual predator/prey behaviour (Spinka *et al.*, 2001). A seal's ability to respond 'plastically' with less common movements could be life-saving. Thus, training for the unexpected could be a potential theory for the function of play in New Zealand fur seals.

Stirling (1971) observed pups play fighting, which he described as waving their heads with vigour but no finesse, from two months of age, stating also stated that they did not exhibit the posturing of adults until nine months old and that their biting was not directed at the neck like mature fighting males. This suggests that mock fighting is a playful behaviour, as it lacks the ritualistic aspects of

adult behaviour (Burghardt, 2005). Northern fur seal, Steller sea lion, South American fur seal and New Zealand fur seal pups fight similarly to adult males, albeit with less coordination and without ritualistic posturing, which may suggest that they learn from the males still defending territories late in the breeding season, or that the behaviour is innate (Farentinos, 1971; Harcourt, 1991; Peterson, 1968; Stirling, 1970; Vaz-Ferreira, 1956). I hypothesise that pups mock-fight when in the presence of territorial males still present in the colony, following the pup's development of mobility. This is partially supported by the gradual decrease in mock fighting observed in this study, aligning roughly with the departure of the remaining territorial males in February (Honeywell & Maher, 2016), however, mock fighting may reduce merely because other behaviours such as swimming become more prominent within the time budget. Unfortunately, the only way to disambiguate between time constraints or the effect of males in the colony is through exclusion of adult males from a colony prior to pup birth, which is impossible in a natural situation.

Mock fighting occurred frequently in situations where pups would 'defend' rocks or high vantage points around a rock pool. This behaviour of obtaining a higher vantage point (rock) is observed in territorial adult male fur seals, presumably to appear bigger during ritualistic stand-offs (Stirling, 1970). However, Burghardt (2005) states that play behaviour over competition for a resource cannot be deemed entirely playful. This 'competition' could be argued to be a form of 'self-handicapping', which is considered to consist of a 50:50 balance, of each individual swapping roles between being advantaged and disadvantaged (fighting from a lower position) whilst still maintaining a playful atmosphere (Altmann, 1962; Pellis, 2002). However, research on dyadic play in domesticated dogs, *Canis familiaris*, rejects current literatures 50:50 self-handicapping hypotheses, suggesting that rather than play being entirely separate from competition, hierarchical dominance was present, though without aggression (Bauer & Smuts, 2007). This suggests that it may serve as a method of practice, whether it is learned and carried into adulthood or innate is yet to be tested.

While male pups may be practicing fighting skills necessary for territoriality as an adult, they will not become sexually competitive until at least 5 – 6 years of age (Stirling, 1970), suggesting more immediate benefits of play may be occurring during the critical period of a pup's life (<5 months). Mock fighting may function as a method for 'self-assessment', where pups can safely determine the level of their motor skills and physicality (Biben, 1998). Alternatively, this could be attributed to cognitive training theory in which mock fighting or being chased (swimming) may mimic the neurochemical pathways of stress (Siviy, 1998) and induce a reduction in the stress response, which may ultimately improve recovery from life threatening experiences (Spinka *et al.*, 2001), although it

is evident that the stress response is a very important survival adaptation and reducing sensitivity to it could also create significant costs. Nevertheless, pups seem to play, regardless of the potential costs. I observed three instances of mothers 'evacuating' pools prior to the arrival of large waves that could sweep away the obviously playing pups. Among South American sea lions (*Arctocephalus australis*), Harcourt (1991) found that 86.4% of pups predated upon by taken by Southern sea lion (*Otaria byronia*) were attacked while they were playing. Harcourt (1991) highlighted the high allocation of their activity budget for playing, which, given its obvious costs in terms of predation, suggests that play must serve a substantial benefit to the pups.

While it is likely that the benefits of play to seal pups are numerous and may include aspects of cognitive training theory and social bonding, for both females and male pups, greater swimming/motor skills should enhance their antipredator responses, as swimming fast, diving and sharp turns are used to escape predators such as sharks, orca and sea lions (Fallows, Martin, & Hammerschlag, 2012). Additionally, it stands to reason that when pups must feed for themselves, the better swimmers they are, the greater their chance of survival. This, swimming play behaviour is likely to have been favoured by natural selection for pups to learn and develop valuable skills quickly, with reduced risk of drowning, predation, getting lost and without the need for constant parental supervision.

In order to better understand some of the roots of play behaviour in New Zealand fur seals, future studies could be improved by tracking individuals and recording whether body condition and sex affects behaviour as well as the recording of individual pups and their mother's milk allocation, which was beyond the scope of this study. These additional data would determine whether maternal investment has an impact on individual pup behaviour. With global temperatures rising rapidly, understanding how pinniped neonates respond to environmental variables will allow us to understand the development of behaviours that may affect pup survival and be important for success in adult life and will aid in conservation efforts in preparation for our warmer future. In light of recent declines and rising global temperatures, improving our understanding of the behaviour and ecology of pinniped neonates can facilitate development of more focussed conservation efforts, while inspiring the development of novel, less invasive population survey methods.

# Chapter Three - A bird's eye view: An assessment of non-invasive population estimates for New Zealand fur seal pups (*Arctocephalus forsteri*).

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## Introduction

Population sampling is an essential part of ecosystem conservation and relies heavily on the accuracy of counting methods for effective monitoring of endangered wildlife population numbers and determining the biodiversity of an ecosystem. Population sampling can also be used to obtain data such as health and condition, genetics, sex ratios, age classes and population distribution. A population survey should be standardized to ensure repeatability and be balanced in sampling effort (minimising time and labour) without losing data interpretability. It is crucial that the methodology is specific to the species being studied (life history) and the specific goals of the project.

On highly heterogeneous terrain or in remote areas, population sampling can be challenging. On the east coast of New Zealand, Kaikōura hosts the largest breeding colony of New Zealand fur seal (*Arctocephalus forsteri*). The colony, located at Ohau Point, is in a state of recolonization after the sealing period in the 1800's and has received protection from poaching under the New Zealand Marine Mammal Protection Act. *Arctocephalus forsteri* populations in Kaikōura are on the rise and this has resulted in the seals being viewed in a negative light by fisherman, as well as, increases in the road collisions with seals (Boren, 2010). As the population grows further north up the east coast of New Zealand, there is potential for conflict between conservation organizations and other stakeholders, for example the Ministry of Primary Industries (Bjørge *et al.*; Wang, McNaughton, Swimmer, & Fisheries, 2008). Whilst population sampling is essential for the monitoring of endangered species or potential pests, it is still crucial that it is conducted as ethically and efficiently as possible in order to reduce the potential negative impacts of human interference.

Despite the highly disruptive effects of entering a pinniped colony, mark-recapture is still the favoured and most accurate method of pinniped population estimation and pup productivity (Boren

*et al.*, 2006; Chilvers, Wilkinson, & Childerhouse, 2007; Shaughnessy, Troy, Kirkwood, & Nicholls, 2000). Mark-recapture sampling is accurate as it allows for the searching and counting of pups and adults that hide in caves and under rocks, as well as, the obtainment of morphometric data, sex and weight. Morphometric data enables the analysis of pup condition and health, and the determination of sex ratio as pups cannot be sexed visually. However, it is highly invasive and can be dangerous for both the seal and the researcher.

Stampedes can be a concern not only for the safety of the seals but also for accurate counting. Pups rush to get into hiding spaces under rocks making them hard to count, but worse, crushing and suffocating each other in the process. In some cases, they are forced under rocks fully submerged in water or being hit by waves. Pups hiding below the high tide mark are counted rapidly or ignored to reduce risk, as pups can drown. Sampling times can be optimized by avoiding the breeding season where males are highly territorial, aggressive and will challenge researchers. In a colony where pup numbers are on the rise, these problems seem like they will only become worse when using traditional mark-recapture methods. This highlights the dire need for a non-invasive sampling method for coastal marine mammals. One flaw from conducting population sampling remotely is the loss of physically obtained morphometric data, such as length, weight and girth. As previously mentioned, these measurements are crucial for measuring health of a pinniped colony (Boren *et al.*, 2006). Photographic morphometrics have been used to study seals, sea lions and whales with limited success (de Bruyn, Bester, Carlini, & Oosthuizen, 2009; Jaquet, 2006).

Aerial surveys and boat surveys have long been used to estimate populations of marine mammals at-sea (Conn *et al.*, 2014; Moreland, Cameron, Angliss, & Boveng, 2015). In contrast, the use and application of Unmanned Aerial Vehicles (UAV) for conservation is in its infancy, with exploratory studies increasing in number of the past 15 years. As drones become cheaper, more accessible and more reliable, concept testing and development for population surveys has rapidly evolved (Wich, 2015). Exploratory studies have included near-shore detection of large cetaceans such as bowhead whales (*Balaena mysticetus*), grey whales (*Eschrichtius robustus*), and humpback whales (*Megaptera novaengliae*) (Lyons, Koski, & Ireland, 2006; N.O.A.A, 2006; Pyper, 2007), as well as smaller cetaceans such as bottlenose dolphins (*Delphinidae Tursiops*) and humpback dolphins (*Delphinidae Sousa*) (Hodgson, Noad, Marsh, Lanyon, & Kniest, 2010). These studies suggest that UAVs are currently capable of detecting small and large species that are near to or breaching the water's surface. However, unlike manned aircraft, UAVs are more susceptible to harsh weather such as wind

and rain than manned aircraft, and have limited flight range, restricting their use to calm days in near-shore waters. The benefits of UAVs include quiet approach, safer flight at low altitude and low running costs. In addition, UAV surveys could replace boat surveys as they cause less disturbance and provide a greater field of vision for observing behaviours such as breaching. The first state-wide abundance estimate for the endangered Florida manatee (*Trichetus manatus latirostris*) was conducted using an unmanned aerial drone with great success and this method may replace boat based surveys in the future (Martin *et al.*, 2015). Martin *et al.* (2015) highlighted the decreased disturbance and risk to marine mammals (decreased collision with watercraft) and the effectiveness of the framework for studying populations of low density over large areas (Bauduin *et al.*, 2013).

Unmanned Aerial Vehicles have been used to survey marine mammals, such as Harp seals (*Pagophilus groenlandicus*) and Hooded seals (*Cystophora cristata*) with great success on land, but the surveys were limited by the drone's flight range and the ice-shelf limiting boat approach (Curry, Maslanik, Holland, & Pinto, 2004). A team of Arctic researchers successfully modified the fixed-wing drone, Aerosonde MK-3, for polar work, suggesting that cold conditions can be overcome with sufficient modification (Curry *et al.*, 2004). Another study conducted over the Bering, Beaufort and Chukchi seas showed that wide scale surveys of ice based seals (bearded seals, ribbon seals, ringed seals and spotted seals) could be achieved with reduced operational costs, flight times and inclusive airspace regulations (Moreland *et al.*, 2015). All studies using a UAV have the benefit of not risking the lives of pilots or researchers during surveys, some of which are conducted in remote or harsh conditions and where a crash would be fatal. Past research has shown great potential for detecting marine mammals aerially that are easily visible on a flat plane (surface water, ice or sand), but this technology has yet to be trialled on a complex rocky shore, with high winds, high wave action and on a species that is reasonably camouflaged with its surroundings.

For this study we used a multi-rotor vertical take-off and landing (VTOL) aircraft to test UAV technology in a harsh, rocky shore environment to survey land-based marine mammals. The objectives in this research were to:

1. Compare the effectiveness of UAV sampling using a multi-rotor VTOL to traditional methods of population monitoring.
2. To determine whether two types of UAV flight over a seal colony causes disturbance.
3. To test the feasibility of using aerial imagery to determine the size and condition of fur seal pups.
4. Estimate the pup productivity and condition of the New Zealand fur seal (*Arctocephalus forsteri*) at Ohau Point, Kaikōura.

## Materials and Methods

### Ethics Statement

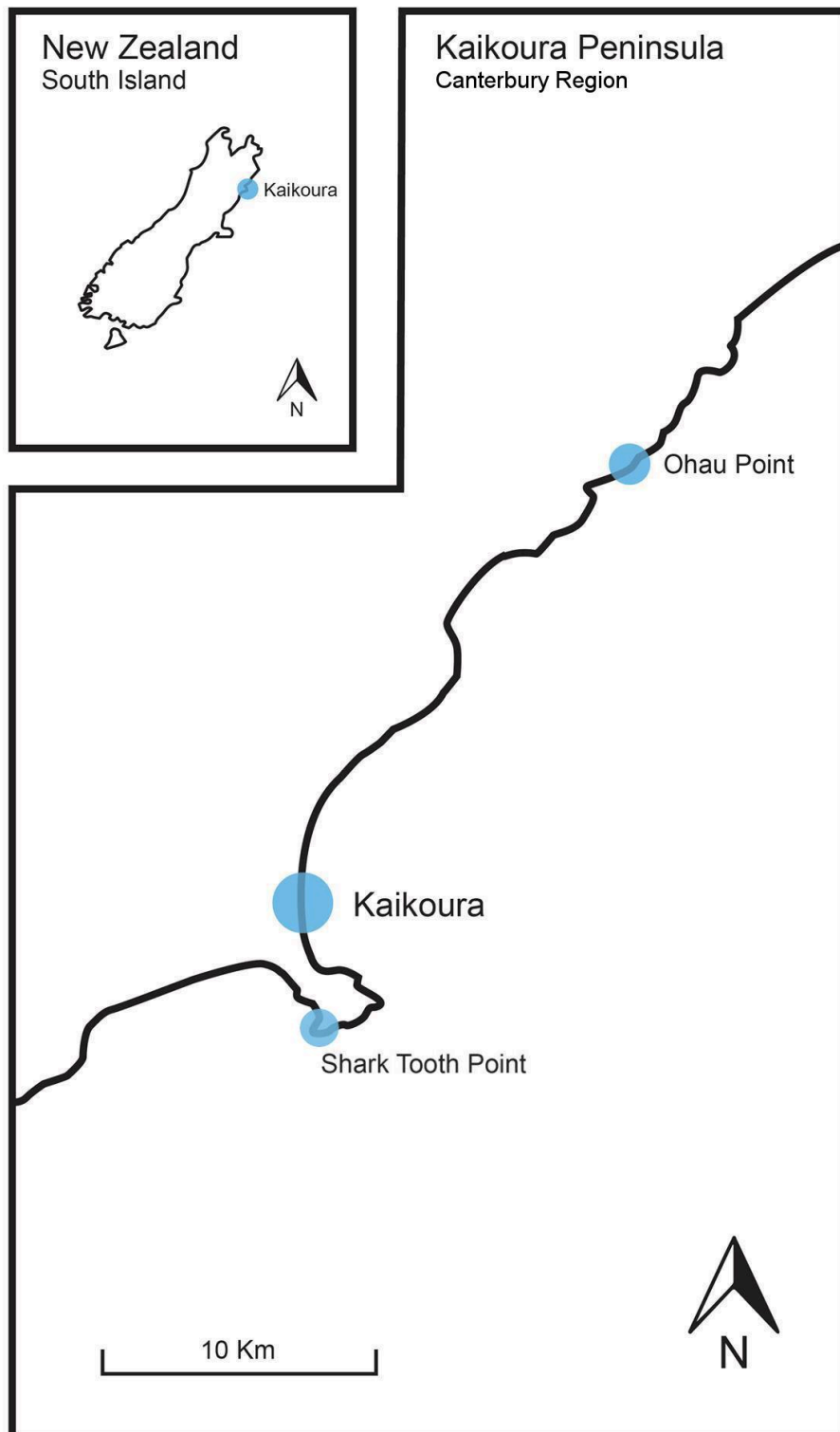
This study was carried out in accordance with University of Canterbury, Animal Ethics approval for animal handling and experiments and with the current New Zealand aviation legislation. The Department of Conservation approved permits to access the fur seal sanctuary and the animal handling procedures (DOC, permit no. 39700-MAR).

In New Zealand, flight of UAV's must be flown under civil aviation regulations outlined by the civil aviation authority of New Zealand (NZCAA). These regulations come into effect on August 1<sup>st</sup> 2015. Wildlife research permit was obtained by the Department of Conservation(DOC permit #39700-MAR) and University of Canterbury animal ethics approval (AEC APPLICATION 2015/18R). Preliminary flights were run with a quad-copter and a fixed-wing UAV at 50 m above the NZ fur seal colony at Ohau Point and at Shark's tooth.

## Study Sites

We conducted flights along the Kaikōura coast, on the East coast of the South Island of New Zealand (Figure 3.1), focussing on two New Zealand fur seal colonies: Shark Tooth point (ST), a non-breeding colony (42°25'55.1"S 173°41'35.7"E) and Ohau Point (OP), a large breeding colony (42°14'52.2"S 173°49'50.2"E). Ohau Point is an exposed rocky shore and is located ~2km away from a deep sea trench that hosts high densities of prey species year round (Benoit-Bird, Würsig, & Mfadden, 2004; Garner & Committee, 1953). These sites are both characterised by their exposed rocky shore environments.





**Figure 3.1.** Map of research sites. Shark Tooth non-breeding NZ fur seal colony and Ohau Point breeding colony on the east coast of New Zealand. Kaikōura has been highlighted for geographic reference (Map graphic created by Lon Van Elk).

## Quantifying Disturbance

We recorded the behavioural responses of the animals during flight using a Panasonic HC-V550M hand-held video camera. The responses were filmed from cliff-side vantage points where the majority of the animals could be viewed without the camera operator's presence causing a disturbance. Behavioural responses were assessed in real-time to determine whether the flight should be aborted, and were later quantified from playback to assess disturbance (Figure 3.2).

Disturbance was assessed by comparing the colony activity level with their average population activity level (APAL). The APAL for a NZ fur seal colony in Kaikoura was estimated at 17% by Boren et al. (Boren, Gemmell, & Barton, 2002) and this level was used as a threshold for disturbance. To determine the colony's activity level, the number of seals deemed "active" versus inactive was counted. A seal was deemed "active" if it was sitting up aware, alert or moving, and included territorial display of neck (Boren *et al.*, 2002). If the seal colony activity level was higher than 17% (critical disturbance threshold) we assumed the colony has been disturbed.



**Figure 3.2.** DraganFlyer X4-P Helicopter conducting preliminary disturbance survey (25 m above sea-level) of group of bull seals at Shark Tooth Point, Kaikoura. The red arrow is pointing at a seal that is looking at the UAV.

## UAV Pup Count

We conducted a flight of the entire Ohau Point colony on the 19<sup>th</sup> February 2015, using the DraganFlyer X4-P Helicopter™ (Table 3.1 and Figure 3.3) by breaking the colony into four segments (1 per battery) to enable the pilot to navigate difficult terrain [(1) North Platform A, (2) North Platform B, (3) Mid Platform and (4) Mid/South Platform]. The environmental conditions were full sun, low cloud cover and slight wind, which became quite strong during the last two flights. Upon setup, the distance from the closest seal was estimated (take off distance) and the take-off and touch-down time recorded. This survey was paired with a mark-recapture survey conducted in February (see methods below).



**Figure 3.3.** Draganflyer X4-P Helicopter (<http://www.draganfly.com/uav-helicopter/draganflyer-x4p/specifications/>).

**Table 3.1.** Helicopter specifications (<http://www.draganfly.com/uav-helicopter/draganflyer-x4p/specifications/>).

<b>Name</b>	<b>Draganflyer X4-P Helicopter</b>
Use	Professional Aerial Photography & Videography
Width (cm)	87cm (Folds to 16cm)
Length (cm)	87cm (Folds to 16cm)
Top Diameter (cm)	107cm
Height (cm)	30cm
Helicopter Weight (incl. battery)	1.67kg
Payload capacity (g)	800g
Max take-off weight (kg)	2.47 kg
Payload Options	SONY RX100, SONY QX100, FLIR Thermal Imaging
Power Source	5400mAH 14.8V LiPo battery. Approximately 10 minutes flight time per battery.
Flight Control	Remote control operated in field of view w. automated VTOL. GPS & Altitude hold.
Max climb rate (m/s)	2m/s
Max descent rate (m/s)	2m/s
Max turn rate (degrees/s)	90 degrees/sec
Max air speed (km/h)	50km/h
Minimum air speed (km/h)	0km/h
Launch type	VTOL (Vertical take-off and landing)
Sound at 1 meter distance (dB)	72dB
Sound at 3 meters distance (dB)	62dB
Control Range (m)	Field of view

The resulting video was processed using VLC video player™ on a Viewsonic VX2439wm 24 inch Full HD monitor. The number of seal pups per flight was recorded three times to provide observer variance and from this a mean number of seal pups was calculated.

We conducted a further survey on the 11<sup>th</sup> of August at Ohau Point colony for a more comprehensive population survey at additional heights using the same set up as the previous survey. Only the north platform (A and B) of the colony was surveyed as landslides had caused rock falls into the colony and a road repair team was utilizing a digger in the study site. The north platform (A & B) survey was conducted in two flights, at cruising heights of 50 m, 35 m and 25 m at 9 am, 12 pm and 4 pm. The environmental conditions were full sun, low cloud cover and no wind. This survey was paired with a visual walkthrough count (less intensive than mark recapture) and a visual estimate from above the colony. A visual walkthrough consisted of 3 researchers actively searching for pups in holes, caves and under rocks in order to get the most accurate count of seal pups possible without handling the pups and causing unnecessary stress. A mark-recapture was not able to be conducted due to the unavailability of research assistants at this time of year.

Video was then processed as described for February survey.

## Pup Production Estimates

A Peterson's estimate of pup production using mark-recapture was conducted at Ohau Point from 28-29<sup>th</sup> February, 2015 (Seber, 1982). January is the first point at which entering the colony is safe for researchers and pups after mating and pupping has completed, and the majority of territorial males have left the colony (Kirkwood *et al.*, 2005; Shaughnessy, Goldsworthy, & Libke, 1995). Bull seals are extremely dangerous during breeding and pupping season as they aggressively defend their territories, however, after late-December they (and other non-pups) will usually flee the colony when approached by humans (Kirkwood *et al.*, 2005).

Mark-recapture allows the accurate estimation of a pup population on a boulder beach shore where pups are able to hide underneath boulders, out of view. The procedure for the mark-recapture study requires the marking of a subset of pups after which a walkthrough is conducted the following day when marked versus unmarked pups are sighted and counted (Boren *et al.*, 2006). Walkthroughs require the active searching of pups and can take 4 – 5 hours to complete with 4 – 6 people. For the mark, we used a haircut to reveal light-brown under fur, where a dab of paint was applied to make pups more distinguishable when wet. Walkthroughs consisted of actively searching for pups under rocks, in caves and in holes. The colony area sampled was assumed to be a "closed" population for the duration of each count, with no migration of pups between areas and mortality was acknowledged when sighted and recorded. To minimise pseudo-counting of the same pups, those that were removed from under rocks or crevices were placed behind the processing line of counters. Multiple counts of the colony should be done to account for variation and pup movement, however, only one count was possible for this study.

Using a modified Peterson formula, pup population was estimated for the Ohau Point breeding colony in 2014/2015 using data from the capture mark re-sight sampling (CMR)(Boren *et al.*, 2006). The estimated pup population for the Ohau Point seal colony (N) was derived from:

$$N = [(M+1)(n+1)/(m+1)]-1$$

where  $M$  is the total number of marked pups in the colony,  $n$  is the total number of pups counted and  $m$  is the number of marked pups sighted (Seber, 1982). The variance for each count ( $V_N$ ) can be calculated following Seber (1982) as:

$$V_N = (M+1)(n+1)(M+m)(n-m)/(m+1)^2(m+2).$$

An arithmetic mean ( $\bar{N}$ ) can also be calculated with multiple counts, as conducted in (Kirkwood *et al.*, 2005; Shaughnessy, Kirkwood, & Warneke, 2002; Shaughnessy *et al.*, 2000). Due to researcher injury, our second count was left 80% complete and this was not able to be calculated.

## **Morphology and Condition**

A sub-sample of pups were weighed and sexed, and morphometric data (Length (L) and Auxiliary Girth (AG)) was recorded in January ( $n= 122$ ), March ( $n= 14$ ) and during the mark-recapture population study in February ( $n= 100$ ) (Boren *et al.*, 2006; Bradshaw, Davis, *et al.*, 2000).

Two condition indices were calculated to measure pup health and condition. Condition Index 1 is calculated using mass (M) divided by length (L) (Pitcher, 1986). Condition Index 2 was calculated by dividing the observed mass by the expected mass (Boren *et al.*, 2006; Bradshaw, Davis, *et al.*, 2000). Expected mass was calculated by using the slope ( $a$ ) and  $y$ -intercept ( $b$ ) derived from the regression between  $\log_e$ (Lemasson, Ouattara, Bouchet, & Zuberbühler, 2010) and  $\log_e$ (Length) as:

$$\log_e(\text{Expected}) = a + b \times \log_e \text{ (Bradshaw, Davis, et al., 2000)}.$$

Morphological characteristics (Mass, Standard Length, Auxiliary Girth, Condition Index 1 and Condition Index 2) were tested for differences between sex using ANOVA. All ANOVA analyses were calculated using R Studio version 3.2.4.

## UAV Sampling

### UC Custom Fixed-Wing (Remote Control Aeroplane)

The UC Custom fixed-wing UAV can be flown manually or autonomously along a set GPS route. It requires propulsion via a slingshot for take-off and a safe, flat runway for landing (Figure 3.4). Sites for take-off and landing were easily available for the Shark Tooth and Ohau Point sites, but were cordoned off to prevent human entry. Remote control Fixed-wing flight laws required that we notify the nearby airport traffic authorities if flying more than 10km distance away from the pilot or operator (NZCAA 2015). Due to high rock formations we flew the transects manually rather than autonomously at both sites.



**Figure 3.4.** UC fixed-wing and slingshot method of launch, featuring University of Canterbury UAV pilot, Paul Bealing, taken in Antarctica (Photo credit: David Risk).

Upon setup, the distance from the UAV to the closest seal was estimated (take off distance) and the take-off and touch-down time recorded. The fixed-wing flight transects were flown at 75 m, 50 m and 35 m at 7 am, 12 pm and 4 pm. Transects were flown in one flight run, from highest to lowest due to financial and time constraints. Therefore, sensitisation bias must be acknowledged for this



study. The fixed-wing was manually flown by a qualified UAV pilot (Nicholas Key, University of Canterbury, Geography department) and was launched from the cliff-side to reduce disturbance.

### DraganFlyer X4-P Helicopter

DraganFlyer X4-P Helicopter™ (Table 3.1 and Figure 3.3) has a payload consisting of a Sony NEX 5N camera (<http://www.sony.co.nz/product/nex-5n>) with 16mm Pancake lens (<http://www.store.sony.com/e-16mm-f2.8-e-mount-prime-lens-zid27-SEL16F28/cat-27-catid-All-Alpha-NEX-Lenses>). It was equipped with a pressure gauge to measure altitude (m above sea level). A full colony survey was conducted at 50 m cruising attitude and was manually flown by a qualified UAV pilot (Nicholas Key, University of Canterbury, Geography department) from the Cliffside (7 m minimum above sea level). The DraganFlyer X4-P takes off and lands vertically (VTOL), allowing landing on a confined and/or thin landing site. The UAV can be flown for approximately 8 – 10 minutes per battery and must be flown in eye sight

### Photographic Morphometric Measurements

To assess the use of aerial photos for morphometric investigation, physical morphometric sampling of 38 seal pups was done in the Ohau Point colony in January 2016 (Figure 3.5). We captured and measured each pup's length and girth using a measuring tape and weighed them using a burlap bag attached to a fish scale. I took photographs of the pups on the board from directly above and constantly once they were released. The seals were processed via a line of researchers and seals were passed behind to reduce pseudoreplication.

Photographs were then analysed using ImageJ™. The image was calibrated for pixel size to distance using the known length of the seal measuring board, using the ImageJ measurement tool. Once calibrated, using the ruler tool, estimates of pup length (tail to nose), width (visible dorsal width), front flipper (outer, inner and base) and rear flipper (tail to tip) (Figure 3.5). Linear regression models were applied for all photographic measurements against physical length, girth and weight (obtained in field).



**Figure 3.5.** Representation of measurements taken from photographs for morphometric estimation. Green lines indicate approximate measures of length, width, front flipper (outer, inner and base) and rear flipper.

## Results

### Preliminary Flights

During the preliminary flights we discovered that birds may be the most at-risk species as they reacted to the AUVs and nearby birds (~50 m) fled from the UAV. These preliminary flights over fur seals were conducted at Ohau Seal colony where very few birds were present, so to be responsive to

this potential disturbance of birds, we documented all encounters with birds during flights and aborted the flights if the UAV became too disruptive to them.

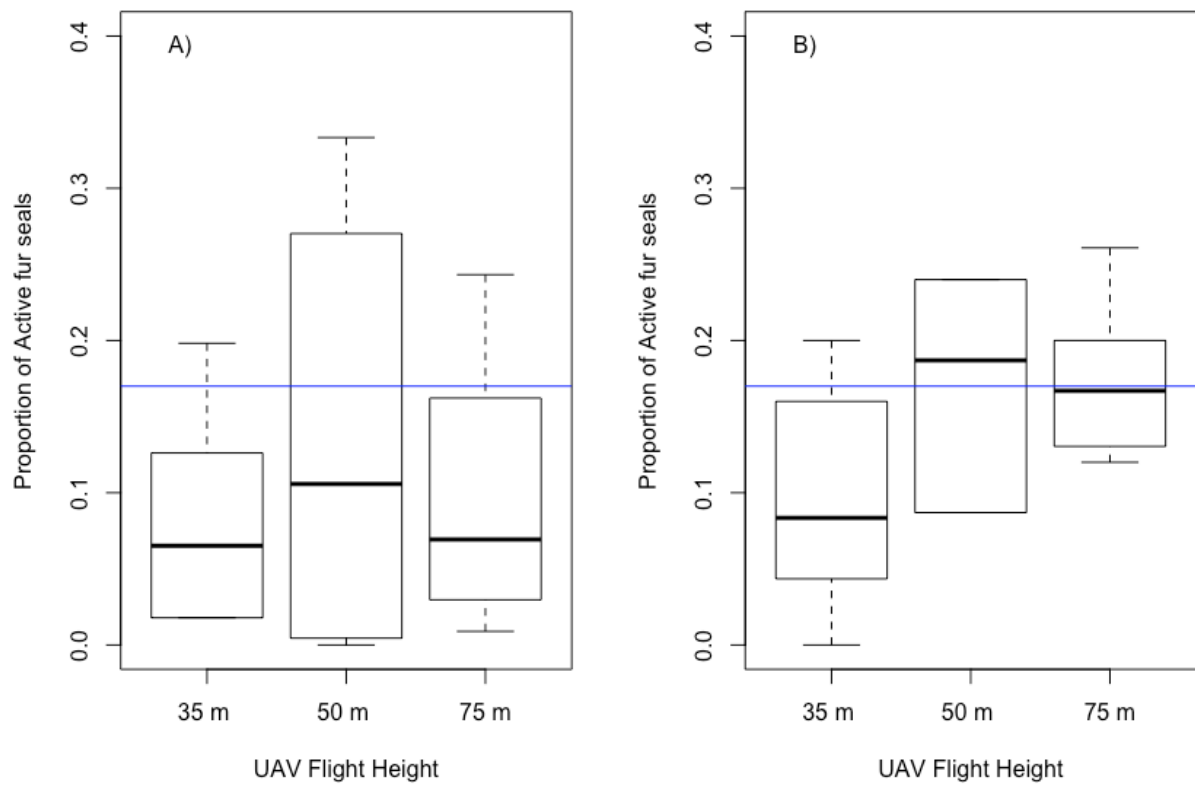
## **UAV Disturbance**

### Fixed-Wing

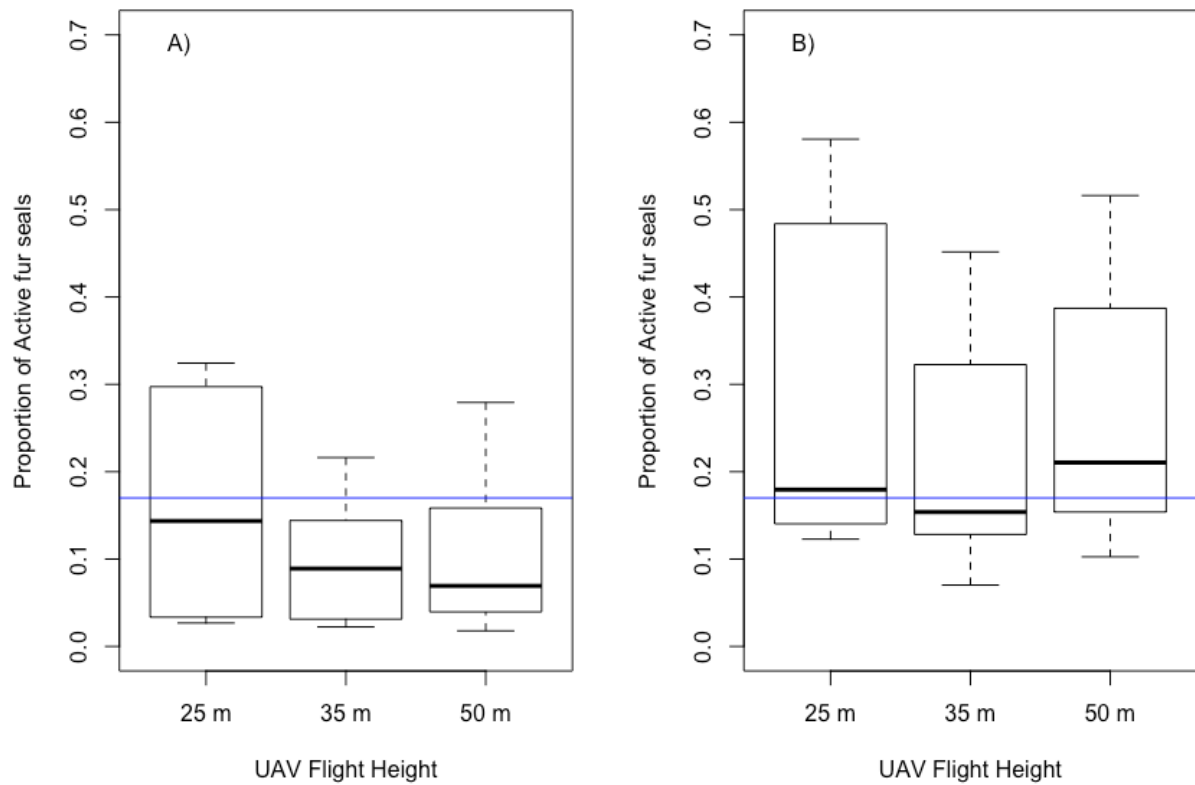
The fixed-wing had a significant effect on fur seal activity level at 35 m height in the breeding colony (GLM:  $z = -3.961$ ,  $p < 0.001$ ) (Figure 3.6b). There was a visible increase in activity level at 35 m height in the non-breeding colony; however, results were non-significant (GLM:  $z = 1.835$ ,  $p = 0.067$ ) (Figure 3.6a). There was no significant effect on activity level at 75 m height (GLM:  $z = 0.482$ ,  $p = 0.630$ ). Time of day had no significant effect on activity level.

### Quad-copter (DraganFlyer)

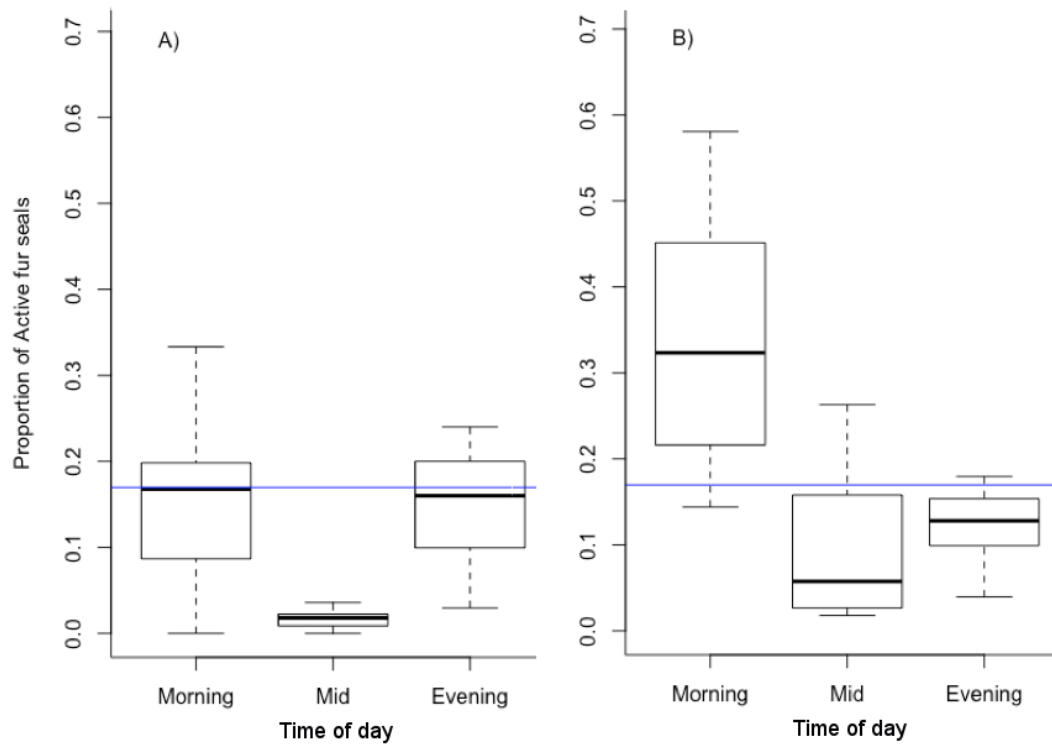
The activity in the breeding and non-breeding colonies was significantly greater during flights at 25 m height, compared to 35 m and 50 m heights (GLM:  $z = -5.362$ ,  $p > 0.001$ ) (Figure 3.7a and b). Flights at 50 m height (GLM:  $z = 0.084$ ,  $p = 0.933$ ) and 35 m height (GLM:  $z = -1.577$ ,  $p = 0.115$ ) did not significantly affect activity level. Activity level was higher in the mornings, compared to mid-day and evening; however, results were non-significant (Figure 3.8).



**Figure 3.6.** Fixed-wing effect on activity level of non-breeding (A) ( $n= 21$ ) and breeding colonies (B) ( $n= 18$ ) of New Zealand fur seals (*A. forsteri*), located at Shark Tooth Point (non-breeding) and Ohau Point (breeding), Kaikoura The horizontal blue line indicates the recommended 17% resting activity level used for determining disturbance (Boren *et al.*, 2002).



**Figure 3.7.** Quadcopter effect on activity level of non-breeding (A) ( $n= 27$ ) and breeding colonies (B) ( $n= 27$ ) of New Zealand fur seals (*A. forsteri*), located at Shark Tooth Point (non-breeding) and Ohau Point (breeding), Kaikoura. The horizontal blue line indicates the recommended 17% resting activity level used for determining disturbance (Boren *et al.*, 2002)



**Figure 3.8.** UAV disturbance effect on activity level of Fixed-wing (A) ( $n= 39$ ) and Quadcopter (B) ( $n= 53$ ) of New Zealand fur seals (*A. forsteri*), at three times of day 7 am, 12 pm and 4 pm over non-breeding (Shark Tooth Point) and breeding (Ohau Point) colonies (combined). The horizontal blue line indicates the recommended 17% resting activity level used for determining disturbance (Boren *et al.*, 2002).

### Mark-Recapture and Pup Production

The mark-recapture survey of the Ohau Point fur seal colony produced a Peterson estimate of 2471 pups produced for the year, from a maximum count of 804 marked pups (Table 3.2). The full colony UAV survey, recording only pups, conducted in February 2015 at 50 m height counted a mean of 193 pups (Table 3.2).

**Table 3.2.** Mark-recapture population estimates conducted in February 2015 at Ohau Point fur seal colony, Kaikōura.

Method	Marked	Unmarked	Marked pups recaptured	Total number of pups	Peterson Estimate	Peterson Estimate including 15% mortality.
Physical Mark-recapture count (n= 1)	804	607	292	-	2471	2908
Mean number of pups counted using UAV at 50 m altitude (n= 3).	-	-	-	193	-	-

The physical walk-through survey, which included retrieving pups from under rocks and in caves, in August 2015 counted 352 pups (Table 3.3). A visual walkthrough of the North Platform counted 304 pups (Table 3.3). Aerial Surveys conducted on the North Platform of Ohau Point at 50 m height detected 40 pups and at 35 and 25 metres both detected a mean of 96 pups (Table 3.3).

**Table 3.3.** Mean North Platform aerial UAV population estimates paired with visual and physical walk-through counts conducted in August 2015 at Ohau Point fur seal colony, Kaikōura.

Count Method	# of Pups
Physical walk-through (n= 1)	352
Visual Count (n= 2)	304
Quadcopter at 50 m height. (n= 3)	40
Quadcopter at 35 m height. (n= 3)	96
Quadcopter at 25 m height. (n= 3)	96

We conducted the survey at 50 metres height in order to minimise disturbance; however, we found this height was insufficient for detecting camouflaged, hiding or clumped pups, detecting only 7.8% of the physically estimated pup productivity (Table 3.1).

The second UAV survey conducted at the North platform of Ohau Point in August was conducted at two additional heights and detected a mean of 40 (50 m), 96 (35 m), 96 (25 m) pups for each height (Table 3.3). Due to the unavailability of field assistants, another mark recapture estimate was not possible and this UAV survey was paired with physical walkthrough estimate (352 pups) and a visual count (304 pups) from the Cliffside. This later survey showed a much greater percentage detected by the UAV at 50 metres (11.4%) than the February survey, however, we must consider that this was compared with a less thorough physical search. This survey also showed a much greater detection percentage at 35 and 25 m (27.3%), than the 50 m height (11.4%). This suggests that 35 metres may be the optimum height for maximising pup detection whilst also minimising disturbance (Figure 3.7).

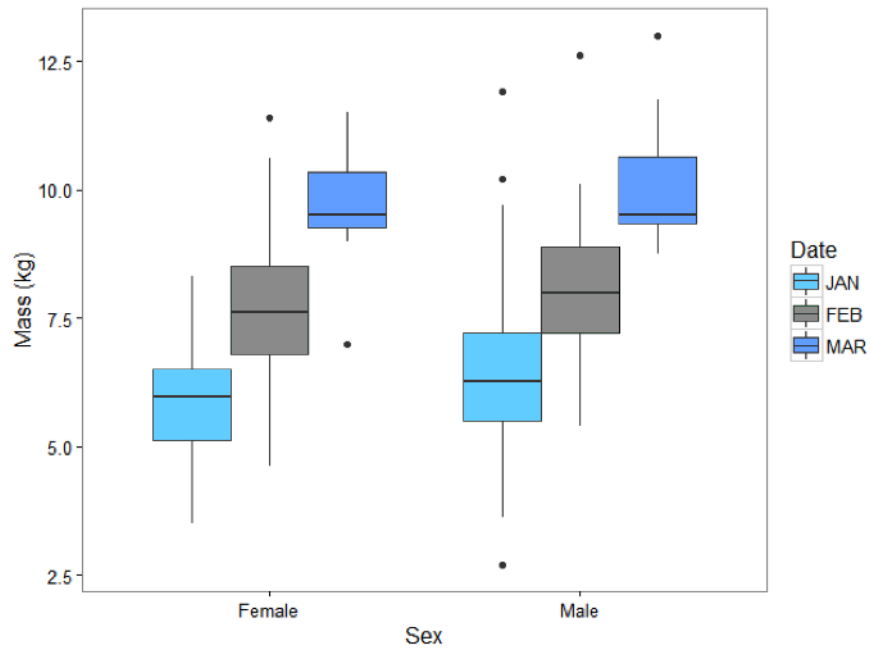
## **Pup Morphology**

I weighed, measured and sexed 67 male and 48 female pups in January 2015, 50 male and 50 female pups in February 2015, 7 male and 7 female pups in March 2015 and 38 in January 2016.

Measurements for 2016 were also paired with photographs for photographic morphometric analysis.

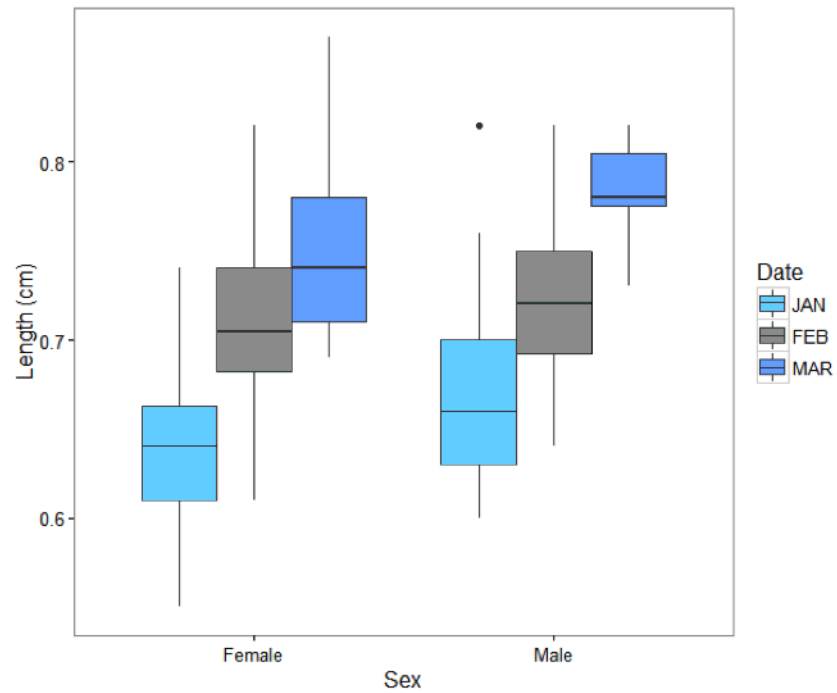
Male pups were significantly heavier ( $\bar{x} = 6.4$  kg) than female pups ( $\bar{x} = 5.8$  kg) in January ( $F_{(1, 120)} = 5.647$ ,  $p = 0.019$ ), but showed no significant difference in February, male ( $\bar{x} = 8.1$  kg) and female ( $\bar{x} = 7.8$ ) ( $F_{(1, 98)} = 1.039$ ,  $p = 0.311$ ) or March ( $F_{(1, 12)} = 0.531$ ,  $p = 0.488$ ), male ( $\bar{x} = 10.2$  kg) and female ( $\bar{x} = 9.6$  kg) (Figure 3.9).





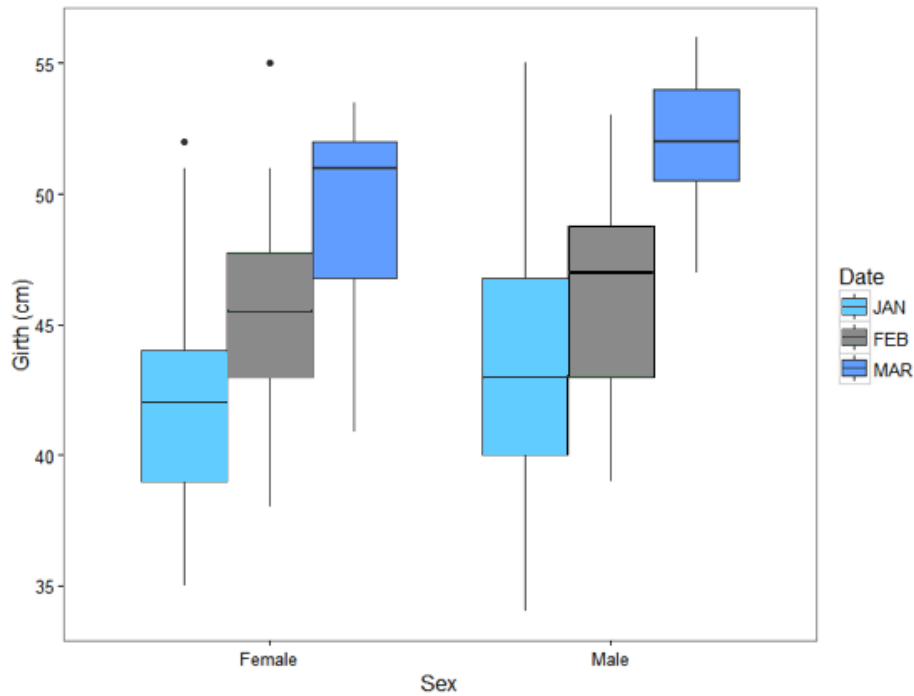
**Figure 3.9.** Median pup mass (kg) for 67 male and 48 female pups in January, 50 male and 50 female pups in February, 7 male and 7 female pups at Ohau Point, Kaikōura, in March during 2015.

Male pups were significantly longer ( $\bar{x} = 0.69$  cm) than female pups ( $\bar{x} = 0.66$ ) in January ( $F_{(1, 120)} = 7.891$ ,  $p = 0.006$ ), but showed no difference in February, males ( $\bar{x} = 0.72$  cm) and females ( $\bar{x} = 0.71$  cm) ( $F_{(1, 98)} = 2.559$ ,  $p = 0.113$ ) or March, males ( $\bar{x} = 0.78$  cm) and females ( $\bar{x} = 0.75$  cm) ( $F_{(1, 12)} = 1.297$ ,  $p = 0.277$ ) (Figure 3.10).



**Figure 3.10.** Median observed *A. forsteri* pup length (cm) for 67 male and 48 female pups in January, 50 male and 50 female pups in February, 7 male and 7 female pups at Ohau Point, Kaikōura, in March during 2015.

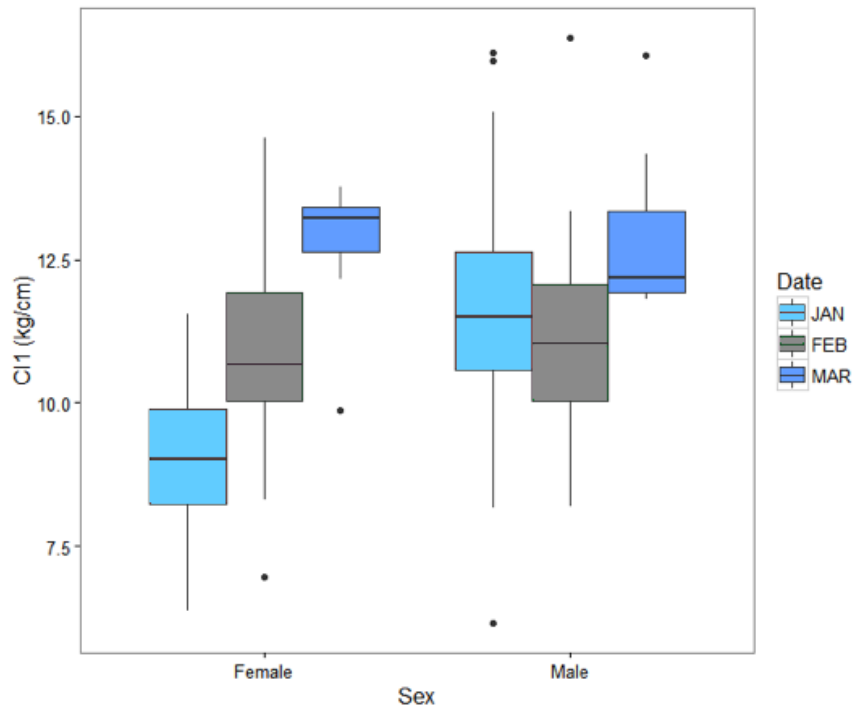
There was no difference between male and female pup auxiliary girth during January ( $F_{(1,120)} = 2.927$ ,  $p = 0.089$ ), February ( $F_{(1,98)} = 1.017$ ,  $p = 0.316$ ) or March ( $F_{(1,12)} = 1.792$ ,  $p = 0.206$ ) (Figure 3.11).



**Figure 3.11.** Median observed *A. forsteri* pup girth (cm) for 67 male and 48 female pups in January, 50 male and 50 female pups in February, 7 male and 7 female pups at Ohau Point, Kaikōura, in March during 2015.

Condition Index 1: Mass/Length

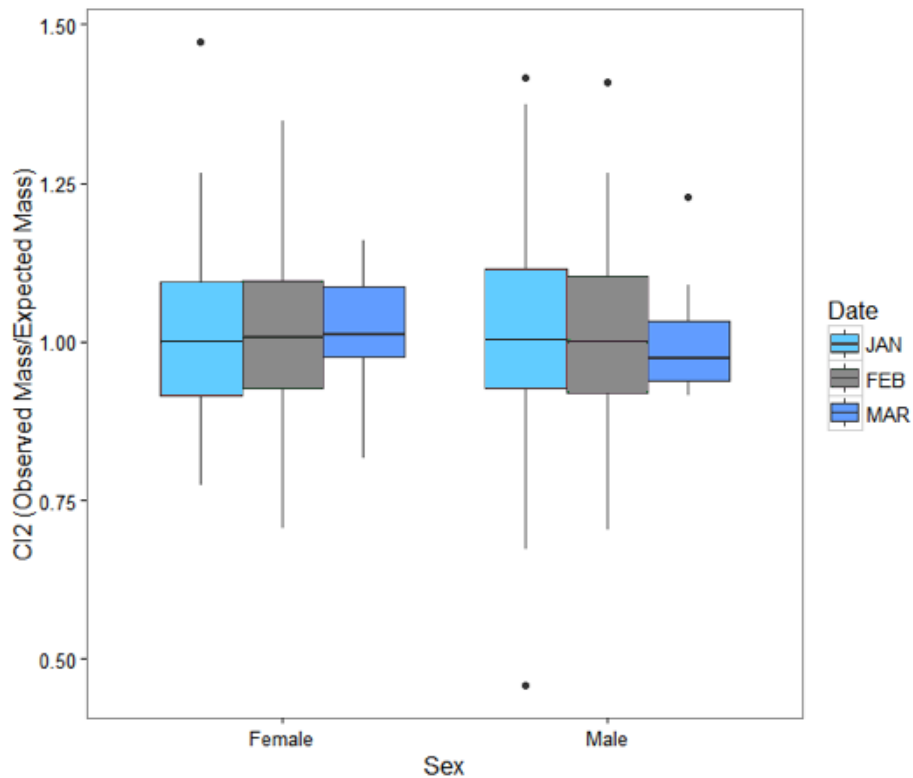
Condition Index 1 indicated that males were significantly heavier per unit length ( $\bar{x} = 11.5$ ) than females ( $\bar{x} = 9.01$ ) in January ( $F_{(1, 120)} = 75.029$ ,  $p < 0.001$ ), February, males ( $\bar{x} = 11.65$ ) and females ( $\bar{x} = 10.92$ ) ( $F_{(1, 98)} = 5.962$ ,  $p = 0.016$ ) but showed no significant difference in March, male ( $\bar{x} = 12.93$ ) and female ( $\bar{x} = 12.7$ ) ( $F_{(1, 12)} = 0.084$ ,  $p = 0.777$ ) (Figure 3.12). Males appear to decline in condition in February, but recover by March.



**Figure 3.12.** Median observed Condition Index 1 (Mass/Length) for 67 male and 48 female *A. forsteri* pups in January, 50 male and 50 female pups in February, 7 male and 7 female pups at Ohau Point, Kaikōura, in March during 2015.

Condition Index 2: (Observed/Expected Mass)

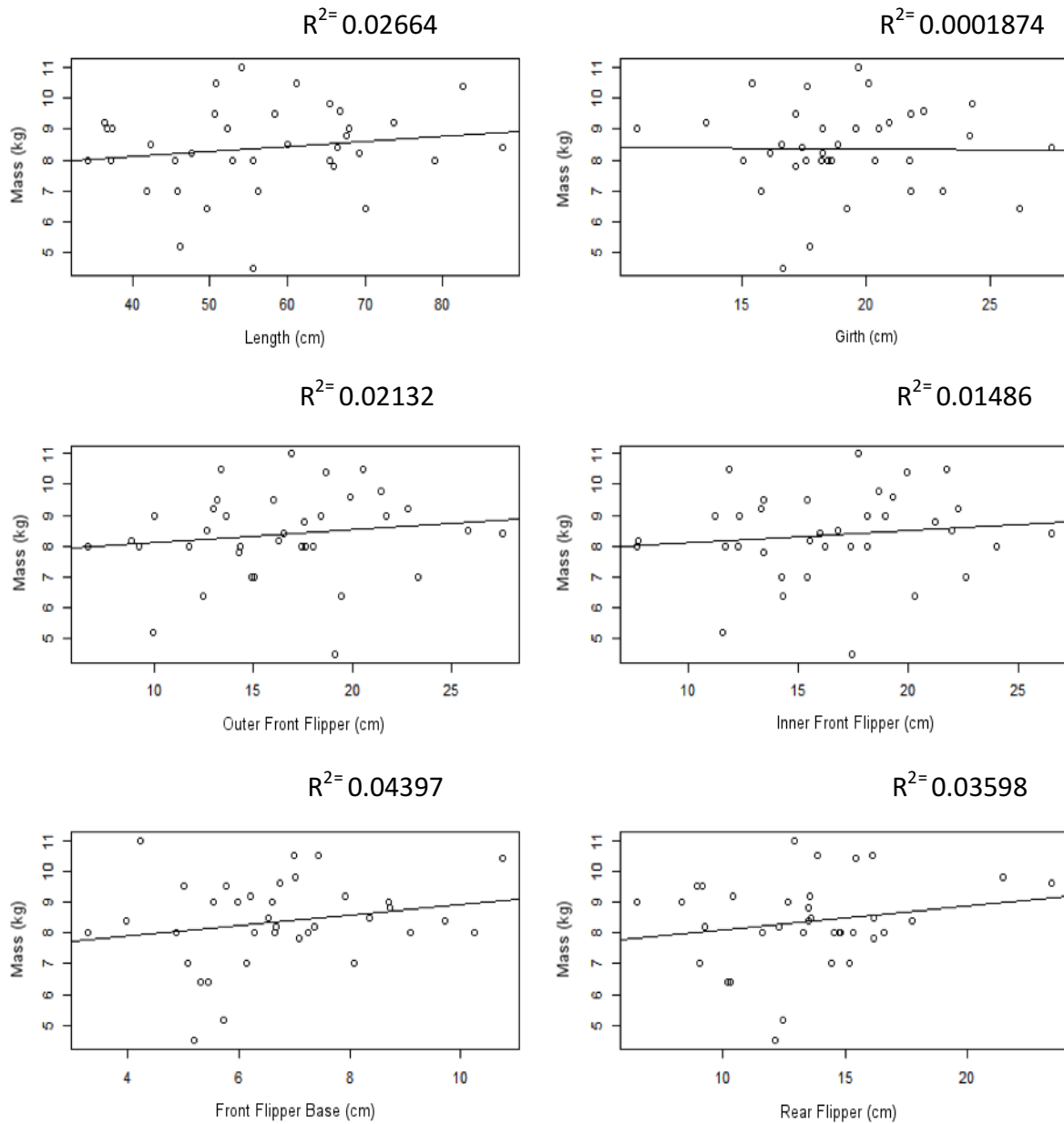
Condition Index 2 indicated that there was no difference between male ( $\bar{x} = 1.02$ ) and female ( $\bar{x} = 1.01$ ) pups in January ( $F_{(1, 120)} = 0.023$ ,  $p = <0.880$ ), February, males ( $\bar{x} = 1.02$ ) and females ( $\bar{x} = 1.0$ ) ( $F_{(1, 98)} = 0.003$ ,  $p = 0.9542$ ) or March, males ( $\bar{x} = 1.00$ ) and female ( $\bar{x} = 1.02$ ) ( $F_{(1, 12)} = 0.019$ ,  $p = 0.891$ ) (Figure 3.13).



**Figure 3.13.** Median observed Condition Index 2 (Observed/Expected Mass) for 67 male and 48 female *A. forsteri* pups in January, 50 male and 50 female pups in February, 7 male and 7 female pups at Ohau Point, Kaikōura, in March during 2015.

### Photographic Estimates

All data was tested for normality and was normally distributed. All regression  $R^2$  values were less than 0.5, indicating a weak correlation (Figure 3.14). Length and girth were also unable to be predicted using any photographic measurement. Weight could not be predicted by any of the photographic measurements (length, width and flipper lengths) calculated in Image J (Figure 3.14).



**Figure 3.14.** Correlation between physical weight (Lemasson *et al.*, 2010) and all photographic morphometric estimates generated in ImageJ™. Trend line represents linear regression for each model.

## Discussion

The revolution of UAVs is facilitating new, innovative ways of conducting research and is currently being experimented with and used in a wide array of different fields (Jin, Ge, Du, & Xu, 2009; Zhang & Kovacs, 2012; Zongjian, 2008). This experiment explored the capabilities of aerial imagery using a multi-rotor and fixed-wing UAV and the potential of these to collect non-invasive, high definition videography to survey land based marine mammals.

The Draganflyer has high manoeuvrability, GPS positioning, fail-safe technology and a fully interchangeable imaging system. The Draganflyer was limited by its wind resistance, compulsory manual flight due to lack of GPS signal, and flight vibration (image stabilization). The Draganflyer showed great potential as a wildlife surveying tool, however, it also highlighted several improvements that could enhance future surveys. Due to the lack of GPS signal caused by the surrounding mountains, the Draganflyer was flown manually and it was difficult to maintain straight transects when wind increased. Regardless of these drawbacks, this method was safe for researchers, non-disruptive and took a substantial sub-sample of the entire population in a fraction of the time required to conduct traditional mark recapture sampling.

### Do Drones Cause Disturbance?

I found that quadcopters caused more disturbance than fixed-wings regardless of colony type and time of day. This could be due to the more familiar, bird wing shape and flight pattern of the fixed-wing or its higher flight height and lower noise. The quadcopter (Draganflyer) is relatively noisy (db. = 72 at 1 m distance and 62 db. at 3m distance) compared to the fixed-wing, even more so on take-off and in high winds.

The fixed-wing and quadcopter aerial vehicles, at the lowest flight heights (35 m and 25 m respectively), caused an increase in resting activity level. The quadcopter caused significantly greater

disturbance in the breeding colony and over all heights warranted the greatest breach of the 17% critical resting activity level threshold (Boren *et al.*, 2002). This supports the theory that the breeding colony is more sensitive to disturbance and that quadcopter or noisy flight over this colony type should be avoided. Unfortunately, we did not control for the potential difference in activity levels at different times of day, instead we chose to utilise a resting activity level based on previous long term studies (17%). However, we have not had access to this data to rigorously assess its application in this study.

Fixed-wing flights were shown to be less disruptive than the quadcopter overall, however, we must acknowledge the greater flight height flown by the fixed-wing. Quadcopters caused more disturbance to fur seals and to nearby sea gulls and must be used with caution. Whilst time of day did not show any significant effects, the position of the sun in regards to the colony was observed to enhance disturbance. Whilst flying over the breeding colony with the quadcopter during the evening, the setting sun was eclipsed by the flying quadcopter and resulted in a very strong escape response by a mature female fur seal and her pup.

## **Can You Count Pups With a UAV?**

An average of 193 pups were detected in the first UAV surveys conducted in February, which is a severe underestimate of the total colony when compared to 804 of pups caught physically during the mark recapture (Table 3.2). This underestimation can be attributed to the quality of photographic equipment, drone stabilisation, weather conditions, and missing all of the pups hidden under rocks or in caves. We used a SONY NEX-5 camera with a pancake lens in order to get a high quality picture of the entire width of the colony, without having to fly multiple transects of the same section of beach. We chose this method to minimise the potential for pseudo-replication due to seal movement as transects were counted in one direction, capturing the entire shore.

The SONY NEX-5 was mounted to the Draganflyer with a gimbal, a gimbal allows the remote control of camera from the pilot. This gimbal was sufficient for the purposes of this experiment, however, more advanced technology is available that would decrease rattle and provide more fluid movement



and therefore enhance the quality of the obtained image. Shaking due to flight and wind negatively affect the processing of the video obtained, however, video was the chosen format in order to utilise movement of seals to enhance detection. Photographs would have provided a higher resolution picture, however, due to the seals camouflage with the substrate the resolution of the picture would not outweigh the benefits of detecting movement. Movement was also crucial for detecting disturbance caused by the drone which could not be viewed by a separate researcher, as human presence itself is very disruptive and this could not be done without being detected by the seals.

Whilst this and other studies have shown success or promise in the application of unmanned aerial vehicles for the survey of marine mammals, New Zealand poses its own set of issues when surveying pinniped populations aerially, such as legislation, harsh weather conditions and a diverse range of sea birds. The New Zealand Civil Aviation Authority has recently reformed New Zealand's laws on the use of drones due to issues of privacy, accidents and conflicts with restricted airspace, however, this doesn't include flight rules around wild animals (New Zealand Civil Aviation Rule Part 101 and 102). The Department of Conservation is currently developing guidelines for the flight of drones around animals, which may pose an obstacle for future surveys.

The Draganflyer is not designed for flight in harsh weather conditions, but handled light wind and rain well. With sufficient take-off and landing area and available GPS signal, a fixed-wing UAV could provide higher quality stable video in high winds, over a huge area (>1 km). Drones are being developed and improved constantly, for example; the MikroKopters™; MK Okto XL 6S12™ (8 rotor copter) has been engineered for stable flight in high wind (<http://www.mikrokopter.de/en/home>) and could allow population surveying in harsh conditions.

## **Pup Morphology**

The results of this study show that male pups were significantly heavier, slightly longer and had a slightly greater girth than female pups (Figures 3.9, 3.10 and 3.11). Males were also in better condition than females for condition index 2 (Mass / Length) (Figure 3.13). These results are consistent with the strong sexual dimorphism in *A. forsteri* as adult male fur seals can weigh up to

three times that of an adult female (Harcourt, 2001; Troy, Mattlin, Shaughnessy, & Davie, 1999). Males tend to be larger at birth which has been theorised to be due to their need to grow much bigger than females (Lea & Hindell, 1997; Lunn & Boyd, 1993; McNab & Crawley, 1975; Wheatley, Bradshaw, Davis, Harcourt, & Hindell, 2006).

The data shows that male and female pups are relatively similar in size during the first three months of their life. This contrasts with previous morphometric studies done on the Ohau Point seal colony, which showed males have a significantly greater mass, length and girth (Boren *et al.*, 2006). This slower rate of growth than previous years could be due to El Nino effects, as well as, heavy landslides and road construction that occurred during the year of 2015. This data whilst useful, is invasive and dangerous for the researcher, hence why we trialled the use of photographic imagery to estimate seal pup morphometrics.

Unfortunately, we were unable to predict physical mass, length or girth using any of the measurements taken from photographic analysis of length, width and various flipper measurements. ImageJ™ analysis was insufficient in accurately estimating the length, which suggests flaw in our experimental design or implementation of techniques. For example, photographers differed throughout pup capture, measurement and photography, which could have resulted in inconsistent measurements or technique when taking photographs. This has been shown to be a substantially limiting factor in a similar study by (de Bruyn *et al.*, 2009). Angle and distance of the camera and the pup were not always equal, due to the unpredictability of the pup once released. Pups are mobile after ~2 weeks and do not often elongate themselves or present their flippers for accurate remote measurement.

Whilst results showed no correlation between physical and photographic measurements, these methods still have potential for future development. The goal was to develop a method of non-invasive population sampling method for pinnipeds that could be applied to terrestrial species worldwide. The utilization of high resolution, non-invasive aerial (UAV) photography may allow for better quality of imagery of pups, as they are not frantically running away from researchers. Past research on pinnipeds all state that a pinniped must be stationary for this method to be accurate, which suggests it may best be employed when fur seals are lying down or sleeping (Bell, Hindell, &

Burton, 1997; de Bruyn *et al.*, 2009). Videography may also enhance measurements as it would allow a wider range of frames from which to choose a suitable picture, however, it would require a more stable gimble and perfect flying conditions to maintain accuracy. Future sampling could also use infrared imagery for sampling as seal eyes and flippers are substantially hotter than the rest of their body (See chapter 4).

## **Conclusive Remarks**

The development of a non-invasive UAV population sampling method is just around the corner. With advancements in drone stabilization, photographic technology and being able to fly repeatable transects with sufficient GPS signal (DraganFlyer), the application of UAV technology in wildlife management seems endless.

# Chapter Four - An assessment of thermal-image acquisition with Unmanned Aerial Vehicles (UAVs) for population sampling of seals and sea lions.

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## Introduction

Population sampling is an essential part of ecosystem conservation and its effectiveness relies heavily on the accuracy of survey methods (Morris & Doak, 2002). Population surveys can be time consuming and logistically difficult in remote or dangerous locations, and they can create disturbances within the population being sampled, as well as among populations of other non-target species (Ditmer *et al.*, 2015). Unmanned aerial vehicle (UAV) technology provides an opportunity for accessing difficult to sample habitats and conducting population sampling. Sampling with UAV technologies removes the need for human intrusion into animal colonies and limits human exposure to potentially dangerous environments. In addition, dense terrain, such as forest, can present challenges for detecting and identifying warm blooded animals for the purpose of population sampling; but image acquisition in the infrared band has been shown to be effective at detecting white-tailed deer, *Odocoileus virginianus*, in complex habitats using their thermal heat signature (Croon *et al.*, 1968; Graves *et al.*, 1972). Thermal imagery has also shown promise in open environments for estimating marine mammal populations such as harbour seal (*Phoca vitulina*) and walrus (*Odobenus rosmarus divergens*) (Burn *et al.*, 2006; Duck *et al.*, 2003).

New Zealand's biodiversity is at risk of decline due to its high degree of endemism, susceptibility to invasive species, and the lack of the economic sectors' consideration for environmental costs (Stewart, 2015). New Zealand is home to a diverse range of seabirds and marine mammals, some of which are considered 'vulnerable' or 'endangered' and are in urgent need of new population sampling methods. The combination of UAV and infrared technology could offer a potentially less invasive way to conduct population monitoring of seabirds and marine mammals, both at land and at sea. Whilst UAVs pose a potential threat to flying seabirds, flightless New Zealand species, such as the little blue and yellow eyed penguin colonies, could be surveyed with lower disturbance than traditional ground counts, and with similar accuracy (Ratcliffe *et al.*, 2015a). The incorporation of infrared technology into Ratcliffe *et al.*, 2015 experimental design could further improve the

accuracy of aerial penguin counts. Traditional ground counts are also the favoured method of population surveying for marine mammals such as the New Zealand sea lion and fur seal, yet, these methods are disruptive to the animals and can be dangerous for the scientist undertaking them.

The New Zealand sea lion (*Phocarctos hookeri*) is currently the rarest sea lion in the world (Robertson & Chilvers, 2011). It has been classified as 'nationally critical' in New Zealand and breeds predominantly on the Auckland and Campbell Islands (Chilvers *et al.*, 2007; Robertson & Chilvers, 2011). New Zealand sea lion pup productivity has dropped by 48% since 1998, potentially due to disease, predation, permanent dispersal or migration, anthropogenic impacts and environment shifts, population 'overshoot', genetic effects, contamination, and direct (bycatch mortality) and indirect effects (resource competition) (Robertson & Chilvers, 2011). On the Auckland islands, sea lions breed colonially on open beaches in harems. After the first month the mothers will begin to move their pups onto other islands or into nearby Rātā forest (*Metrosideros umbellata*), which can be characterized by dense canopy and a contorted network of branches and roots (Figure 4.1)(Childerhouse & Gales, 1998). Sea lions have started colonising new regions of New Zealand such as the Snares, Stewart Island and Otago peninsula (, Childerhouse & Gales 1998 and McConkey 2002). Stewart Island in particular has seen increases in pup numbers over the last five years and has been considered an important subpopulation in recent conservation efforts. Sea lions on Stewart Island are not pupping colonially and this can make population sampling very challenging, especially as they are in dense bush rather than open beaches. We are in urgent need of a novel, non-invasive, population sampling methods for finding sea lions in dense forest habitats.

The purpose of this study was to determine the effectiveness of infrared detection on pinniped neonates within a forest habitat (>95% canopy cover). Kaikoura (East Coast of New Zealand) hosts New Zealand's largest breeding colony of fur seal (*Arctocephalus forsteri*). During the mothers feeding periods at sea, NZ fur seal pups undertake the iconic migration up a connected freshwater stream to Ohau forest (Figure 4.2) under the cover of trees, more akin to sea lion mother and pup migration into the bush on offshore islands (Campbell, Chilvers, Childerhouse, & Gales, 2006). The seal pups become increasingly hard to monitor as they move further into the bush and into denser tree cover, which makes it an ideal substitute study organism for the New Zealand sea lion. We conducted surveys of Ohau Point stream using a quadcopter fitted with infrared for aerial sampling and a walk-through ground count for comparison.



**Figure 4.1.** Rātā forest (*Metrosideros umbellata*) on Enderby Island, one of the Auckland Islands, a common habitat for local NZ sea lions (Photo credit: Kelly Buckle).





**Figure 4.2.** Ohau forest on the Kaikoura coast, a seasonal nursery site for local NZ fur seal pups.

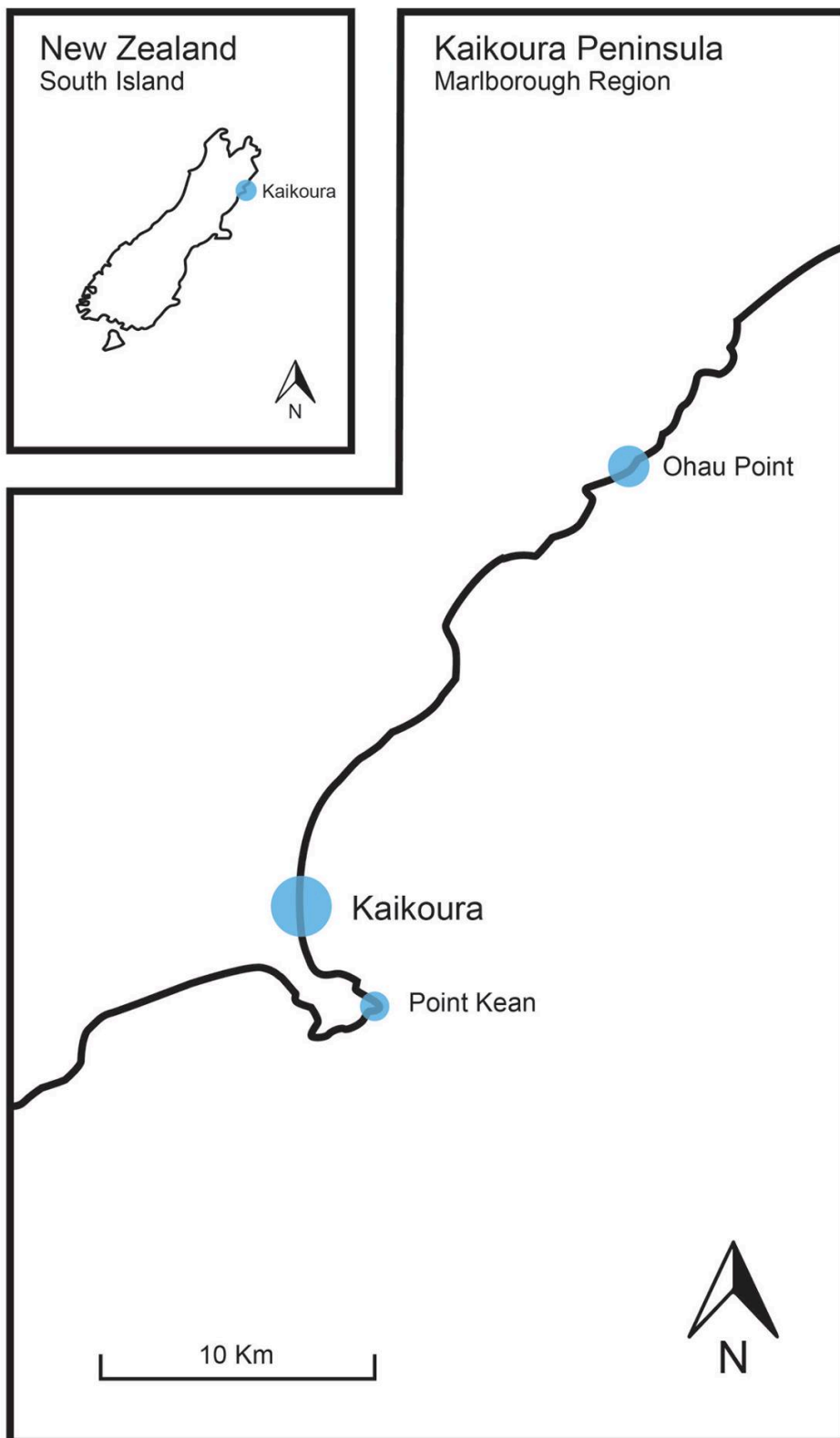
The aim of this research was to assess the detectability of marine mammals in a forested habitat through canopy cover and through ground counts at different times of the day in order to guide future directions and applications of infrared use in terrestrial population sampling of warm blooded mammals. We conducted an exploratory infrared survey of the NZ fur seal pups (*A. forsteri*) within a forested habitat and evaluated the effectiveness of thermal imagery on the ground and from the air, using a vertical take-off and landing (VTOL) quadcopter and a tripod mounted thermal camera. Our specific objective was to determine whether pinnipeds could be detected within a forest habitat using thermal imagery and whether they can be counted accurately enough to replace invasive walk-through counts.

## Materials and Methods

### Study Sites

Infrared surveys were conducted at two New Zealand fur seal colonies; Ohau Point (OP) and Point Kean (PK), on the East coast of the South Island of New Zealand (Figure 4.3). Ohau Point is one of the largest breeding colonies of NZ fur seals in New Zealand and is located 27 km north of the Kaikoura township (42°14'52.2"S 173°49'50.2"E). This site is characterized by a freshwater stream with dense canopy cover that leads to a waterfall, (from here referred as stream) (Figure 4.4a). Point Kean is located on the Kaikoura Peninsula and is host to a small, but rapidly increasing breeding population. This site is characterized by a flat rocky shore platform and bush, separated by a tourist car park (from here referred to coast) (Figure 4.4b).





**Figure 4.3.** Map of research sites (blue), Ohau stream and Point Kean on the South Island, Kaikoura, New Zealand (Created by Lon van Elk).



**Figure 4.4.** Photograph taken from Draganflyer X4-P Helicopter at 50 m height using a SONY NEX-5 camera above Ohau Stream (A) and Point Kean (B).

## Thermal Imagery Surveys

### DraganFlyer X4-P Helicopter™ (Quadcopter)

Flights were conducted using the DraganFlyer X4-P Helicopter™ (see chapter 2 methods). Its payload (the camera or thermal sensors attached) consisted of a T320 19 mm infrared camera (Table 4.1).

The UAV is equipped with a pressure gauge, allowing for flight height to be accurately measured and for the UAV to be flown within the legal guidelines.

**Table 4.1.** T320 19 mm Infrared Camera Technical Specifications.

<b>T320 19mm Infrared Camera</b>	
<b>Temperature range</b>	-40 - 80°C
<b>Analog Video Display Formats</b>	640 x 480 (NTSC) 640 x 512 (PAL)
<b>Detector</b>	Uncooled VOx Microbolometer
<b>Spectral band</b>	7.5 – 13.5 µm
<b>Sensitivity (NEΔT)</b>	<50 mKat f/1.0
<b>Software</b>	MicroD Player

The DraganFlyer X4-P takes off and lands vertically, allowing landing on a confined and/or thin landing site. The UAV can be flown for 8–10 minutes per battery using the SONY NEX5N and 15-17 minutes with the FLIR thermal attachment and legally must be flown in line-of-sight. Prior to commencement of the mission, a suitable take-off and landing site was established in the tourist carpark. This required an 8 m<sup>2</sup> area closed off to prevent tourists entering for their safety. The T320 19 mm Infrared camera was connected to a wireless monitor and radio link, so data could be recorded and viewed in real-time. Prior to take off, the standard operating safety procedures for the DraganFlyer X4-P Helicopter™ were conducted, the time of take-off and landing recorded and then flew six transects above the canopy of Ohau Stream and Point Kean. Three quadcopter transects were flown at 7 am, 12 pm and 4 pm for the photographic and thermal camera separately (Table 4.2). The Quadcopter was manually flown by a qualified UAV pilot due to the steepness of terrain and insufficient GPS signal for automated flight. Each transect took approximately 10 – 20 minutes to conduct, depending on prevailing wind conditions and tourist activity in the area. For missions

that tracked over the stream, a walk through count was conducted to provide a comparison with the acquired images.

**Table 4.2.** Aerial and ground thermal survey of New Zealand fur seal details conducted at 7 am, 12 pm and 4 pm on the east coast of the South Island, Kaikoura, New Zealand.

Camera	Location	Times	Total No. of transects/photographs
T320 19 mm Infrared Camera (UAV mounted)	a. Ohau Stream b. Point Kean	7 am, 12 pm & 4 pm	18
Optris PL450 (Fixed tripod)	a. Ohau Stream (2 sites) b. Point Kean (4 sites)	7 am, 12 pm & 4 pm	18

### **Ground Mounted Forward Looking Infrared Camera (FLIR) Data Collection.**

The Optris PL450 Infrared camera was used for our fixed thermal camera comparisons (Table 4.3). The Optris PL450 Infrared camera is a high speed, high resolution thermographic camera. It is able to provide real-time thermographic images at high speed, which enables the focusing and altering of the thermal sensitivity (temperature range) to focus and display the required detection temperatures (Hoffmann, Schmidt, & Ammon, 2015). This allows for better detection in denser foliage, but needs to be developed and tested from the air.

**Table 4.3.** Optris PL450 Infrared camera specifications (<http://www.optris.com/thermal-imager-pi400>).

<b>PL450 Specifications</b>	
<b>Temperature ranges</b>	-20 - 100 °C 0 - 250 °C 150 - 900 °C
<b>Spectral range</b>	7.5 - 13µm
<b>Detector</b>	UFPA, 382 x 288 pixel@80 Hz (Switchable to 27 Hz)
<b>System accuracy</b>	±2 °C
<b>Temperature resolutions</b>	0.08 K <sup>1</sup> with 38° 62°, 0.01 K <sup>1</sup> with 13°
<b>Warm-up time</b>	10 min
<b>Software</b>	PI Connect™

To determine the effectiveness of the Optris PL450 Infrared camera at detecting New Zealand fur seals through different foliage, fixed ground trials were conducted using a tripod. The Optris PL450 requires direct connection to a laptop or tablet running windows XP or higher. The camera is focused manually using the lens and data is displayed and recorded using PI Connect™. (<http://www.optris.com/optris-pi-connect>). Thermal images were taken of vantage points at both colonies (KP and OP) and paired with photographic images (SONY NEX-5) to determine the detection rate of both systems through different foliage types (Table 4.3). The Optris PL450 is designed specifically for use on UAV platforms, however, it is not currently configured for attachment to the DraganFlyer X4-P. Future research would require modification for the Optris PL450 to be integrated into the DraganFlyer gimbal and video system.

## **Data Processing**

All thermal and photographic imagery was displayed and counted on a Viewsonic™ (VX2439WN) 24 inch Full HD (1080p) monitor (<http://www.viewsonic.com/us/monitors/entertainment-vx-series/vx2475smhl-4k.html>). Thermal imagery from the T320 19mm infrared camera can only be viewed and processed using Micro-D player (<http://micro-dvd.en.softonic.com>).

Optris PL450 thermal imagery was processed using PI Connect™ (<http://www.optris.com/optris-pi-connect>).

## **Results**

### **Seal Identification**

Identification of a seal can be difficult in complex habitats such as dense forests, where the canopy can obstruct infrared radiation. Pinnipeds can have unique thermal qualities such as a distinct head shape and movement, very hot distinct eyes (which provides a thermal contrast with the rest of the body) and naturally hot flippers (used for thermoregulation). In a forested environment, we can identify seals by their swaying head movement between trees and their hot bright eyes (Figure 4.5). On the exposed rocky shore, the same cues can be used, however, on warmer days' seals are more homogenous and their thermal profiles can become merged when clumped which can make detection difficult. Therefore, seals are more accurately detected in the mornings, when it is colder and the seals are not too clumped. Seal pups can be harder to detect than adults because of their size.



**Figure 4.5.** A close-up thermal image of a New Zealand fur seal pup taken using the Optris PL450 in Ohau Stream, Kaikoura. The number indicates the temperature in degrees Celsius of the pixel beneath the user's cursor (PI Connect™).

Our identifications from thermal imagery required the detection of one or more of these features to ensure accurate identification:

1. Movement
2. Pinniped body shape
3. Hot eyes
4. Swaying head
5. Distinct flipper shape, thermal outline or fanning



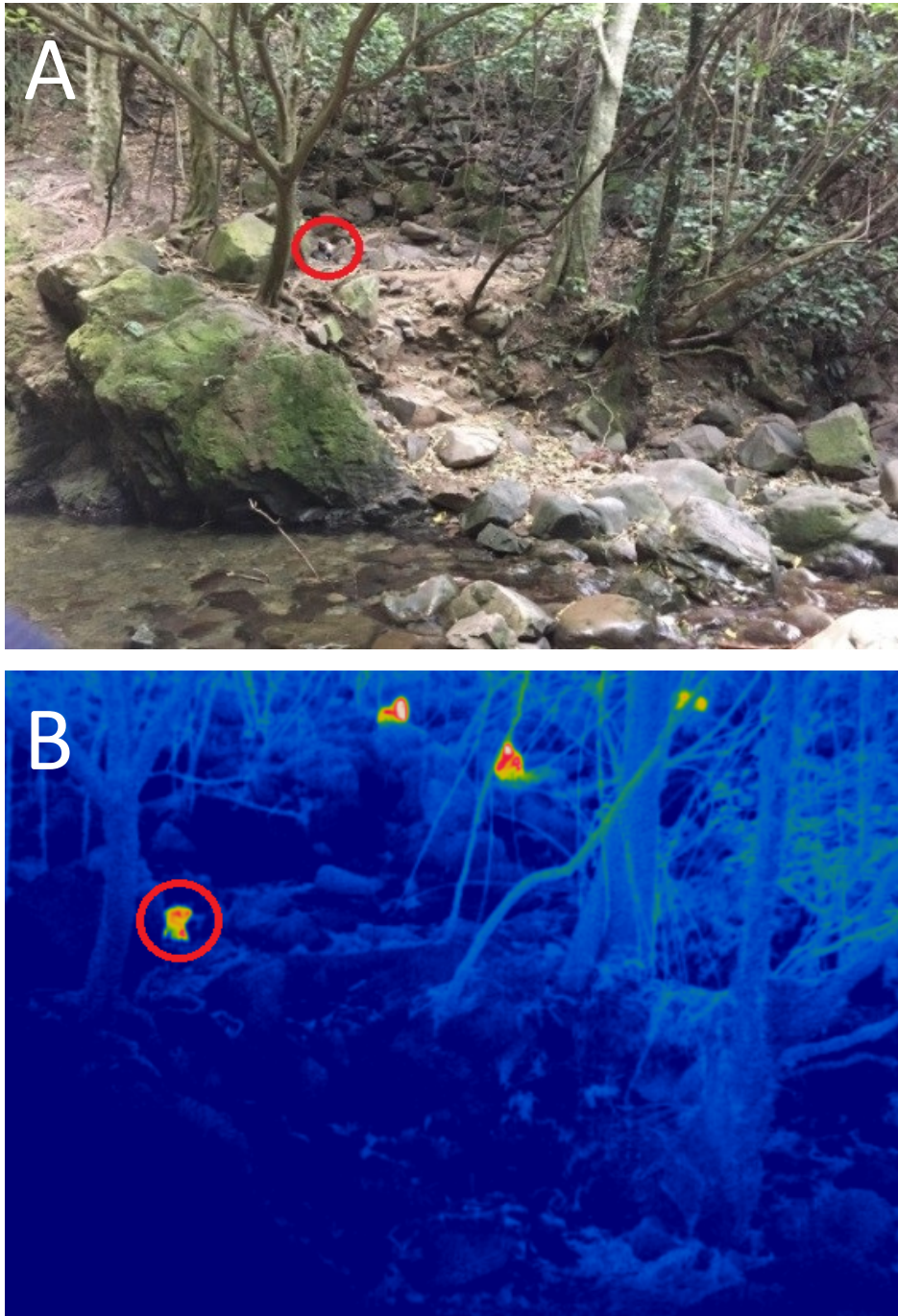
## Thermal Detection

The UAV mounted T320 19mm Infrared camera was able to detect some fur seals in low density, defined as less than <50% canopy cover. The percentage of seals detected in low density bush using aerial infrared compared to a thorough walk-through search ranged from 19.4 to 67%, with detection rate being greatest in the morning (Figure 4.6, Table 4.4). In contrast, the UAV mounted T320 19 mm infrared camera was unable to detect fur seal pups through a forest of greater than 95% canopy cover, shown by a 0% detection rate for every flight (Table 4.5). In comparison, the Optris PL450 had a greater seal detection rate than photographic detection, but only during the morning and afternoon at both sites (Figure 4.7, Table 4.6).



**Figure 4.6.** Photograph taken from Draganflyer X4-P Helicopter at 50 m height using a SONY NEX-5 camera overlaid with an aerial thermal image taken using the T320 19mm infrared camera at Point Kean, Kaikoura. Note: Seals have moved positions between flights.





**Figure 4.7.** Photograph taken from a tripod at ground level using a SONY NEX-5 camera (A) paired with a thermal image of the same frame using the Optris PL450 (B), at Ohau Stream, Kaikoura.

**Table 4.4.** Mean number (st.error) of seals detected using aerial thermal imagery (T320 19mm Infrared camera) vs. physical ground counts at Point Kean, Kaikoura, New Zealand. Detection percentage is calculated as the percentage of seals detected with ground counts that were also detected using infrared camera

Detection method	Morning	Mid-day	Afternoon
T320 Infrared (n= 9)	23 (5.48)	2 (0.88)	22 (1.53)
Bush Walk-through (n= 3)	34	12	49
Detection Percentage (%)	67	19.4	44.9

**Table 4.5.** Mean number of seals detected using aerial thermal imagery (T320 19mm Infrared camera) and by physical ground counts at Ohau Stream (>95% canopy cover), Ohau Point, Kaikoura, New Zealand. Detection percentage is calculated as the percentage of seals detected with ground counts that were also detected using infrared camera

Detection method	Morning	Mid-day	Afternoon
<b>T320 Infrared (n= 9).</b>	0	0	<b>0</b>
<b>Ground count (n= 3)</b>	12	9	<b>5</b>
<b>Detection Percentage (%)</b>	0%	0%	<b>0%</b>

**Table 4.6.** Total counts of New Zealand fur seals detected using Optris PL450 Infrared camera vs photographic image (SONY NEX-5) through different foliage types on the Kaikoura Coast.

Location	Foliage Type	Morning		Mid-day		Afternoon	
		Visual	Thermal	Visual	Thermal	Visual	Thermal
coast	Dense Bush (80%)	11	17	4	4	8	18
coast	Uncovered flat ground and Bush (40 %)	9	15	6	10	6	12
coast	Tall Grass (60 %)	6	10	5	5	5	5
coast	Moderate Bush (70 %)	-	3	1	0	1	5
stream	Dense contorted branches.	7	6	-	7	3	5
stream	Moderate Bush	3	5	2	3	1	5

## Discussion

The use of Unmanned Aerial Vehicle for surveying marine mammals offers an innovative, non-disruptive method of population sampling (Gooday, Zawar Reza, & Goldstien, 2016). This research has shown that the effectiveness of aerial thermal imagery depends on the time of day, the type of camera, the weather and the type of foliage.

We conducted sampling at three different times in order to determine whether there was an optimum time of day for sampling. We found that the morning and afternoon showed the highest rate of detection, which may be due to the lower temperature of surface-cover creating a larger thermal contrast between the vegetation and the fur seals (Davis & Sharma, 2004). Whilst this may

suggest that mid-day is the least optimal time for sampling, we must be mindful that there were also fewer seals under the foliage at mid-day during our study.

For the UAV flights we used the T320 19mm Infrared camera. The T320 19mm Infrared camera is a hot-spot camera which is small, versatile and can be attached to a drone. The drawbacks of this camera are its low resolution and the inability to measure temperature from the thermal image recorded. This camera was able to detect seals in the open and in very low density foliage but was insufficient when the foliage density was too great or seals were too closely clumped together. When conducting population counts using this camera, one must acknowledge the potential to underestimate counts due to missing seals under foliage (Boonstra, Krebs, Boutin, & Eadie, 1994). Due to the water composition of foliage, the canopy is highly absorptive and opaque which hides any warm blooded animals underneath. Thermal technology is also limited by the inability to detect the outline of thermally homogenous animals which can lead to underestimating grouped seals and also mistaking hot rocks for seals. Multi-rotor UAV's were crucial to the successful detection of seals as they are manoeuvrable and can fly continuously or stop and hover if a seal was spotted. This allowed for detecting movement or defining characteristics, such as the head or eyes. Hovering to detect movement also aided in the distinguishing of the number of individuals in groups and their size. The manoeuvrability of the Draganflyer™ and its gimbal (the camera support that allows rotation) also allowed fine scale manipulation of the flight pattern and camera angle. The camera angle manipulation was the key to the success of the Point Kean surveys. We were able to fly just under the canopy at an angle, which improved the detection rate as the canopy was less dense from this angle. Multi-rotor UAVs manoeuvrability and versatility make them perfect for this kind of sampling of marine mammals, however, most models are very susceptible to wind, shorter flight distances compared to fixed-wings and the payload attachments to rain (Jones IV, Pearlstine, & Percival, 2006).

Infrared cameras are not without limitations. Water is a potential issue as it can mask a seal's thermal signature by substantially evaporative cooling of the seal's surface. When a seal has just exited the water, the initial thick layer of water on its fur will make it appear cold or invisible as the camera detects the thermal signature of the water and not the seal (McCafferty, 2007). This could hide a seal and bias results during a population survey. Conducting an infrared survey in the rain can also present similar issues, as the image will appear faded or blurry due to the camera picking up the thermal emission of rain. Another issue we faced was that rocks hold their temperature for a very

long time and maintain temperatures that typically coincide with the seals. Conducting population sampling over rocks in the morning before they heat up could counter this issue.

## **Concluding Remarks**

The conservation of marine mammals is in pressing need of new, less invasive population sampling methods. The vulnerable New Zealand sea lion and rapidly expanding New Zealand fur seal are both excellent species on which to focus research, due to their biological similarities and different risk levels (Boren *et al.*, 2006; Robertson & Chilvers, 2011). This study will inform the design of future research through the exploration of infrared detectability of mammals in a terrestrial environment.

- Infrared detection of mammals is best conducted during the night or early morning to increase the thermal gradient between vegetation and the mammal.
- Multi-rotor platforms have better manoeuvrability than fixed-wing UAVs and can hover to confirm heat signatures.
- Hot spot cameras are effective at detecting mammals in open areas but are ineffective through foliage. Higher resolution cameras such as the Optris PL450 may offer greater accuracy counts.

## Chapter 5 – General Discussion

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Rarely do we get an opportunity for immediate application of our work in an ecological crisis. However, on the 14<sup>th</sup> November 2016 while in editorial phase of my thesis an unprecedented earthquake event caused an uplift of the coastal reef in my study area, with major landslides devastating the breeding colony in which my work was based. The immediate application of the results of my study to this natural disaster will be addressed at the end of the discussion. First, I will discuss the importance of understanding the vulnerable stages of these coastal marine mammals within the context of my work to develop non-invasive tools to better monitor the populations.

### The Ontogeny of Pup Behaviour

In this study, I observed the behaviour of seal pups located on the breeding rookery at Ohau Point during the period 2014 – 2015. I observed consistently high swimming behaviour and decreasing grooming and mock-fighting behaviour over the first five months of life in pups around rock pools. In particular, swimming increased over their critical period (January to April), whilst grooming, resting and fighting decreased. The ontogeny of pup behaviour has been studied previously in different species of pinniped, however, understanding of pup behaviour in New Zealand fur seal pups (*Arctocephalus forsteri*) until now, was qualitative (Crawley & Warneke, 1979; Stirling, 1970). This is the first quantitative baseline for NZ fur seal pup behaviour. Seal pup behaviour overall, changed with increasing temperatures. In particular, resting and grooming increased with increase in temperatures. Though this research found rock temperature and month to have a significant effect on pup behaviour, the inability to statistically separate these suggests further study is needed.

Understanding the early ontogeny of pup behaviour in relation to environmental conditions may improve our understanding of pup productivity, health and condition and the implications for future expansion. Particularly, as pups are known to explore and utilise ‘foreign’ environments. For example, every year<sup>1</sup> at the Ohau Stream waterfall, a unique phenomenon has occurred, where NZ

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<sup>1</sup> On November 14<sup>th</sup> 2016, multiple earthquakes caused massive landslides and sea bed rises along the Kaikoura coastline. Ohau Stream have suffered heavy damage from rock-fall. Access is currently limited and we will not know whether the pups will return up the stream again until April 2016.

fur seal pups spend a large proportion of their time inland. There are many possible explanations for this exploration, such learning to swim, interact, fight and rest in an environment without dangerous waves and aggressive territorial males. Other conditions such as weather and food availability are also likely to be contributing factors. Ohau Stream has become a tourist hotspot and receives thousands of visitors each year (doc.govt.nz). This suggests that the disruptive nature of tourists does not outweigh the benefits of visiting the pool, however, personal observations made between 2014-2016 have suggested that pups are spending less time near the tourist accessed areas. Understanding how pups behave and interact with humans is essential for effective and respectful ecotourism management.

As the New Zealand fur seal population grows and expands<sup>2</sup> further up the coast of New Zealand, pups are likely to come in more frequent contact with humans and urbanized areas with potentially negative consequences. For example, seal related road collisions on State highway 1 in Kaikoura have greatly risen in the last four years (Redmond, Hannaby, & Stratton, 2014; Redmond, Small, & Stratton, 2013, 2014, 2015). This trend is likely due to the rapid expansion of the Ohau Point seal colony, and the fact that fur seals tend to move on to the road for shelter and warmth during periods of extreme weather (Boren *et al.*, 2006). As the colony density continues to increase<sup>2</sup>, seal call outs are likely to become more frequent, not only resulting in a greater cost to the New Zealand Transport Agency (NZTA) but also increasing the risks to road users and rates of mortality for seals. The Department of Conservation (DOC) road kill data on fur seals in Kaikoura (1996-2005) documented on average 12 call outs for seals on the road annually, with a vehicle related mortality of 40%; 61% of these animals being pups (Boren *et al.*, 2008). As seal populations continue to increase and expand, understanding the natural behaviour that drives them to migrate inland may provide us with the necessary information to minimise negative interactions between humans and seals. For example, the presence of coastal rock pools is essential for pup development, growth and thermoregulation, therefore, implementing man-made pools may discourage pups from moving inland or migrating to areas where they may be a nuisance.

By providing a foundation for the future study of a species greatly linked to anthropogenic change, future research can begin to assess how rising global temperatures and human expansion effect arguably the most important, yet not completely functional pup behaviour, play.

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<sup>2</sup> Another impact of the recent earthquakes is the inevitable expansion of the Ohau Point fur seal colony. Seal density may have been initially reduced by earthquake mortality and further effected by emigration due to habitat loss.

## **Play – A Potential Model Species for the Function of Play?**

From an evolutionary perspective, play has a cost and therefore must serve some ecological benefit to the species (Burghardt, 1999). To study behaviour comparatively between species, it is crucial the definition of play is uniform between all studies. Building on the work of the pioneers of the study of play, Fagen and Bekoff, Burghardt (2005) created five criteria and three types for determining whether behaviour was play. However, for the last century, the function of play has been debated and current hypotheses are numerous. New Zealand fur seal pups spend majority of their juvenile life resting and playing (swimming and mock-fighting) and so may be an ideal species for the study of the function of play and how anthropogenic impacts, such as rising temperatures and disturbance may affect play. From 2 weeks of age, pups are swimming, mock fighting and investigating unknown objects. Pups conduct the three forms of play, from the most primitive, locomotive play to the more developed social and object play.

Play in New Zealand fur seals was comprised predominantly of swimming, however, mock fighting was also present and strongly resembled the territorial fighting behaviour of adult males. Whilst it was uncoordinated and lacked the ritualistic behaviour prior to an aggressive engagement in adults, pups occasionally fought over territories or ideal resting spots, suggesting that mock fighting behaviour, may in fact not be entirely playful. Further study on New Zealand fur seals could also assess size, health and condition as an indicator of hierarchical position, to investigate whether there is any hierarchical effect on play fighting. Mock fighting is not completely functional, spontaneous and not ritualised, and is more likely play if not hierarchically influenced than these competitive aspects suggest. It could also function as a method of developing a hierarchy early, without the risk of aggressive interaction, as suggested in the yellow bellied marmot (Blumstein, Chung, & Smith, 2013).

Caro (1995) states that the function of play behaviour is to develop behaviours that will improve your fitness. Locomotor play (such as swimming) is relatively primitive and consists of jumping, running or other motor activities in an unpredictable manner (Bekoff, 1984; Burghardt, 1999). These behaviours have been hypothesised to function as training and physical development for adult hood (practice theory) through muscle and cardiac hypertrophy and bone growth (Spinka *et al.*, 2001;



Vieira & Sartorio, 2002). This is the most likely theory for the function of swimming play, as pups spend most of their time swimming in rock pools, prior to being weaned at ~11 – 12 months of age. This suggests that they are ‘training’ so that once weaned, they are confident swimmers and able to catch their own food. To test this, one could assess swimming prowess through speed loggers similar to \_ and assessing whether time spend playing (swimming) had a positive effect on swim speed and acceleration.

Social play involves more than one animal (Spinka *et al.*, 2001), usually of the same age class and size (Markus & Croft, 1995; Thompson, 1996). Mock fighting, a common type of social play, has been observed in rats, mice, cheetahs, sea lions, fur seals (Caro, 1995; Harcourt, 1991; Ruffer, 1965) and can continue in adulthood (Pellis & Pellis, 1991). Whilst generally competitive in nature, mock fighting can appear aggressive, however, injury is uncommon (Beckel, 1991). The function of social play appears to support the social bonding theory, to develop social skills, reduce tension and improve social cohesion (Bekoff, 1984; Fagen & Fagen, 1981). The data obtained in this research is sufficient to test this, but exceeds the time limitations, however, by correlating the number of pups around a pool and the time spent playing, one could infer whether play is increasing social cohesion. Other projects that would prove interesting is the assessment of play, in regards to feeding. Pups are entirely reliant on their mother’s milk until they are one year of age, and thus rely entirely on the energy obtained from their mothers 5 - 6 day long, fishing trips.

## **Other Behaviours**

Object play is the behaviour of manipulating or interacting with an inanimate object (Bekoff, 1984). Whilst unanalysed in this study, object play was observed frequently and has been considered an indicator of higher intelligence (Pellis, 1991). Object play is more common in the presence of conspecifics (Baldwin & Baldwin, 1973; Cheney, 1978), however, it has been observed in individual animals (Gamble & Cristol, 2002). Whilst common in mammals, object play is also found in birds such as Herring gulls (*Larus argentatus*), which will drop and catch an object repeatedly (Gamble & Cristol, 2002) or Neotropic cormorant (*Phalacrocorax brasilianus*) and Green Heron (*Butorides striata*) which have been observed playing with sticks and leaves, and throwing dead fish (Sazima, 2008).

In the last 10 years, Ohau stream has become a tourist hotspot. With ever increasing numbers of tourists, the ability to regulate tourist behaviour, especially in a free access site, is becoming

increasingly difficult (Boren *et al.*, 2002). Tourists have been encouraged through social media videos and less ethical tourism companies to bring toys such as balls and human pool toys, to throw into the waterfall pool and watch the seals happily play with them. Whilst this may seem initially charming, there are potential immediate negative impacts such as choking or the consumption of toxic materials. Object play behaviour has been shown to have positive effects on cognitive development, however, this increase in unnatural human to animal interaction may also be facilitating inquisitive behaviour in fur seals, such as increasing their desire to investigate anthropogenic sea waste or to interact with fisheries equipment, which could increase rates of entanglement and mortality (Page *et al.*, 2004). It may also result in seals becoming less afraid of humans, and increase rates of seals entering urbanised areas, as seen in Wellington City when a seal wandered through the streets.

Grooming behaviour in pups found in Ohau Stream was much lower than on the shore (pers. obs.). This could be due to a reduction in parasites through cleansing in freshwater, or because they are no longer experiencing salt irritation. Furthermore, in this study, when pups weren't resting or playing, they would be grooming, potentially removing parasites from their fur. This is supported by Sharpe (Sharpe *et al.*, 2002), who suggested an increase in parasite load would result in a decrease in play.

Play has been considered a reliable indicator animal welfare in many species, wild and domestic (Held & Špinka, 2011). For example, a 17x reduction in play was observed rhesus monkeys, (*Macaca mulatta*), following a 22-day acute food shortage (Loy, 1970). Similar behaviour was observed in bottle-fed white-tailed deer young, (*Odocoileus virginianus*), with a 35% observed reduction in play (Muller-Schwarze, Stagge, & Muller-Schwarze, 1982). Similarly, Sharpe *et al.* (Sharpe *et al.*, 2002) concluded that supplementary feeding in meerkats, (*Suricata suricatta*) resulted in twice the rate of play. Palagi *et al.* (Palagi *et al.*, 2004) observed chimpanzees play behaviour to increase prior to feeding, which was hypothesised to reduced competitive tendencies through tension reduction. This cannot be directly applied to fur seals, as only one pup is usually fed at a time, and competition for food like captive chimpanzees is unlikely. Regardless, future study could measure maternal investment or suckling behaviour to determine whether time since last feed increases play, which could provide development opportunities for a non-invasive indicator of pup condition that could be paired with Unmanned Aerial Vehicle surveys (Held & Špinka, 2011).

## UAV and Thermal Imagery

This study is the first quantitative application of UAV systems over a coastal rocky shore, which came with its own unique set of challenges and resolutions (Chabot & Bird, 2015).

My results confirm that UAVs with attached camera can non-invasively and accurately detect visible pups on a heterogeneous rocky shore at 35 m height, with 27% of the accuracy of traditional mark-recapture method. The addition of a thermal imaging camera enhanced detection in low-density forest cover and in open areas, during the cooler periods of the day. This fulfils the aim of the study, to develop a non-invasive population sampling method for measuring pup productivity within any pinniped colony.

I conducted a non-invasive sampling method utilizing Unmanned Aerial Vehicles to investigate the value of UAV surveys over complex the rocky shore habitat (Ohau Point). My surveys detected substantially lower pup counts than traditional mark recapture methods; however, comparing these methods directly undervalues the benefits of UAV based population surveys. The UAV surveys conducted in this study provided an immediate snapshot of the current number of pups, visible from the air in less than 20 minutes with two scientists. A mark recapture survey of the same colony aims to count all pups within a colony and requires at least four scientists and takes approximately 2 – 3 days to complete, depending on weather and fatigue. To record indices of pup health and condition or attach long term tags to pups, would require significantly more time in the colony. Human entry into the colony is extremely disruptive and can cause stampedes and pup mortality, and can be dangerous for the scientists involved (Boren *et al.*, 2006). The most accurate UAV survey in this study counted 27% of the pups in a fraction of the time required for mark recapture with relatively low visible disturbance. This rapid method of population sampling could be used for rapid-response surveying of coastal mammals after a natural disaster, such as an earthquake, storm or landslide, as well as, reoccurring population surveys (Pettinga, Yetton, Van Dissen, & Downes, 2001; Turner, Harley, & Drummond, 2016).

UAV surveys have been used for surveying wildlife in the past with various degrees of success. UAVs have been utilized to detect aquatic (Martin *et al.*, 2012; Stark, Parthasarathy, & Johnson, 2003) and terrestrial mammals (Schiffman, 2014), birds (Watts *et al.*, 2008), reptiles and amphibians (Brooke *et al.*, 2015; Jones IV *et al.*, 2006) with various degrees of success. Promising UAV surveys have been conducted successfully on elephants (Vermeulen *et al.*, 2013), small and large cetaceans (Harwood,

Innes, Norton, & Kingsley, 1996), birds (Ratcliffe *et al.*, 2015b; Vas, Lescroël, Duriez, Boguszewski, & Grémillet, 2015), deer (Israel, 2011b) and chimpanzee and orangutan nests (Hodgson, Baylis, Mott, Herrod, & Clarke, 2016; Van Andel *et al.*, 2015). Aerial surveys of pinnipeds such as, bearded seals, ribbon seals, ringed seals and spotted seals were relatively successful, whilst surveys detected Harp seals (*Pagophilus groenlandicus*) and Hooded seals (*Cystophora cristata*), but were limited by the range of the UAV and ice-shelf obstruction (Curry *et al.*, 2004; Moreland *et al.*, 2015). Whilst successful, current pinniped surveys are conducted on relatively flat habitat, which requires only a contrast of colours between pinniped and substrate for easy detection. In contrast, multi-spectrum photography captures and filters data at different frequencies across the electromagnetic spectrum (colours) and has been tested in wide open areas. For example, a high-endurance UAV was deployed from a National Oceanic and Atmospheric Administration vessel to survey Alaskan ice seals (Moreland *et al.*, 2015). Moreland *et al.* (2015) concluded that the survey results were promising and significantly less disruptive than low helicopter surveys, however, the UAV and boat costs were too high to warrant the loss in detection rate.

Regardless of the species, the greatest challenges when conducting UAV surveys can be habitat type, airspace regulations, disturbance, weather and technological malfunction. UAVs have been employed over a wide range of habitat types with ranging success, from wetlands (Watts *et al.*, 2010) and sandy beaches (Barasona *et al.*, 2014), to forest (Mancini *et al.*, 2013), rangelands (Beck, Booth, & Kennedy, 2014) and polar regions (Curry *et al.*, 2004). UAV's are able to access hard-to-reach locations, cover expansive areas with relatively low cost, and do so with minimal risk to the researcher. UAVs have been used to assess the previously challenging aquatic habitats, previously surveyed by manned aircraft and considered unnecessarily hazardous (Chabot & Bird, 2015). From the easiest application on Florida manatees (*Trichechus manatus*) found in shallow, clear water in the Homosassa River (Flamm, Owen, Owen, Wells, & Nowacek, 2000) to autonomous detecting and tracking of whales at sea (Selby, Corke, & Rus, 2011). Drones have also been utilized for covering huge open expanses of land, to conduct head counts of bison (*Bison bison*)(Watts *et al.*, 2010), to conduct a population census of Antarctic fur seal (*Arctocephalus gazelle*) (Goebel *et al.*, 2015), or to protect African elephants (*Elephas maximus sumatranus* and *Loxodonta Africana*) (Koh & Wich, 2012; Vermeulen *et al.*, 2013), rhinos (*Diceros bicornis* and *Ceratotherium simum*) and giraffes (*Giraffa Camelopardalis*) from poachers (Mulero-Pázmány, Stolper, van Essen, Negro, & Sassen, 2014). The reduction in researcher fatigue, access to remote locations and collection of a permanent data record (allowing review for quality control) (Hodgson, Kelly, & Peel, 2013) allows for easier collection and analysis of data.

UAVs paired with high resolution photographic technology not only allow the detection of animals in difficult habitats, but have also ventured into the assessment of size. This study aimed to assess photographic morphometric sampling from above, however, there was no relationship between any physically collected data and photographic data. This is supported by a study that collected similar morphometric data on leopard seals (*Hydrurga leptonyx*) in order to assess condition, who's results were also unsuccessful with GPS accuracy being insufficient to accurately identify individual seals and inconsistency in seal measurement (Pomeroy, O'Connor, & Davies, 2015). Pomeroy et al. (2015) also trialled photo identification of individual Gray seals (*Halichoerus grypus*) and Harbor seals (*Phoca vitulina*) and found video footage from 35 m height sufficient for individual pelage patterns to be identified for Gray seals. Photo identification of harbor seals was conducted at an elevated flight height of 50 metres due to a noisier octocopter (Skyjib™) being used. This resulted in inaccurate identification without additional personal knowledge of individual seals and their locality (Pomeroy et al., 2015). Preliminary work has also been conducted on tracking, acceleration and velocity calculation on humans and was concluded to be extremely easy to use and was able to track the location, acceleration and velocity of multiple free ranging animals simultaneously (Harvey et al., 2016). The culmination of this research highlights the requirement of extremely high resolution images, image stabilization, GPS accuracy and accurate physical and digital measurement for aerial morphometrics to replace traditional methods. This is the final challenge for UAV surveys of pinnipeds to fully replace traditional mark recapture and physical measurement methods for assessment of colony growth, health and condition.

UAVs have not only been used to detect animals, but also signs of animals. For example, UAV surveys have successfully detected chimpanzee and orangutan nests, located at the tops of trees in Gunung Leuser National Park in Sumatra, Indonesia (Koh & Wich, 2012). Presence of Northern pocket gophers has also been implied through UAV detection of their mounds in southwestern Saskatchewan open grasslands (Whitehead & Hugenholtz, 2014).

The potential applications of this technology are endless, however, to replace invasive methods, disturbance to the target species must be minimised. Unfortunately, with rise in hobbyist the effect of UAV on species behaviour was of high priority in this study. I aimed to quantify disturbance of UAV flight over pinnipeds. These data were utilized in the validation of my methodology as non-disruptive, and was provided as a report to The Department of Conservation, to aid in the development of rules and regulations for the flight of UAVs around coastal habitats.

Disturbance observed in the Ohau the breeding colony consisting of mothers and pups, had a greater colony activity level (disturbance) than a non-breeding colony consisting of territorial males during UAV flights. My results suggest that whilst UAVs may cause minor disturbance to a pinniped colony when flying at low heights (35 m), this intermediate height maximises count accuracy whilst keeping disturbance at an acceptable level. The conflict between flight height and disturbance can be a balance between count accuracy and disturbance.

This study showed the successful detection of seal pups, with limited disturbance which supports the aim of the study, to develop a non-invasive population sampling method. Prior to this study, very little had been documented regarding the impacts of UAV flight around animals. Majority of previous studies using drones for population sampling have stated their methods cause no disturbance without any quantitative analysis to support their claim (Jones IV *et al.*, 2006; Ratcliffe *et al.*, 2015b). Additionally, the permitted use of UAV's without consideration for disturbance, for monitoring of endangered rhinos (*Diceros bicornis* and *Ceratotherium simum*), arctic ice species by oil and gas companies and for ecotourism, highlight the potential for the oversight of UAV disturbance (Ditmer *et al.*, 2015).

Currently, quantification and analysis of UAV disturbance on wildlife in current literature is scarce (Potapov, Utekhina, McGrady, & Rimlinger, 2013; Vas *et al.*, 2015). The most vulnerable animal during UAV flights is birds, but the disturbance of UAVs on birds has also been studied more than any other animal. Recent research showed only 20% of UAV flights were disruptive to highly territorial waterbirds and waterbirds could be approached up to 4 m without an escape response (Vas *et al.*, 2015). This study was conducted on semi-captive mallards (*Anas platyrhynchos*), wild flamingos (*Phoenicopterus roseus*) and common greenshanks (*Tringa nebularia*). Vas *et al.* (2015) focused on the behavioural response of grounded wetland birds, which while valuable, does not address the most dangerous of interactions between UAV and bird, while the bird is airborne. Potapov (Potapov *et al.*, 2013) utilized UAVs for nest checks of Steller's sea eagle (*Haliaeetus pelagicus*) and concluded that though defensive behaviours such as mobbing still occur, at least researcher safety was improved. This idea is supported by similar studies on hooded crow (*Corvus cornix*) nests (Weissensteiner, Poelstra, & Wolf, 2015). A study on Adélie penguins (*Pygoscelis adeliae*) recorded disturbance immediately after take-off and during flight between 20 – 50 m height, with <20 m height elevating disturbance to the entire colony (Rümmeler, Mustafa, Maercker,

Peter, & Esefeld, 2015). These three studies suggest that bird disturbance is a much greater issue for all UAV flight, and that further research is needed to minimize any flight risk, especially around endangered species (Stewart, 2015). The interaction between UAV and bird are crucial for any coastal UAV study in New Zealand due to our high number of indigenous and endemic coastal species. In developing this tool, I considered it necessary to make it non-disruptive for all animals, not just target species.

A study on black bears found that UAV flights elicited a physiological response to UAV approach, whilst remaining 'behaviourally' undisturbed (Ditmer *et al.*, 2015). This suggests that whilst behaviourally my methods were of low disturbance, fur seals may have been physiologically disturbed and thus the non-disruptive appeal of this methodology must be interpreted with caution. The results of this study are also based on measuring the activity level (%) of the colony, to see whether colony activity level increased during flight. The resting activity level of the Ohau Point colony was previously documented at 17% (Boren *et al.*, 2002) which was based on a yearlong measurement of activity and did not account for differences between colony types, time of day or weather conditions. The caveat for use of this method is that it doesn't account for natural movement or behaviour of the colony and it did not establish a control for each colony type and time of day which would have strengthened this study. As UAVs become cheaper and more effective, we have a responsibility as scientists to utilize the most advanced technology as possible to minimise our impact on our study species.

Another drawback of UAV's is the potential for malfunction or unreliability that is inherently paired with the use of any technology. Though the DraganFlyer used in this study has failsafe hardware, not common in cheaper retail models, it is reliant on GPS for positioning and thus is redundant in GPS lacking areas such as Ohau Point, Kaikoura. Due to the hills and the lack of GPS signal, automated flight and inbuilt safety mechanisms were not used, which resulted more conservative flying. UAVs, regardless of price point can randomly fall from the sky and it is crucial that researchers minimise any potential risks to the target species, non-target species and equipment (Takahashi, 2015). Majority of UAVs are fragile and must be kept dry, whilst the DraganFlyer was able to fly in low precipitation with no issues, heavier rain or a less capable drone could lead to a crash. The DraganFlyer is also perfect for remote sampling as the propellers detach and it can fold up and easily fit inside an average backpack. Understanding equipment limitations before commencing flight over wildlife is essential for safe, less disruptive flight and ultimately will enhance population counts.

Though this method has many ecological applications, the recent 'drone revolution' has been met with rapid development of UAV airspace regulations and legal requirements, which can limit where and how we fly (Wallace, 2016).

The practical applications of drones are endless, however, recent rises in the hobbyist use of drones has led to increasing numbers of unqualified pilots and blanket protection laws being introduced. As the 'drone revolution' currently booms, governing agencies are racing to implement and enforce laws and regulations to protect airspace, people, property and wildlife. In New Zealand, the number of reported drone occurrences has risen from one in 2010, to 128 in 2015 and is still rising, currently 136 in October 2016 (NZCAA unpublished data), three of these occurrences being crashes.

## Thermal Imaging

Infrared thermography is a non-invasive method for remote sensing the temperature of any surface and has been used in many commercial applications from veterinary medicine, law enforcement, border control, construction, biology and ecology (McCafferty, 2007). Thermal imaging has been a promising ecological tool for over 40 years, being used first to detect deer in open areas from 300 m above the ground (Graves *et al.*, 1972). The greatest challenges when detecting wildlife with thermal imagery are vegetation, water, sunlight and target species densities. Similarly, I found thermal imaging to be effective at detecting New Zealand fur seals from the ground in the bush and by UAV on the rocky shore during the cooler parts of the day. Thermal imaging paired with photography for validation has been used to detect polar bears (Amstrup, York, McDonald, Nielson, & Simac, 2004), pinnipeds (Chernook *et al.*, 1999; Speckman *et al.*, 2011), big horn sheep (Bernatas & Nelson, 2004) and ungulates (Franke, Goll, Hohmann, & Heurich, 2012; Kissell Jr & Nimmo, 2011).

Graves (Graves *et al.*, 1972) first documented the inability to detect deer efficiently behind vegetation. This is further supported by this study, in which I was unable to detect fur seals through dense vegetation from UAV surveys. In contrast, a study using an autonomous UAV fixed with a thermal camera was used to detect roe deer (*Capreolus capreolus*) fawns hiding in bushes to prevent them being killed by pasture mowing machines, suggesting the limitation vegetation imposes on thermal imagery depends on bush density (Israel, 2011a). The critically endangered, New Zealand sea lion females migrate into the bush to give birth (Childerhouse & Gales, 1998). The Ministry for Primary Industries utilized the thermal data from this research, as preliminary trials for application in



active pup productivity surveys that occur annually on New Zealand's smaller islands. These surveys generally involve searching through dense bush on foot, where sea lions can be extremely difficult to find. Thermal imagery could improve these surveys greatly, provided the weather conditions remain relatively dry.

One caveat of my thermal study is that it was conducted over dense bush surrounding a stream that the pups swim in, which this study has shown, hides their thermal signature. I used the Optris PI 450, which was also sensitive to sea spray and precipitation, common on the exposed harsh east coast of New Zealand, as the thermal imager would detect the surface temperature of each water droplet, resulting in a fuzzy image. Fur seals recently emerging from water that were detectable by the naked eye, appeared dark and blended in with their environment. A study testing the ability to detect white-tailed deer surrogates in water versus on land found 4 out of 20 were detected in water, whereas 16 of 17 were detected on land (Kissell Jr & Tappe, 2004). Fur seals are marine mammals and spend a large proportion of their time in water; therefore, water interference on thermal imaging must be considered for future sampling efforts.

Sunlight, or substrate temperature was a major limitation of all thermal detection surveys conducted during this research. All mid-day surveys, conducted during the sunniest and warmest period of the day, yielded the lowest detection rate in the bush and on the shore. All ground substrate heats up in the sun, especially rocks which can hold heat for prolonged periods, and which are used as resting points by the NZ fur seals. This thermal storage resulted in masking of fur seals or production of 'noise', visually portrayed as hot spots. Similar results were observed in a study assessing the factors that affect polar bear den detection using Forward Looking Infrared, the dominant negative factors being solar radiation, wind speed and wall thickness (Robinson, Smith, Larsen, & Kirschhoffer, 2014). This highlights another caveat of thermal research, in that, rocks or other hot (and similar shaped) objects can lead to misidentification of animals and over counting. A similar study on moose and wild turkey populations found that moose populations were severely underestimated by untrained observers, whereas flocks of wild turkeys were accurately counted by flying concentric circles above them (Garner, Underwood, & Porter, 1995).

Thermal imaging has the greatest potential in polar regions, where a warm blooded animal will have a greater thermal contrast with its environment. Thermal trials on bearded seals (*Erignathus barbatus*), ribbon seals (*Histiophoca fasciata*), ringed seals (*Phoca hispida*) and spotted seals (*Phoca largha*) over the eastern Bering Sea determined detection of these species was possible, however,

due to automation species misidentification, false positives and incomplete detection were common (Conn *et al.*, 2014). Conn *et al.* 2014 were largely limited by their data, which they based their automation modelling around and believe that automation in thermal and UAV sampling is extremely promising for future research. Another study analysed the spectral reflectance of Arctic mammal pelts and determined all pelts could be distinguished from clean snow at many wave lengths, however, variation within each species pelt made discrimination difficult (Leblanc, Francis, Soffer, Kalacska, & de Gea, 2016). A thorough understanding of the reflectance of all arctic animals, snow and other environmental elements would allow rapid detection and possible automation of remote arctic sensing.

UAV technology is a rapidly growing industry with expanding application, in particular, remote wildlife monitoring. Paired with thermal imagery, thermal imaging equipment and Unmanned Aerial Vehicles will become part of any ecologists everyday tool bag.

## **Immediate Application 2016**

A recent natural disaster has provided immediate application for the use of this research, the methodological framework and its baseline data. On the 14<sup>th</sup> of November, a magnitude 7.5 earthquake, centred in Culverden, devastated a large portion of the East Coast of New Zealand from Christchurch to Wellington (Geonet, 2016 #666). The earthquake and continuous aftershocks have caused sporadic damage to roads along the entire East coast, as well as, landslides and uplift of the sea bed. Unfortunately, rock fall has completely covered approximately 80% of the Ohau Point seal colony, leaving it unrecognisable and potentially less habitable for New Zealand fur seals. The colony is currently inaccessible and any assessment of the damage to the landscape, road and seal colony has been made from public plane and helicopter based aerial photography. It is crucial that we act fast, to obtain accurate documentation of colony dynamics that will advise scientific, civil engineering, fisheries and local council organisations of the status of the fur seal colony in the immediate future.

The week following the hand in of this thesis, I will be conducting helicopter based aerial thermal imagery assessments of the Ohau Point seal colony. The aerial use of the Optris PI450 high resolution thermal camera, will allow an accurate snapshot of the seals along the East coast, from Barneys rock to Cape Campbell. By conducting the flights early in the morning, thermal imagery will

provide a population count, which can then be compared with the UAV data obtained in Chapter three. By reanalysing the UAV data from chapter 3, I can conduct a count of the adult seal population to provide a comparison with post-earthquake numbers. It is crucial that we obtain an immediate population count of the entire coast to assess colony decline and potential expansion. (Geonet, 2016 #666). Thermal imagery is advantageous on a rocky shore, as it can reveal any seals potentially in caves or crevices, as well as, verify dead pups by lack of a heat signature compared to a normal photograph. This method must consider the 'camouflaging' effect of water on wet seals, especially when identifying dead seals. This unique opportunity also offers the potential to determine whether thermal imagery can detect female fur seal pregnancy status, as well as, any potential earthquake related injuries. This method will be paired with an aerial photographic survey as well, in order to verify hotspots and further develop the methodology.

I also propose to undertake a complete population count using the DraganFlyer quadcopter, either from land or sea (depending on accessibility). This survey will provide valuable information on the colony population numbers, mortality, and habitat assessment. Habitat assessment will be crucial for future expansion of the colony, as colony density and habitat type can affect Adult female fur seal behaviour (Kim, 2016) Photographic images taken from the DraganFlyer will be closer and of higher resolution than from the helicopter, allowing identification of sex, age classes and pup mortality. This data will be essential for documenting and assessing the colonies recovery after a natural disaster.

Additionally, a thermal survey will be conducted of the two Hutton's Shearwater (*Puffinus huttoni*) colonies. Hutton's shearwater is an endangered sea bird that nests and breeds in the Kaikoura mountain ranges (Sommer *et al.*, 2009). Hutton's shearwaters lay eggs in shallow underground nests, which could have been destroyed in the earthquake. Peak egg laying time is early November, which highlights the urgent need for assessment of this critical colony. All road access to the colonies has been blocked by landslides and any assessment of the Hutton's colony has been impossible. The Hutton's shearwater colonies need to be assessed to quantify habitat damage, any visible birds and damaged nests. Utilizing helicopter based thermal imagery, we can detect any birds above ground, whilst also testing the efficacy of thermal imaging for nest burrow detection. Past research has shown successful detection of cavity-nesting birds such as the pileated woodpecker (*Dryocopus pileatus*), the northern flicker (*Colaptes auratus*), Barrow's goldeneye (*Bucephala islandica*), and the bufflehead (*Bucephala albeola*) (Boonstra, 1995 #665). Boonstra et al (1995) concluded that efficacy of thermal imagery depends on the insulative quality of their nest and feathers. Thermal

imagery will allow us to remotely assess the Hutton's colony, prior to more in-depth investigation once the region is safe.

Pup behaviour has also been potentially negatively affected by earthquake induced habitat change. Pups require rock pools to safely learn to swim, caves and crevices for shade and high areas to escape high wave action during storms. During the helicopter based surveys next week, I will be assessing the pups' current habitat and whether it provides the ability to play which is essential for their growth and development. The understanding of the ontogeny of pup behaviour will allow us to predict the potential loss of fitness in pups due to habitat change forcing the alteration of their behaviour.

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## **Appendix One: Publication currently in review (Journal of Unmanned Aerial Vehicles).**

**Note to thesis marker: Figures excluded due to journal submission rules. See chapter four.**

**Title of project:** An assessment of thermal-image acquisition with Unmanned Aerial Vehicles (UAVs) for population sampling of seals and sea lions.

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[Keywords: aerial, thermal, imagery, \*Arctocephalus forsteri\*, survey, pinniped.](#)

## Abstract

We investigated the efficacy of infrared thermal imaging devices for detecting warm blooded marine mammals in forested environments. Our objective was to determine whether pinnipeds could be detected through the forest canopy using thermal imagery. We used a UAV mounted T320 19 mm infrared camera and a ground mounted Optris PL450™ to survey New Zealand fur seal (*Arctocephalus forsteri*) located in Ohau Stream and Point Kean bush, on the East Coast of New Zealand. Ground surveys using the Optris PL450™ detected more seals than paired photographs during the cooler times of the day (morning and evening). Aerial thermal surveys were successful in detecting fur seals in open areas, but were unsuccessful in areas of high canopy cover (>80 %). We discuss the advantages and limitations of thermal imaging for population sampling and provide some recommendations for future research. We conclude that thermal imagery has the potential to become an effective and widely used tool for ecological population surveys.

## Introduction

Population sampling is an essential part of ecosystem conservation and its effectiveness relies heavily on the accuracy of survey methods (Morris & Doak, 2002). Population surveys can be time consuming and logistically difficult in remote or dangerous locations, and they can create disturbances within the population being sampled, as well as among populations of other non-target species (Ditmer et al., 2015). Unmanned aerial vehicle (UAV) technology provides an opportunity for accessing difficult to sample habitats and conducting population sampling. Sampling with UAV technologies removes the need for human intrusion into animal colonies and limits human exposure to potentially dangerous environments. In addition, dense terrain, such as forests, can present challenges for detecting and identifying warm blooded animals for the purpose of population sampling; but image acquisition in the infrared band has been shown to be effective at detecting white-tailed deer, *Odocoileus virginianus*, in complex habitats using their thermal heat signature (Croon, McCullough, Olson Jr, & Queal, 1968; Graves, Bellis, & Knuth, 1972). Thermal imagery has also shown promise in open environments for estimating marine mammal populations such as harbour seal (*Phoca vitulina*) and walrus (*Odobenus rosmarus divergens*) (Burn, Webber, & Udevitz, 2006; Duck, Thompson, & Cunningham, 2003).

New Zealand's biodiversity is at risk of decline due to its high degree of endemism, susceptibility to invasive species, and the lack of the economic sectors' consideration for environmental costs (Stewart, 2015). New Zealand is home to a diverse range of seabirds and marine mammals, some of which are considered 'vulnerable' or 'endangered' and are in urgent need of new population sampling methods. The combination of UAV and infrared

technology could offer a potentially less invasive way to conduct population monitoring of seabirds and marine mammals, both at land and at sea. Whilst UAVs pose a potential threat to flying seabirds, flightless New Zealand species, such as the little blue and yellow eyed penguin colonies, could be surveyed with lower disturbance than traditional ground counts, and with similar accuracy (Ratcliffe et al., 2015). The incorporation of infrared technology into Ratcliffe et al., 2015 experimental design could further improve the accuracy of aerial penguin counts. Traditional ground counts are also the favoured method of population surveying for marine mammals such as the New Zealand sea lion and fur seal, yet, these methods are disruptive to the animals and can be dangerous for the scientist undertaking them.

The New Zealand sea lion (*Phocarctos hookeri*) is currently the rarest sea lion in the world (Robertson & Chilvers, 2011). It has been classified as 'nationally critical' in New Zealand and breeds predominantly on the Auckland and Campbell Islands (Chilvers, Wilkinson, & Childerhouse, 2007; Robertson & Chilvers, 2011). New Zealand sea lion pup productivity has dropped 48% since 1998, potentially due to disease, predation, permanent dispersal or migration, anthropogenic impacts and environment shifts, population 'overshoot', genetic effects, contamination, and direct (bycatch mortality) and indirect effects (resource competition) (Robertson & Chilvers, 2011). On the Auckland islands, sea lions breed colonially on open beaches in harems. After the first month the mothers will begin to move their pups onto other islands or into nearby Rātā forest (*Metrosideros umbellata*), which can be characterized by dense canopy and a contorted network of branches and roots (Figure 1)(Childerhouse & Gales, 1998). Sea lions have started colonising new regions of New Zealand such as the Snares, Stewart Island and Otago peninsula (Crawley & Cameron 1972,

Childerhouse & Gales 1998 and McConkey 2002). Stewart Island in particular has seen increases in pup numbers over the last five years (c. 30) and has been considered an important subpopulation in recent conservation efforts. Sea lions on Stewart Island are not pupping colonially and this can make population sampling very challenging, especially as they are in dense bush rather than open beaches. We are in urgent need of a novel, non-invasive, population sampling methods for finding sea lions in dense forest habitats.

The purpose of this study was to determine the effectiveness of infrared detection on pinniped neonates within a forest habitat (>95% canopy cover). Kaikoura (East Coast of New Zealand) hosts New Zealand's largest breeding colony of fur seal (*Arctocephalus forsteri*). During the mothers feeding periods at sea, NZ fur seal pups undertake the iconic migration up a connected freshwater stream (Ohau Stream) under the cover of trees, more akin to sea lion mother and pup migration into the bush on offshore islands (Campbell, Chilvers, Childerhouse, & Gales, 2006). The seal pups become increasingly hard to monitor as they move further into the bush and into denser tree cover, which makes it an ideal substitute study organism for the New Zealand sea lion. We conducted surveys of Ohau Point stream using a quadcopter fitted with infrared for aerial sampling and a walk-through ground count for comparison.

The aim of this research was to assess the detectability of marine mammals in a forested habitat through canopy cover and through ground counts at different times of the day in order to guide future directions and applications of infrared use in terrestrial population sampling of warm blooded mammals. We conducted an exploratory infrared survey of the NZ fur seal pups (*A. forsteri*) within a forested habitat and evaluated the effectiveness of thermal imagery on the ground and from the air, using a vertical take-off and landing (VTOL)

quadcopter and a tripod mounted thermal camera. Our specific objective was to determine whether pinnipeds could be detected within a forest habitat using thermal imagery and whether they can be counted accurately enough to replace invasive walk-through counts.

## **Materials and Methods**

### **Study Sites**

Infrared surveys were conducted at two New Zealand fur seal colonies; Ohau Point (OP) and Point Kean (PK), on the East coast of the South Island of New Zealand (Figure 2). Ohau Point is one of the largest breeding colonies of NZ fur seals in New Zealand and is located 30 km north of the Kaikoura township (42°14'52.2"S 173°49'50.2"E). This site is characterized by a freshwater stream with dense canopy cover that leads to a waterfall, (from here referred as stream) (Figure 3). Point Kean is located on the Kaikoura Peninsula and is host to a small, but rapidly increasing breeding population. This site is characterized by a flat rocky shore platform and bush, separated by a tourist car park (from here referred to coast) (Figure 4).

### **Thermal imagery surveys**

#### *DraganFlyer X4-P Helicopter™ (Quadcopter)*

Flights were conducted using the DraganFlyer X4-P Helicopter™

(<http://www.draganfly.com/uav-helicopter/draganflyer-x4p/specifications>) (Figure 5, Table

1). Its payload (the camera or thermal sensors attached) consisted of a T320 19 mm infrared



camera (Table 2). The UAV is equipped with a pressure gauge, allowing for flight height to be accurately measured and for the UAV to be flown within the legal guidelines.

The DraganFlyer X4-P takes off and lands vertically, allowing landing on a confined and/or thin landing site. The UAV can be flown for 8–10 minutes per battery using the SONY NEX5N and 15-17 minutes with the FLIR thermal attachment and legally must be flown in line-of-sight. Prior to commencement of the mission, a suitable take-off and landing site was established in the tourist carpark. This required an 8 m<sup>2</sup> area closed off to prevent tourists entering for their safety. The T320 19 mm Infrared camera was connected to a wireless monitor and radio link, so data could be recorded and viewed in real-time. Prior to take off, the standard operating safety procedures for the DraganFlyer X4-P Helicopter™ were conducted, the time of take-off and landing recorded and then flew six transects above the canopy of Ohau Stream and Point Kean (Figure 2). Three quadcopter transects were flown at 7 am, 12 pm and 4 pm for the photographic and thermal camera separately (Table 3, Figure 7). The Quadcopter was manually flown by a qualified UAV pilot due to the steepness of terrain and insufficient GPS signal for automated flight. Each transect took approximately 10-20 minutes to conduct, depending on prevailing wind conditions and tourist activity in the area. For missions that tracked over the stream, a walk through count was conducted to provide a comparison with the acquired images.

#### *Ground mounted Forward Looking Infrared Camera (FLIR) data collection.*

The Optris PL450 Infrared camera was used for our fixed thermal camera comparisons (Table 4). The Optris PL450 Infrared camera is a high speed, high resolution thermographic

camera. It is able to provide real-time thermographic images at high speed, which enables the focusing and altering of the thermal sensitivity (temperature range) to focus and display the required detection temperatures (Hoffmann, Schmidt, & Ammon, 2015). This allows for better detection in denser foliage, but needs to be developed and tested from the air.

To determine the effectiveness of the Optris PL450 Infrared camera at detecting New Zealand fur seals through different foliage, fixed ground trials were conducted using a tripod. The Optris PL450 requires direct connection to a laptop or tablet running windows XP or higher. The camera is focused manually using the lens and data is displayed and recorded using PI Connect™.

(<http://www.optris.com/optris-pi-connect>). Thermal images were taken of vantage points at both colonies (KP and OP) and paired with photographic images (SONY NEX-5) to determine the detection rate of both systems through different foliage types (Table 3, Figure 8). The Optris PL450 is designed specifically for use on UAV platforms, however, it is not currently configured for attachment to the DraganFlyer X4-P. Future research would require modification for the Optris PL450 to be integrated into the DraganFlyer gimbal and video system.

### **Data Processing**

All thermal and photographic imagery was displayed and counted on a Viewsonic™ (VX2439WN) 24 inch Full HD (1080p) monitor

(<http://www.viewsonic.com/us/monitors/entertainment-vx-series/vx2475smhl-4k.html>).

Thermal imagery from the T320 19mm infrared camera can only be viewed and processed using Micro-D player (<http://micro-dvd.en.softonic.com>).

Optris PL450 thermal imagery was processed using PI Connect™ (<http://www.optris.com/optris-pi-connect>).

## **Results**

### *Seal Identification*

Identification of a seal can be difficult in complex habitats such as dense forests, where the canopy can obstruct infrared radiation. Pinnipeds can have unique thermal qualities such as a distinct head shape and movement, very hot distinct eyes (which provides a thermal contrast with the rest of the body) and naturally hot flippers (used for thermoregulation). In a forested environment, we can identify seals by their swaying head movement between trees and their hot bright eyes (Figure 6). On the exposed rocky shore, the same cues can be used, however, on warmer days' seals are more homogenous and their thermal profiles can become merged when clumped which can make detection difficult. Therefore, seals are more accurately detected in the mornings, when it is colder and the seals are not too clumped. Seal pups can be harder to detect than adults because of their size.

Our identifications from thermal imagery required the detection of one or more of these features to ensure accurate identification:

6. Movement
7. Pinniped body shape
8. Hot eyes
9. Swaying head
10. Distinct flipper shape, thermal outline or fanning

#### *UAV survey*

The UAV mounted T320 19mm Infrared camera was able to detect some fur seals in low density, defined as less than <50% canopy cover. The percentage of seals detected in low density bush using aerial infrared compared to a thorough walk-through search ranged from 19.4 to 67%, with detection rate being greatest in the morning (Figure 7, Table 6). In contrast, the UAV mounted T320 19 mm infrared camera was unable to detect fur seal pups through a forest of greater than 95% canopy cover, shown by a 0% detection rate for every flight (Table 5).

In comparison, the Optris PL450 had a greater seal detection rate than photographic detection, but only during the morning and afternoon at both sites (Table 7).

## Discussion

The use of Unmanned Aerial Vehicle for surveying marine mammals offers an innovative, non-disruptive method of population sampling (Gooday, Zawar Reza, & Goldstien, 2016). This research has shown that the effectiveness of aerial thermal imagery depends on the time of day, the type of camera, the weather and the type of foliage.

We conducted sampling at three different times in order to determine whether there was an optimum time of day for sampling. We found that the morning and afternoon showed the highest rate of detection, which may be due to the lower temperature of surface-cover creating a larger thermal contrast between the vegetation and the fur seals (Davis & Sharma, 2004). Whilst this may suggest that mid-day is the least optimal time for sampling, we must be mindful that there were also fewer seals under the foliage at mid-day during our study.

For the UAV flights we used the T320 19mm Infrared camera. The T320 19mm Infrared camera is a hot-spot camera which is small, versatile and can be attached to a drone. The drawbacks of this camera are its low resolution and the inability to measure temperature from the thermal image recorded. This camera was able to detect seals in the open and in very low density foliage but was insufficient when the foliage density was too great or seals were too closely clumped together. When conducting population counts using this camera, one must acknowledge the potential to underestimate counts due to missing seals under foliage (Boonstra, Krebs, Boutin, & Eadie, 1994). Due to the water composition of foliage, the canopy is highly absorptive and opaque which hides any warm blooded animals

underneath. Thermal technology is also limited by the inability to detect the outline of thermally homogenous animals which can lead to underestimating grouped seals and also mistaking hot rocks for seals. Multi-rotor UAV's were crucial to the successful detection of seals as they are manoeuvrable and can fly continuously or stop and hover if a seal was spotted. This allowed for detecting movement or defining characteristics, such as the head or eyes. Hovering to detect movement also aided in the distinguishing of the number of individuals in groups and their size. The manoeuvrability of the Draganflyer™ and its gimbal (the camera support that allows rotation) also allowed fine scale manipulation of the flight pattern and camera angle. The camera angle manipulation was the key to the success of the Point Kean surveys. We were able to fly just under the canopy at an angle, which improved the detection rate as the canopy was less dense from this angle. Multi-rotor UAVs manoeuvrability and versatility make them perfect for this kind of sampling of marine mammals, however, most models are very susceptible to wind, shorter flight distances compared to fixed wings and the payload attachments to rain (Jones IV, Pearlstine, & Percival, 2006).

Infrared cameras are not without limitations. Water is a potential issue as it can mask a seal's thermal signature by substantially evaporative cooling of the seal's surface. When a seal has just exited the water, the initial thick layer of water on its fur will make it appear cold or invisible as the camera detects the thermal signature of the water and not the seal (McCafferty, 2007). This could hide a seal and bias results during a population survey.

Conducting an infrared survey in the rain can also present similar issues, as the image will appear faded or blurry due to the camera picking up the thermal emission of rain. Another issue we faced was that rocks hold their temperature for a very long time and maintain

temperatures that typically coincide with the seals. Conducting population sampling over rocks in the morning before they heat up could counter this issue.

### *Concluding remarks*

The conservation of marine mammals is in pressing need of new, less invasive population sampling methods. The vulnerable New Zealand sea lion and rapidly expanding New Zealand fur seal are both excellent species on which to focus research, due to their biological similarities and different risk levels (Boren, Muller, & Gemmell, 2006; Robertson & Chilvers, 2011). This study will inform the design of future research through the exploration of infrared detectability of mammals in a terrestrial environment.

- Infrared detection of mammals is best conducted during the night or early morning to increase the thermal gradient between vegetation and the mammal.
- Multi-rotor platforms have better manoeuvrability than fixed wing UAVs and can hover to confirm heat signatures.
- Hot spot cameras are effective at detecting mammals in open areas but are ineffective through foliage. Higher resolution cameras such as the Optris PL450 may offer greater accuracy counts.

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[Table 1: Draganflyer X4-P Technical Specifications.](#)

<u>Draganflyer X4-P specifications</u>		
<b><u>Dimensions</u></b>	<u>Width</u>	<u>87 cm</u>
	<u>Length</u>	<u>87 cm</u>
	<u>Top diameter</u>	<u>107 cm</u>
	<u>Height</u>	<u>30 cm</u>
<b><u>Weight and payload</u></b>	<u>Weight with battery</u>	<u>1.67 kg</u>
	<u>Payload capacity</u>	<u>800 g</u>
	<u>Max take-off weight</u>	<u>2.47 kg</u>
<b><u>Flight characteristics</u></b>	<u>Max climb rate</u>	<u>2 m/s</u>
	<u>Max descent rate</u>	<u>2 m/s</u>
	<u>Max air speed</u>	<u>90 degrees / second</u>
	<u>Minimum air speed</u>	<u>50 km/h</u>
	<u>Launch type</u>	<u>Vertical take-off and</u>
	<u>Max altitude</u>	<u>landing</u>
	<u>Approximate sound at 1 m distance</u>	<u>2,438 m</u>
	<u>Approximate sound at 3 m distance</u>	<u>72 db</u>
		<u>62 db</u>

Table 2: T320 19 mm Infrared Camera [Technical Specifications](#).

T320 19mm Infrared Camera	
Temperature range	-40 - 80°C
Analog Video Display Formats	640 x 480 (NTSC) 640 x 512 (PAL)
Detector	Uncooled VOx Microbolometer
Spectral band	7.5 – 13.5 μm
Sensitivity (NEΔT)	<50 mKat f/1.0
Software	MicroD Player

Table 3: Aerial and ground thermal survey of New Zealand fur seal details conducted at 7 am, 12 pm and 4 pm on the east coast of the South Island, Kaikoura, New Zealand.

Camera	Location	Times	Total No. of transects/photographs
T320 19 mm Infrared Camera (UAV mounted)	c. Ohau Stream d. Point Kean	7 am, 12 pm & 4 pm	18
Optris PL450 (Fixed tripod)	c. Ohau Stream (2 sites) d. Point Kean (4 sites)	7 am, 12 pm & 4 pm	18

Table 4: Optris PL450 Infrared camera specifications (<http://www.optris.com/thermal-imager-pi400>).

PL450 Specifications	
Temperature ranges	-20 -100 °C 0 - 250 °C 150 - 900 °C
Spectral range	7.5 - 13µm
Detector	UFPA, 382 x 288 pixel@80 Hz (Switchable to 27 Hz)
System accuracy	±2 °C
Temperature resolutions	0.08 K <sup>1</sup> with 38° 62°, 0.01 K <sup>1</sup> with 13°

Warm-up time	10 min
Software	PI Connect™

Table 5: Mean number of seals detected using aerial thermal imagery (T320 19mm Infrared camera) and by physical ground counts at Ohau Stream (>95% canopy cover), Ohau Point, Kaikoura, New Zealand. Detection percentage is calculated as the percentage of seals detected with ground counts that were also detected using infrared camera

Detection method	Morning	Mid-day	Afternoon
T320 Infrared (n= 9).	0	0	0

Ground count (n= 3)	12	9	5
Detection	0%	0%	0%
Percentage (%)			

Table 6: Mean number (st.error) of seals detected using aerial thermal imagery (T320 19mm Infrared camera) vs. physical ground counts at Point Kean, Kaikoura, New Zealand.

Detection percentage is calculated as the percentage of seals detected with ground counts that were also detected using infrared camera

Detection method	Morning	Mid-day	Afternoon
T320 Infrared (n= 9)	23 (5.48)	2 (0.88)	22 (1.53)
Bush Walk-through (n= 3)	34	12	49
Detection Percentage (%)	67	19.4	44.9

Table 7: Total counts of New Zealand fur seals detected using Optris PL450 Infrared camera vs photographic image (SONY NEX-5) through different foliage types on the Kaikoura Coast.

Location	Foliage Type	Morning		Mid-day		Afternoon	
		Visual	Thermal	Visual	Thermal	Visual	Thermal
coast	Dense Bush (80%)	11	17	4	4	8	18
coast	Uncovered flat ground and Bush (40 %)	9	15	6	10	6	12
coast	Tall Grass (60 %)	6	10	5	5	5	5
coast	Moderate Bush (70 %)	-	3	1	0	1	5
stream	Dense contorted branches.	7	6	-	7	3	5
stream	Moderate Bush	3	5	2	3	1	5



## Figure Legends

Figure 1: Rātā forest (*Metrosideros umbellata*) on Enderby Island, one of the Auckland Islands, a common habitat for local NZ sea lions (see left, Photo credit: Kelly Buckle), compared to Ohau forest on the Kaikoura coast, a seasonal nursery site for local NZ fur seal pups (see right).

Figure 2: Map of Research sites (blue), Ohau stream and Point Kean on the South Island, Kaikoura, New Zealand (Created by Lon Van Elk).

Figure 3: Photograph taken from Draganflyer X4-P Helicopter at 50 m height using a SONY NEX-5 camera above Ohau Stream.

Figure 4: Photograph taken from Draganflyer X4-P Helicopter at 50 m height using a SONY NEX-5 camera above the various bush types at Point Kean.

Figure 5: Draganflyer X4-P Helicopter (<http://www.draganfly.com/uav-helicopter/draganflyer-x4p/specifications>).

Figure 6: A close-up thermal image of a New Zealand fur seal pup taken using the Optris PL450 in Ohau Stream, Kaikoura. The number indicates the temperature in degrees Celsius of the pixel beneath the user's cursor (PI Connect™).

Figure 7: Photograph taken from Draganflyer X4-P Helicopter at 50 m height using a SONY NEX-5 camera (A) paired with an aerial thermal image taken using the T320 19mm infrared camera at Point Kean, Kaikoura (B).

Figure 8: Photograph taken from a tripod at ground level using a SONY NEX-5 camera (A) paired with a thermal image of the same frame using the Optris PL450 at Ohau Stream, Kaikoura (B).