Doubtful Sound/Patea and Dusky Sound Bottlenose Dolphins

Comparative visual health assessment using dorsal fin photographs and photogrammetry

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Comparative visual health assessment of bottlenose dolphins from Doubtful/Patea and Dusky Sounds using dorsal fin photographs and photogrammetry

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Executive Summary

1. The bottlenose dolphin population in Doubtful Sound/Patea, New Zealand is declining and subject to potential impacts from tourism and habitat modification *via* freshwater discharge from the Manapouri hydroelectric power station. The bottlenose dolphin population in neighbouring Dusky Sound is exposed to much lower levels of tourism and the fiord receives only natural freshwater run-off.
2. We used dorsal fin identification photographs from the both populations to compare levels of epidermal disease. Further, we used laser photogrammetry to measure the dorsal fin base length of calves (< one year old) to assess differences in calf size and birth seasonality between the populations.
3. Epidermal lesions were common in both populations (affecting > 95% of individuals), but lesion severity (recorded as percentage cover) was four times higher in Doubtful Sound. Within Doubtful Sound, lesion severity was higher for females than males. No such differences were observed in Dusky Sound. Calves were larger and were born over a wider period in Dusky Sound.
4. The freshwater discharge into Doubtful Sound alters temperature and salinity regimes in the fiord, which may exacerbate naturally occurring epidermal disease. The increased incidence of disease in females and the smaller size of calves in Doubtful Sound may help to account for the low survival of calves in the population. The narrow calving season in Doubtful Sound may be an adaptation to localised temperature conditions.
5. In order to tease apart the effects of water temperature on calving season, and examine the potential influence of the freshwater discharge into Doubtful Sound, comparative studies of calving seasonality, calf survival, calf size, and sea-surface temperature will be needed in both Dusky and Doubtful Sounds.

CONTENTS

Introduction

The bottlenose dolphins of Fiordland (*Tursiops truncatus*) are thought to be the world's southern-most resident groups of bottlenose dolphins (Bräger & Schneider 1998). The population inhabiting the Doubtful/Patea-Thompson Sound complex (referred to as Doubtful Sound) is experiencing a decline in abundance and survival, threatening the long-term viability of the population (Lusseau *et al* 2006, Currey *et al* 2007, Currey *et al* in press). Over the past 12 years the population declined by more than 34%, with just 56 individuals (CV=1.3%) residing in the fiord in February 2008 (Currey *et al* 2007, Currey & Rowe 2008). Population modelling demonstrates that a key factor in the population decline is the poor survival of calves in their first year of life (Currey *et al* in press). The current calf survival rate is the lowest recorded for any bottlenose dolphin population (Currey *et al* in press).

Factors recognised as potential sources of impact on the Doubtful Sound population include tourism, habitat modification and prey depletion. There is no information available on the current abundance or biomass of prey species within Doubtful Sound but there is information regarding the effects of tourism and habitat modification. A scenic cruise industry operates in Doubtful Sound year round, with the bottlenose dolphins forming a key resource (Lusseau 2005). Disturbances from tour boat interactions result in behavioural change and consequently increased energetic costs, particularly for females (Lusseau 2003a, 2003b, 2004, 2006, Lusseau *et al* 2006). A multi-level marine mammal sanctuary has been proposed for Doubtful Sound (Lusseau & Higham 2004, Lusseau *et al* 2006) and in 2008 a voluntary Code of Management was implemented to restrict boat activity within areas that include some of the critical habitats identified by Lusseau and Higham (2004).

Doubtful Sound is a modified environment due to the freshwater input from the Manapouri hydroelectric power station. The power station discharges freshwater from Lake Manapouri into the head of Doubtful Sound, adding two to three times the natural catchment run-off of freshwater into the fiord (Gibbs *et al* 2000). This increased freshwater inflow has caused substantial ecological changes to intertidal and infaunal communities within the fiord (Boyle *et al* 2001, Tallis *et al* 2004, Rutger & Wing 2006, McLeod & Wing 2008) with an undetermined effect on higher trophic levels.

Recently, Currey *et al* (in press) examined the demographic factors involved in the decline in bottlenose dolphin abundance in the fiord. They found that the survival of calves dropped by more than half to the current unsustainable level in 2002. The number of vessels operating in Doubtful Sound increased between 2000 and 2002, but the time dolphins spent interacting with vessels did not increase during this period (Lusseau 2005). The only other known potential impact to occur in 2002 was the opening of a second tailrace tunnel from the power station, which resulted in an altered freshwater discharge regime. It is unclear whether this represents coincidence or causality, and the mechanism by which a change in freshwater input could impact calf survival is unknown.

In light of the population decline in Doubtful Sound, ascertaining the present status of the remaining bottlenose dolphin populations in Fiordland has become crucial. Consequently, recent research has focused on the least studied of the three

Fiordland bottlenose dolphin populations: a group that appears to be resident in the Dusky-Breaksea Sound complex (referred to as Dusky Sound). Dusky Sound receives only natural freshwater runoff and because of its isolation, experiences much lower levels of tourism than Doubtful Sound (Lusseau 2004). In February 2008 there were 102 (CV = 0.9%) bottlenose dolphins in Dusky Sound (Currey & Rowe 2008). Presently there is no information available on population trends or calf survival. Given that the Dusky Sound bottlenose dolphin population is exposed to fewer impacts, it could provide data that help explain the decline in abundance and calf survival in Doubtful Sound (Currey & Rowe 2008).

Knowledge of wildlife health is critical for conservation management because the occurrence and spread of disease can be sensitive indicators of a change in the ecology of a population (Junge & Louis 2005). The health status of different bottlenose dolphin populations can be compared to determine the effect of different anthropogenic impacts affecting ecosystems. For example, Reif *et al* (2008) compared the health of two bottlenose dolphin populations in the south-eastern United States in habitats that experience different degrees of land use, industrialisation and anthropogenic contaminants. The health assessment of Reif *et al* (2008), like many other health assessment programmes for coastal bottlenose dolphins, requires invasive techniques that either involve live capture of individuals or biopsy darting to collect blood and tissue samples (*e.g*. Berrow *et al* 2002, Wells *et al* 2004, Fair *et al* 2006). Recently, photography and photogrammetry have emerged as powerful non-invasive tools that researchers can apply to evaluate the health status of individual whales and dolphins (Harzen & Brunnick 1997, Wilson *et al* 1997, Perryman & Lynn 2002, Pettis *et al* 2004).

The aim of this study was to compare the health status of bottlenose dolphins in Doubtful Sound, a population experiencing tourism impacts and habitat modification, and in Dusky Sound, where such impacts are minimal. Photographic evaluation of skin condition was employed to assess the occurrence of epidermal lesions, which are common among bottlenose dolphins, but more severe in populations exposed to cold water and low salinity (Wilson *et al* 1999a). Using dorsal fin photographs we compared the severity and prevalence of epidermal disease between the two fiords. Within each fiord we examined differences by gender. Further, we used laser-photogrammetry (Durban & Parsons 2006, Rowe & Dawson in press-b) to measure the dorsal fin base length of "newborn" (*i.e*. young-of-the-year) calves from both fiords with the aim of gathering morphometric data on the members of the population for which survival is especially poor. In other bottlenose dolphin populations, poor calf condition is the primary cause of mortality (Mann & Watson-Capps 2005). Hence photogrammetry of newborn calves could reveal a link between calf size and survival.

Materials and Methods

DATA COLLECTION

Dorsal fin photographs were collected during a series of field trips to Doubtful/Thompson Sound complex (45°30’ S; 167°00’ E) and Dusky/Breaksea Sound complex (45°45’ S; 166°35’ E) (Fig. 1). We visited both sites in November-December 2007 (early summer), February-March 2008 (late summer) and June-July 2008 (winter). Photographs were taken from a 5.5m aluminium-hulled boat, *Patio 1*, powered by a 90hp two-stroke outboard engine. We conducted daily systematic surveys of both fiords that followed a pre-determined route in order to locate any persistently isolated dolphin groups (Schneider 1999, Currey & Rowe 2008). Once dolphins were encountered, the survey route was suspended and the boat approached the dolphins in accordance with the Marine Mammal Protection Regulations (1992) and the Code of Practice developed by Schneider (1999). Photographic effort began when the boat was within approximately 15m of a dolphin group.

Fig. 1. Map of southern Fiordland, New Zealand.

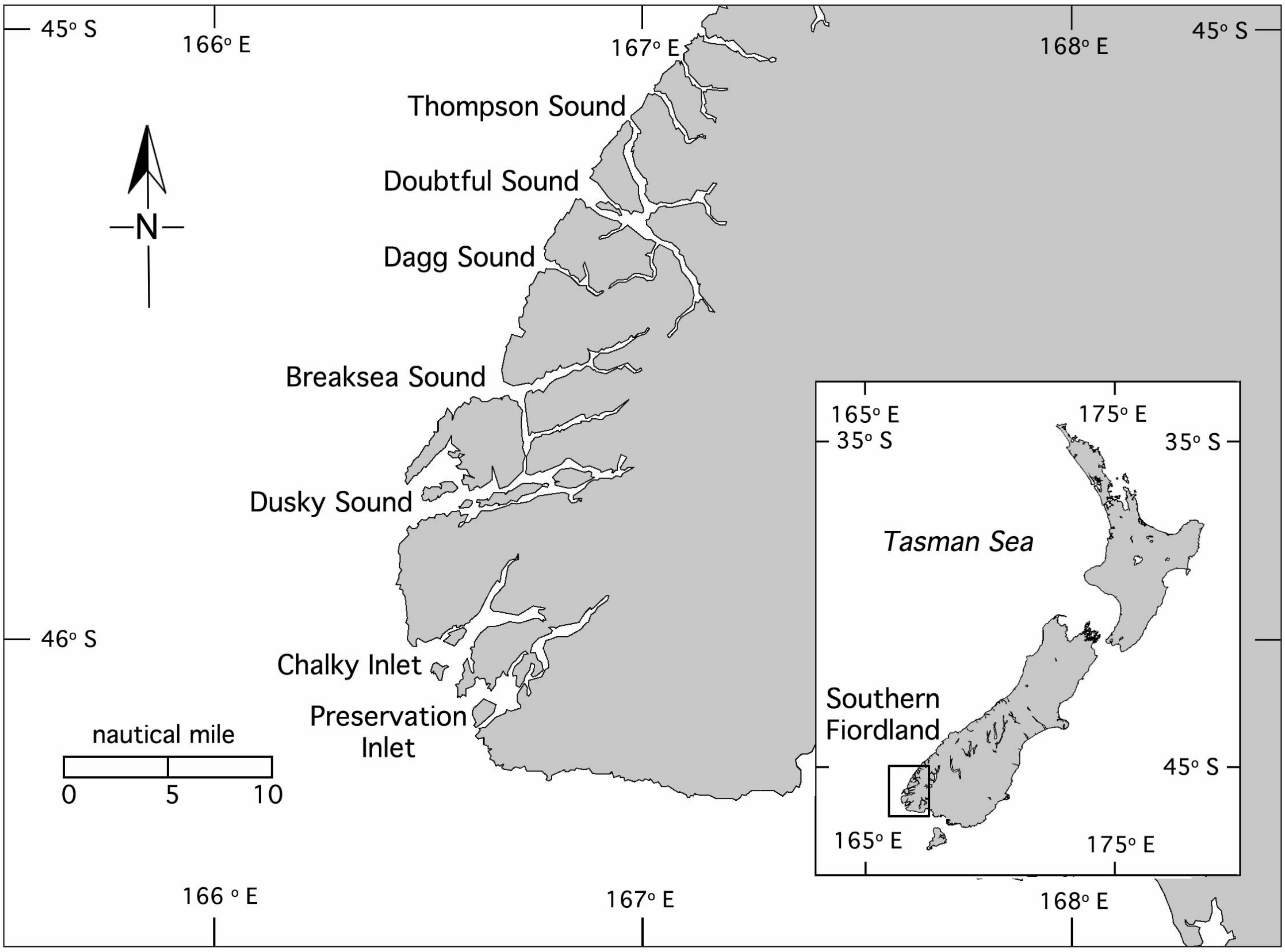


PHOTO-IDENTIFICATION

Dorsal fin photo-identification (photo-ID) allows individual dolphins to be identified by unique patterns in naturally occurring marks (Würsig & Würsig 1977). Markings such as nicks in the trailing edge of the dorsal fin are essentially permanent and enable individuals to be repeatedly identified over many years. In comparison, tooth rakes, scars, pigmentation patterns, and lesioning are subtle, temporary marks that allow identification of un-nicked individuals over short periods (Wilson *et al* 1999b). High-intensity field effort during the study period ensured that subtly marked animals could be identified and consistently re-sighted. Each new photograph was compared with, and matched to, previously identified individuals in the current photo-ID catalogue (Currey *et al* 2007, Currey & Rowe 2008). To minimise the chance of misidentification, photographs were required to be well exposed, in sharp focus, with the dorsal fin orientated parallel to, and occupying a large proportion of the frame. Photographs were taken with a Nikon digital SLR camera (Nikon D70s) equipped with an AF Nikkor lens (80–200 mm f2.8 or 70–200 mm f2.8 VR).

SEVERITY OF EPIDERMAL LESIONS

Epidermal lesions have previously been described for bottlenose dolphins (Thompson & Hammond 1992, Wilson *et al* 1997, 1999a, 2000). Lesion severity develops over time (Wilson *et al* 2000) and a previous study of lesion severity in Doubtful Sound focused on animals older than four years (Rowe & Dawson in press-a). To facilitate comparison, we limited our analysis to the same age group. Exclusion of animals younger than four years was simple in Doubtful Sound because the population has been studied since 1990 (Williams *et al* 1993) and there are minimum age estimates for the entire population. Similar age estimates were not available for the Dusky Sound population. Currey and Rowe (2008) classified dolphins from Dusky Sound as younger or older than four years based on the base length of their dorsal fin exceeding a threshold measurement derived from four year old individuals from Doubtful Sound.

Gender-specific differences in the rate of epidermal lesioning have been observed in Moray Firth and Doubtful Sound (Wilson *et al* 1997, Rowe & Dawson in press-a). Due to the long-term nature of the research in Doubtful Sound, all individuals older than four years had been sexed by underwater video or oppurtunistic observation. Females were sexed either by observation of their genital region and the presence of mammary slits or by consistent association with a calf. Males were sexed by observation of their genital region or an erect penis. The Dusky Sound population is far less studied, but a subset of individuals has been sexed by opportunistic observations. Seventy-nine animals older than four years have had their sexes predicted based on a morphometric model (Currey & Rowe 2008). We used either the observed sex or the predicted sex to stratify the Dusky Sound data set into males and females.

Epidermal lesions were identified by their physical characteristics following Wilson *et al* (1997). Lesions may appear as white, black or blue-greyish plaque-like patches with sharp or indistinct edges and include circular, outline, and amorphous shapes (Wilson *et al* 1997). Lesions are distinct from scarred areas, which are composed of scratch marks and tooth rakes, as well as scar tissue resulting from direct physical injury rather than disease. To provide a measure of lesion severity, the proportion of an individual's dorsal fin covered by lesions was measured following methods developed by Rowe and Dawson (in press-a). The highest quality photograph of each individual's fin was selected and the image of the dorsal fin extracted from the background using the extract tool in *Adobe Photoshop* (version 7.0, Adobe Systems Inc, California). The extracted image was cropped at the dorsal fin baseline and the perimeter of individual lesions was traced. In *ImageJ* (version 1.37, National Institute of Health, USA) the area of the traced lesions was selected by a threshold technique and expressed as a percentage of the total area of the dorsal fin (Fig. 2). To eliminate any affect of season on lesion severity we only analysed photographs that were taken during the late summer fieldtrips. To ensure consistency, all image selection, manipulations, and measurements were made by the same person.

Fig. 2. An example of an extracted bottlenose dolphin dorsal fin image (left). Black marks represent the traced areas epidermal lesions (right). This dorsal fin had epidermal lesions covering 11.4% of its surface area.

LASER PHOTOGRAMMETRY

Laser photogrammetry, also known as laser-metrics, uses two parallel lasers that project dots a known distance apart onto the object being photographed. Laser pointers are fixed 100mm apart inside a rectangular plastic mounting block that attaches directly to the camera. Provided the object of interest is perpendicular to the axis of the lasers, measurements are possible at any range over which the dots are visible. Laser photogrammetry has been used to obtain measurements of the dorsal fins of free-ranging killer whales (Durban & Parsons 2006) and bottlenose dolphins (Rowe & Dawson in press-b).

The laser photogrammetry system was calibrated daily by following this procedure: The laser projection was photographed on a grid with 100mm divisions and a scale for the photograph was set by allowing the number of pixels between a grid division to equal 100mm in *Image J*. Then the distance between the laser dots was measured and corrected to 100mm by adjusting a bolt in the mounting block. After adjustments were made another photograph was taken to confirm that the inter-dot distance was 100mm ± 1mm over a distance of 15m. We calibrated the lasers at a distance of 15m on land because it ensured the 100mm separation would be constant over the range photography was conducted. Any photographs taken at range greater than 15m were rejected during quality grading, as the dorsal fin did not occupy a large enough proportion of the frame. During photographic effort the distance between the laser dots was checked regularly to ensure the 100mm alignment by projecting the lasers on to a measurement grid onboard the boat.

Laser photogrammetry, as with all photogrammetric techniques, has a degree of bias and measurement error (Gingras *et al* 1998, Durban & Parsons 2006). Nonparallel alignment of the laser pointers is a potential source of bias, but can be controlled by using sturdy laser mounts, conducting regular calibrations, and by constraining the range within which photographs are taken (Gingras *et al* 1998). Parallax error occurs when the dolphin surfaces on an angle with their dorsal fin not perpendicular to the photographer, and creates a negative bias. A trigonometric analysis indicated that the effect of slight deviations (< 10°) from perpendicular is minimal (Rowe & Dawson in press-a). Larger deviations from perpendicular could be detected in the field, and the photograph would not have been taken. Laser-metric photographs were subject to the same quality grading procedures as described above for photo-ID, with the addition that the laser dots were required to be clearly visible in each photograph.

We used laser photogrammetry to measure the dorsal fin base length (DBL) of calves (< one year old). Dorsal fin base length is a straight-line distance that runs parallel to the long axis of the body and has the strongest relationship with total length of the characters able to be measured from a dorsal fin (Webster 2008). Calves were easily identified in Doubtful Sound because consistent photo-ID study of the population meant all dolphins born since 2004 were of known age. In Dusky Sound we classified a dolphin as a calf based on observations of size relative to the mother, depth of foetal folds and erratic surfacing behaviour (Whitehead & Mann 2000). Compared to adult dolphins, the dorsal fins of calves offer a considerably smaller target to aim the laser pointers at, and most high quality photographs had the laser dots projected onto the upper flank and not the dorsal fin. We included photographs with the laser dots projected onto the upper flank in our analysis because the distance between the dorsal fin and the upper flank is trivial compared to the distance at which the photograph was taken. Laser-metric studies of other species found no detectable difference between measurements made from photographs with the laser dots on the upper flank instead of the dorsal fin (Webster 2008).

The lower margin of the dorsal fin was defined by using the prominent crease to indicate the anterior insertion point of the dorsal fin. The posterior insertion point was defined by drawing a reference line that followed the main axis of the back. The point where the plane of the back deviated to the plane of the dorsal fin was defined as the posterior insertion point. *Intaglio* (version 2.9.4, Purgatory Design) was used to draw the reference lines and make measurements of dorsal fin base length (Fig. 3). All measurements were calibrated to actual size using the laser dots on the fin. A dorsal fin base length estimate was only calculated if there were multiple high-quality photographs of an individual calf. The measurement error associated with this technique has been quantified and is sufficiently small (ME = 5.17%) that replicate measurements of the same individual were averaged for further analysis (Rowe & Dawson in press-b).

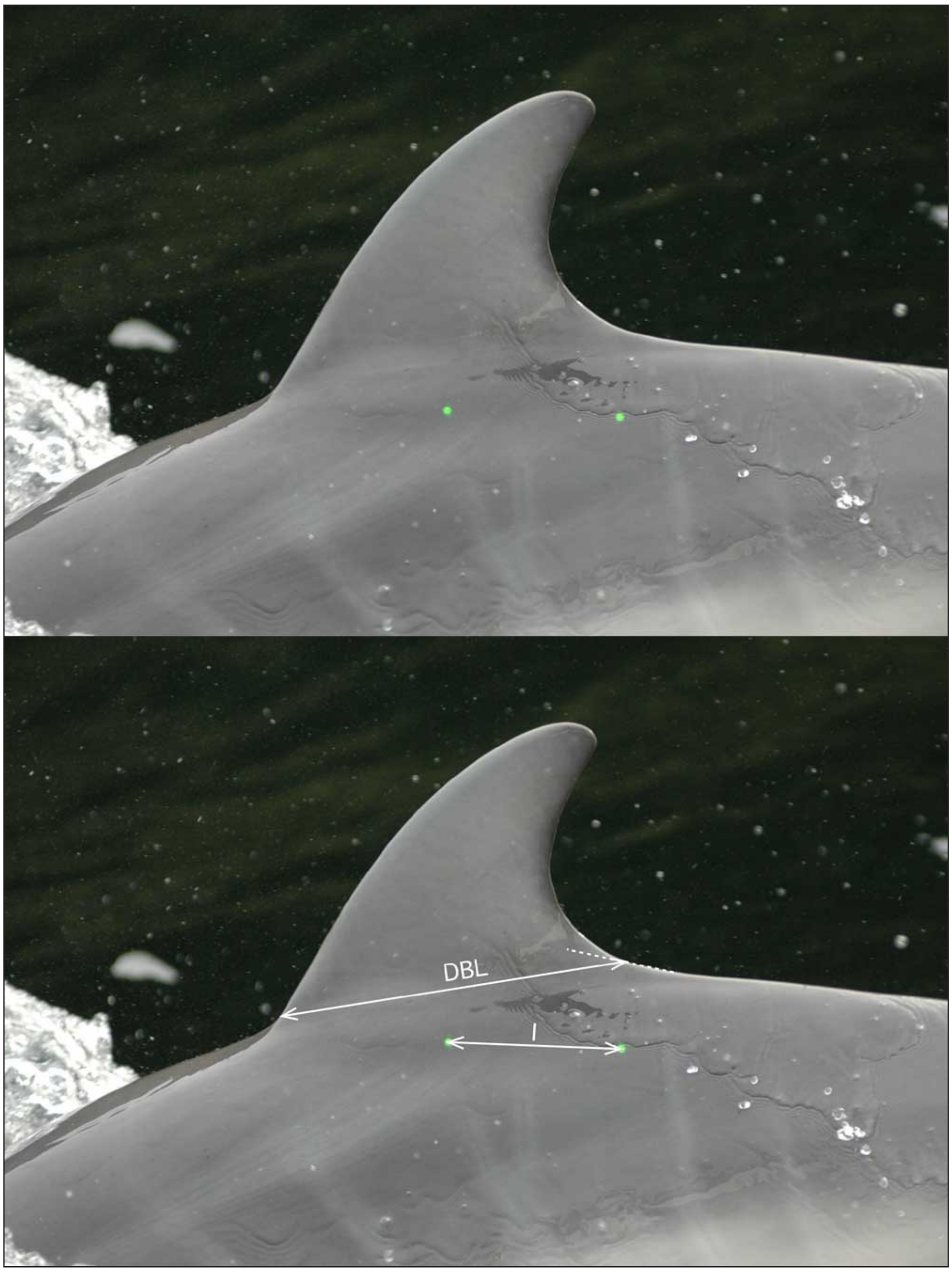


Fig. 3. The two fixed-distance laser dots (top) projected onto the upper flank of a bottlenose dolphin calf (less than one year old). Dorsal fin base length (DBL) was measured from the photograph (bottom). Measurements were calibrated to actual size based on the measured dimensions between the laser dots (l).

STATISTICAL ANALYSIS

The measurements of lesion severity were not normally distributed so non-parametric testing was used for analysis. Wilcoxon rank sum tests of lesion severity between Doubtful and Dusky Sound, and between the sexes within each fiord were performed in *JMP* 6.0 (SAS Institute Inc, Cary, NC). Laser-metric photographs were taken of calves over the three periods of fieldwork. However we possessed insufficient corresponding samples to enable analyses using repeated measures. Hence we used unpaired two-tailed *t*-tests to compare measurements of calves when first observed in both fiords, and between calves from Dusky Sound that were first observed during the first two field trips and those first observed during the winter field trip.

Results

EPIDERMAL LESIONS

Photo-identification pictures of the dorsal fins of 121 individual bottlenose dolphins (42 from Doubtful Sound, 79 from Dusky Sound) were analysed for epidermal lesion prevalence and severity. The sample represented 98% of the sub-adult and adult dolphins (> four years old) in each fiord. Epidermal lesions were prevalent across both populations (100% in Doubtful Sound, 96.2% in Dusky Sound), but dolphins from Doubtful Sound had a significantly larger proportion of their dorsal fin covered in lesions than those in Dusky Sound (Wilcoxon rank-sum test, $Z = 6.460$; $P < 0.0001$). The median percentage coverage of lesions in Doubtful Sound was 6.23% (Inter-quartile range [IQR]: 4.34-10.24), four times the median percentage coverage of 1.48% (IQR: 0.61-2.62) in Dusky Sound. Within Doubtful Sound the severity of epidermal lesions was significantly higher for females than males (Wilcoxon rank-sum test, $Z = -2.25$; $P < 0.024$; Fig. 5) but no gender differences were observed in Dusky Sound (Wilcoxon rank-sum test, $Z = -0.16$; $P = 0.875$; Fig. 5). The most severe case of lesioning was a female from Doubtful Sound that had lesions covering 82.9% of its dorsal fin, and lesions appeared to cover the entire flank of the animal (Fig. 4).

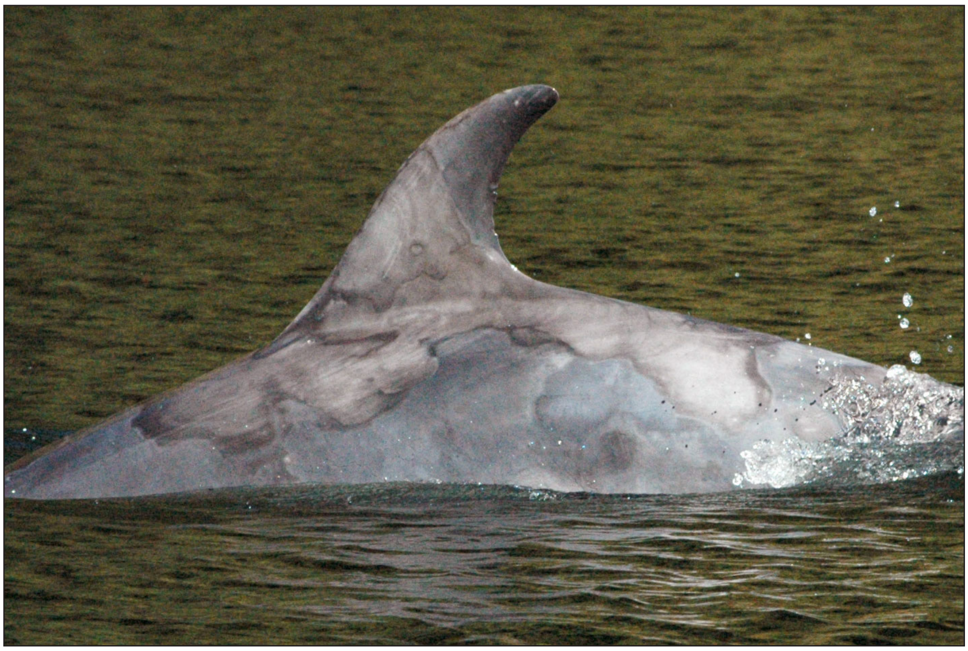
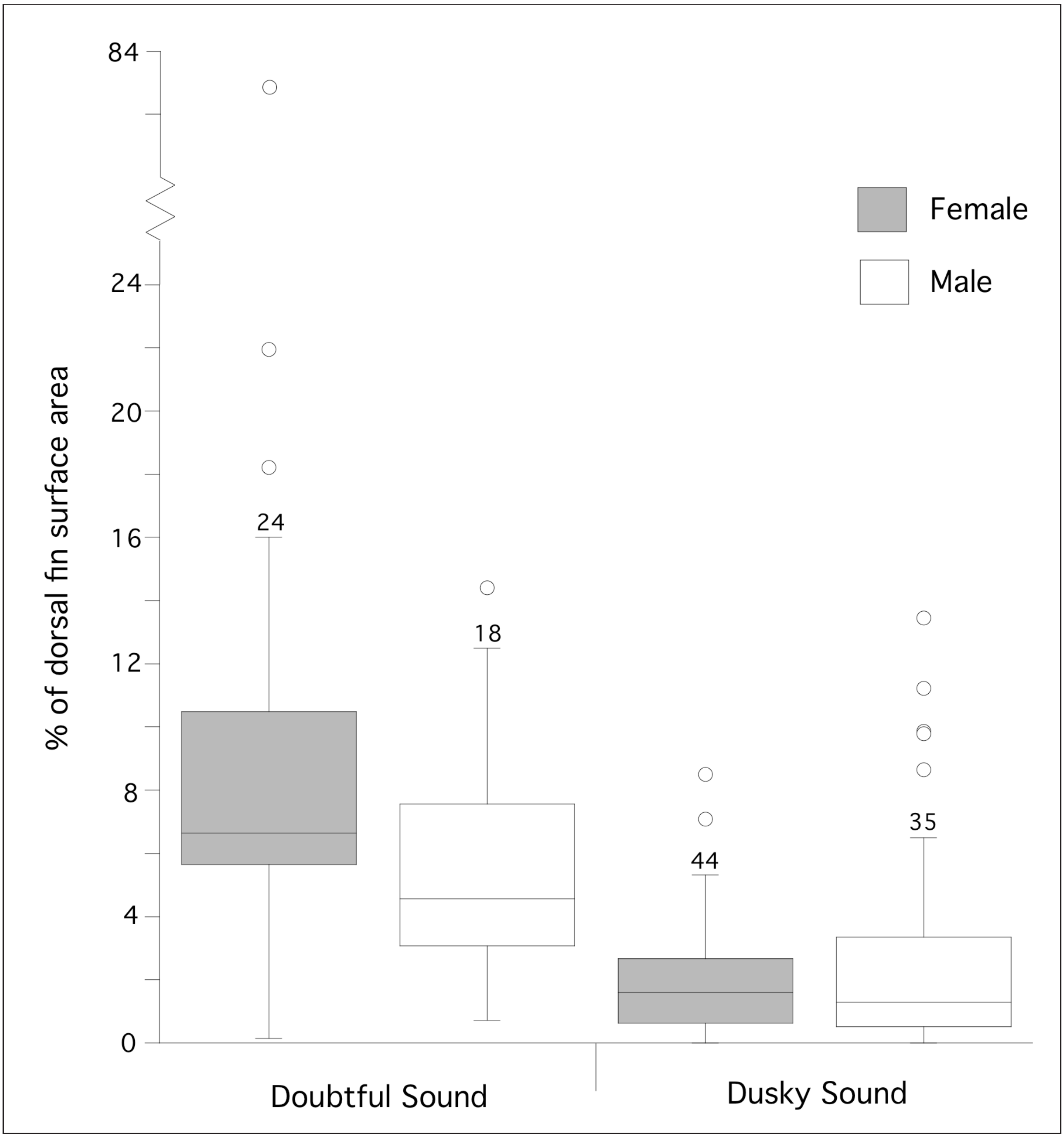


Fig. 4. Female bottlenose dolphin from Doubtful Sound with a severe case of epidermal disease.

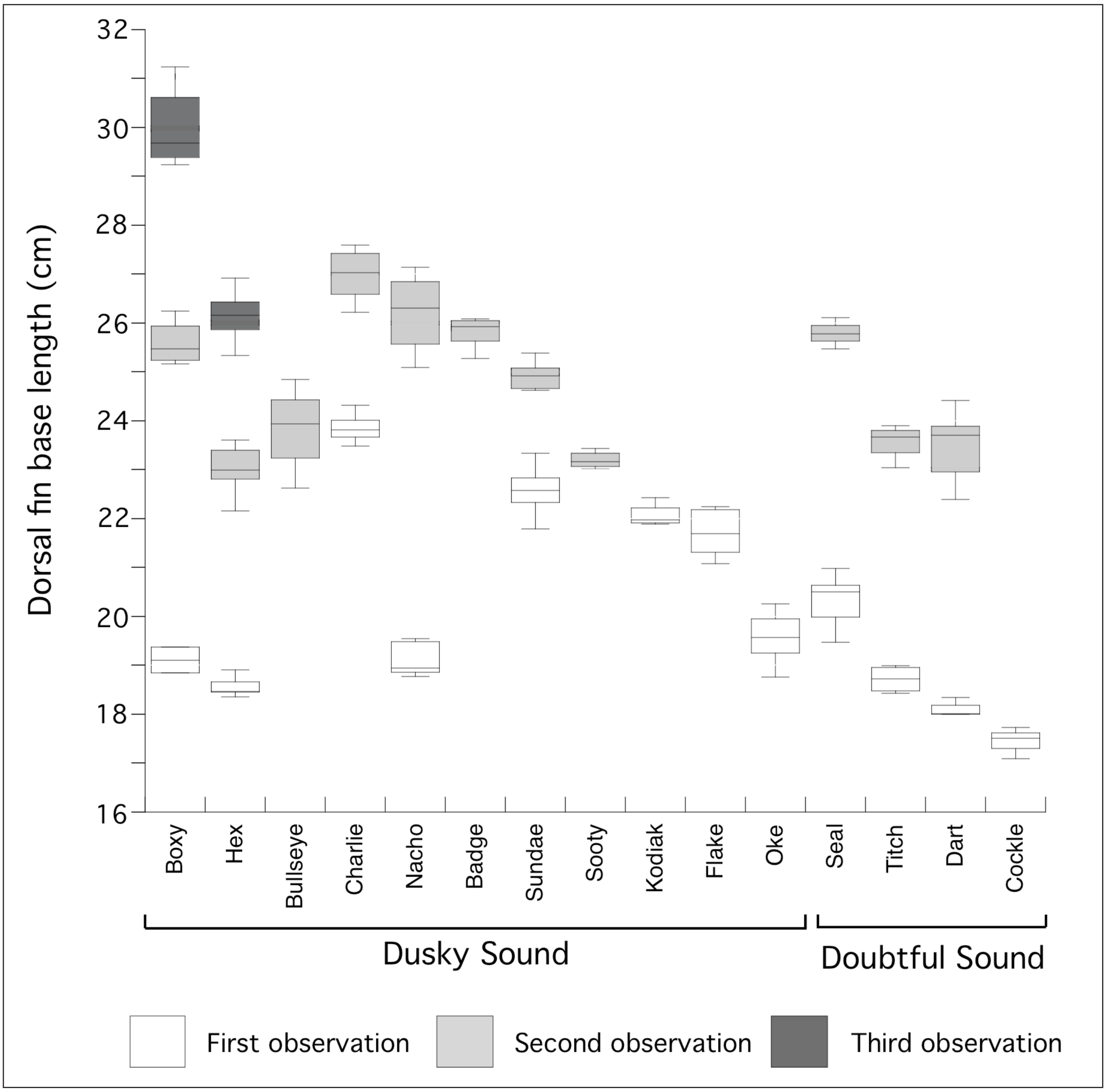
Fig. 5. Box and whisker plot showing percentage of dorsal fin surface area covered by epidermal lesions in bottlenose dolphins from Doubtful Sound and Dusky Sound. Whiskers show minimum and maximum values; boxes show lower and upper quartile; midlines show medians; and circles show outliers. Values above each box represent number of individuals in each sample.



CALF DORSAL FIN SIZE

A total of 16 calves were observed over the study period, four in Doubtful Sound and 12 in Dusky Sound. Laser-metric photographs were taken of calves over the three periods of fieldwork, but due to the staggered nature of the births, only two calves were photographed in all three periods. Some calves were observed during a field trip but were not photographed with sufficient replication to allow a measurement estimate to be calculated. Thus size estimates were not available for every individual from each field trip. New calves were observed during all three field trips to Dusky Sound, but only in the late summer trip to Doubtful Sound. Late summer was when half of the Dusky Sound calves were first sighted (6 of 12) with three calves born before each of the other fieldtrips. Replicate laser-metric photographs were obtained for 15 of the 16 calves. A total of 143 laser-metric photographs of calves were measured (average 5.9 photographs per individual per field trip, range 2-11). Calves from Doubtful Sound were smaller at first observation than those from Dusky Sound (unpaired *t*-test, df =9, P = 0.043), suggesting that calves from Doubtful Sound are smaller when born than those in Dusky Sound (Fig. 5). We recommend that this result be interpreted cautiously: because of constraints on the duration and timing of our sampling trips, we were not able to estimate time of birth with great accuracy and therefore size and age may be confounded in this result.

Fig. 6. Box and Whisker plot showing dorsal fin base length of bottlenose dolphin calves (< one year old) from Dusky Sound and Doubtful Sound during a series of field trips between Nov-Dec 2007, Feb-Mar 2008 and Jun-Jul 2008. Whiskers show minimum and maximum values; boxes show lower and upper quartile; and midlines show medians.



Three new calves were observed during the winter fieldtrip to Dusky Sound.

These calves were significantly smaller in DBL when compared to the measurements made from the winter field trip of the calves than were born in early and late summer (unpaired *t*-test, df =6, $P = 0.003$). If the calves that were first observed in winter were present in the summer but were not sighted we would have expected them to be similar in size to the other calves. The fact that they are significantly smaller indicates that they were born after the late summer field trip, between March and July. One of the calves first observed in July (Oke) has a DBL similar to some of the calves that were less than 2 months old during the late summer trip (Fig. 6), which suggests it was born very late in the season, perhaps in May or June. It is interesting to note that the smallest calf measured in this study was from Doubtful Sound and this individual was not sighted in July, despite repeated sightings of its presumed mother, and is presumed not to have survived.

Discussion

Epidermal disease appears to occur in all coastal populations of bottlenose dolphins (Wilson *et al* 1999a). Resident populations at high latitudes, representing the extremes of the species' distribution, exhibit the greatest severity of epidermal lesions (Wilson *et al* 1999a). The Fiordland bottlenose dolphins are the southern-most resident populations of bottlenose dolphins (Brāger & Schneider 1998). The poor epidermal condition of dolphins in Doubtful Sound was considered by Wilson *et al* (1999a) to be a result of physiological stresses associated with being a frontier group. Considering their close geographic proximity, we expected lesion severity to be similar between Doubtful and Dusky Sounds. The much higher severity of epidermal lesions in Doubtful Sound indicates that lesion severity is not simply a function of living at high-latitude, and is a result of factors specific to a population's habitat.

The pathological agents that cause epidermal lesions are incompletely known, but there is a positive correlation between low water temperature and salinity and the severity of epidermal lesions (Wilson *et al* 1999a). These conditions may compromise epidermal integrity, allowing infection by microbes in the surrounding environment (Wilson et al 1999a). The high annual rainfall in the Fiordland region (>6000 mm yr) results in a well-defined low salinity layer on the surface of the fiords (Stanton & Pickard 1981). The presence of the low salinity layer (LSL) is a natural feature of fiord systems but is considerably more prominent in Doubtful Sound due to additional freshwater discharge from the Manapouri hydroelectric power plant (Gibbs 2001). The influx of freshwater from the power station tailrace amounts to two to three times the natural catchment run-off, augmenting the naturally occurring LSL (Gibbs *et al* 2000). This freshwater discharge ensures the LSL is a constant feature in Doubtful Sound (Gibbs 2001) and the bottlenose dolphin population's exposure to a consistent and more expansive LSL may explain the higher severity of epidermal lesions. Continual exposure to the augmented LSL may exacerbate naturally occurring epidermal disease.

The freshwater discharge from the power station may intensify epidermal disease in the fiord, but it alone cannot explain the disparity in lesion severity between the sexes. Dolphins in Doubtful Sound live in mixed-sex schools (Lusseau *et al* 2003) and therefore encounter broadly the same temperature and salinity regimes. One explanation for the higher severity of epidermal disease in females is that they are exposed to the freshwater layer on the surface of the fiord more than males. Females that are accompanied by calves may spend more time near the surface because their calves do not need to spend time at depth to forage, but this has not been quantified.

Another explanation is that the difference in lesion severity may result from the different physiological constraints between the sexes. On average, females in Doubtful Sound have shorter dive intervals than males (Lusseau 2003b). This could be a result of higher energetic demands arising from pregnancy and lactation (Cheal & Gales 1992), as well as increased thermal stress from the cold-water environment due to their smaller body size (Read *et al* 1993, Tolley *et al* 1995). Lusseau (2003b) argued that the fact that females react to tour boat disturbance later than males indicates that females are more physiologically constrained (*i.e.* cannot afford to react earlier). If boat interactions do incur a greater biological cost to females, and that cost is combined with additional energetic demands, the result could be that females are experiencing greater physiological stress.

In a variety of species, environmental factors have been shown to cause physiological stress that is manifested by reduced survival, reproductive rate and resistance to disease (Moberg 1985, St Aubin & Dierauf 2001). High levels of epidermal disease in bottlenose dolphins are thought to indicate depressed or overworked immune systems that would normally counteract such disease (Harzen & Brunnick 1997). The severity of epidermal lesions suggests that female dolphins in Doubtful Sound are physiologically stressed, most probably by several cumulative impacts. The altered temperature and salinity regime in the fiord may exacerbate natural levels of epidermal disease. The additional energetic costs associated with disturbance from tour boats (Lusseau 2003a, 2003b, 2006) could lead to increased physiological stress, which in turn may depress their immune response to epidermal disease. Increased physiological stress and reduced immunity in females may help to account for the high incidence of stillbirths and the low survival of calves in Doubtful Sound (Lusseau *et al* 2006, Currey *et al* 2007, Currey *et al* in press).

For bottlenose dolphin populations with seasonal breeding, calving usually peaks between summer and autumn, coinciding with the highest water temperatures (*e.g.* Bearzi *et al* 1997, Moller & Harcourt 1998, Mann *et al* 2000). Aside from water temperature, seasonal calving may also be associated with peak periods of food availability to allow mothers access to maximum resources (Oftedal 1984, Urian *et al* 1996). In Doubtful Sound almost all births occur within a short summer season from December to February (Haase & Schneider 2001). During this study, all of the calves in Doubtful Sound and 6 of the 12 calves from Dusky Sound were born within the described birthing season. Our results, albeit spanning a single year, suggest that calving may not be as strictly seasonal in Dusky Sound as observed in Doubtful Sound. Three calves from Dusky Sound were born between mid March and July, but we suspect, based on dorsal fin base length and observations of surfacing behaviour, that one of these calves was less than 2 months old when first observed in mid-July. Our results suggest that in Dusky Sound the number of births peaks during January and February as it does in Doubtful Sound. The distribution of births, however, appears to be wider in Dusky Sound, extending from early December to May or June. This pattern would be similar to that observed in a bottlenose dolphin population in the Bay of Islands, New Zealand, where births peak in summer months but occur between November and July (Constantine 2002).

Variation in the timing of breeding and calving can vary among conspecific, same-latitude, populations due to females in each population adapting to local conditions (Börjesson & Read 2003). For example, three populations of bottlenose dolphins at similar latitudes in the southeastern USA differ greatly in reproductive seasonality in apparent response to variation in seasonal prey availability (Urian *et al* 1996). Births in Doubtful Sound are strongly associated with the periods of highest surface water temperature; birthing during the warmest months may help the thinly insulated calves avoid thermal stress (Haase & Schneider 2001).

Prior to our work in Dusky Sound, we would have expected to find a very similar calving season there, yet it appears to be wider. This suggests that the Dusky Sound dolphins may experience less thermal stress, despite being marginally further south. Several questions emerge: Do the dolphins in Dusky Sound experience a different temperature regime to those in Doubtful Sound, enabling them to calve over a wider period (*i.e.* the surface water is warmer for a longer period)? Have females in Doubtful Sound adapted to the altered surface water temperature regime by restricting calving to the warmest three months of the year?

The surface waters in Doubtful Sound show dramatic seasonal fluctuations in temperature compared to the underlying marine layer. The temperature of the LSL is determined by the temperature of the inflowing freshwater from catchment run-off and tailrace discharge (Cornelisen *et al* 2007). The LSL is coolest in spring when tailrace discharge peaks due to spring snowmelt (Gibbs 2001, Mabin 2008). Comparing the surface waters of the two fiord systems, Dusky Sound is in general more saline, and warmer, especially over the spring-summer period when calving peaks (Wing *et al* 2004). We suggest that the narrow breeding season in Doubtful Sound may be a response to the temperature fluctuations in the augmented LSL. This hypothesis requires testing *via* comparative studies of sea surface temperatures and the timing of births across the two fiords. Additionally, future research effort in Dusky Sound will need to be more frequent or span longer periods to increase the precision of estimated time of birth and enable the length of the calving season to be assessed more precisely. Collection of comparative sea surface temperature data needs to be a routine part of any future monitoring.

Size and condition are the most important factors influencing calf mortality (Mann & Watson-Capps 2005). We found that calves in Doubtful Sound were smaller at first observation that those in Dusky Sound. Could small calf size be playing a role in the poor calf survival in the fiord? To answer this question, calf size and mortality will need to be measured over multiple years and time of birth estimated with greater precision. Bottlenose dolphins exposed to low water temperatures show a decrease in core body temperature, and it is thought that dolphins of small mass, such as neonates, would be particularly vulnerable to thermal stress (Yeates & Houser 2008). The possibility that females in Doubtful Sound are giving birth to smaller calves raises concerns about maternal condition. Poor maternal condition may also play a role in calf survival, as mothers may not be able to sustain the high energetic demands of prolonged lactation (Cheal & Gales 1992).

The poor survival of calves in Doubtful Sound is a key factor in the population decline (Currey *et al* in press), and unfortunately calves are the members of the population that are most difficult to gather data from. Using laser photogrammetry we have developed a way to gather elusive morphometric data from living calves. Laser-metric photographs taken of calves over several summers could investigate if there is a link between size and mortality in Doubtful Sound. It will be essential to obtain laser-metric photographs of all calves, including those that subsequently die, to ensure data are not biased towards survivors. In a population with such high rates of perinatal mortality this will require high-intensity fieldwork during the summer months to enable researchers to observe calves shortly after birth and to gain sufficient replicate laser-metric photographs.

The higher severity of epidermal disease in females than males in Doubtful Sound is an indication that females may be experiencing cumulative impacts, most likely from the freshwater discharge and tour boat interactions. Fishing is an additional human activity with potential effects on the Doubtful Sound dolphin population. Bycatch is not an issue but past fishing practices have led to declines in Fiordland fish stocks (Beentjes & Carbines 2005). Given that the Doubtful Sound dolphins are reliant on local productivity (Lusseau & Wing 2006) a depletion of prey may have an impact on the condition and health of mothers and consequently the survival of calves in the population.

The results from this study contribute to a body of circumstantial evidence that indicates the freshwater discharge from the hydroelectric power station may be impacting the bottlenose dolphins of Doubtful Sound. The steep decline in dolphin abundance in Doubtful Sound is driven by a decline in calf survival that is coincident with the opening of the second tailrace tunnel (Currey *et al* in press). The clear seasonal changes in the distribution of the Doubtful Sound population, previously thought to be an adaptation to life at high-latitude, are not obvious in Dusky Sound (Schneider 1999, Currey & Rowe 2008). It is possible that these changes in distribution are an avoidance response to cold temperatures in the inner fiord during peak tailrace flow in spring (Currey & Rowe 2008). In this report we have quantified levels of epidermal disease, a condition correlated with low salinity and water temperature, and found them to be significantly higher in Doubtful Sound than in Dusky Sound. The additional freshwater discharge from the power station may exacerbate epidermal disease in the population, with an undetermined effect on the health of affected individuals. Although our results are preliminary, they also indicate that the narrow calving season in Doubtful Sound may not be consistent across Fiordland, and could be an adaptation to localised temperature conditions within Doubtful Sound. The results of this study, and of previous work (Currey *et al* 2007, Currey & Rowe 2008, Currey *et al* in press), suggest that management of the potential impacts of the freshwater discharge into Doubtful Sound should be precautionary.

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Appendix

SUMMARY OF FINDINGS FROM BOTTLENOSE DOLPHIN POPULATION MONITORING IN DOUBTFUL AND DUSKY SOUND: WINTER 2008

Please note that these findings are derived from a photographic census and not capture-recapture analysis.

Doubtful Sound

We conducted fieldwork in Doubtful Sound between 19th and the 28th June 2008. We searched for dolphins on 9 days (totalling 52 hours) surveying a distance of 486 nautical miles. All regions of the fiord were searched at least once during the field trip. We encountered dolphins on 6 days, recorded 11 dolphin groups, observing them for 28 hours and made 110 behavioural and spatial observations. We found dolphin groups as far inshore as Hall Arm but most commonly within the typical winter distribution pattern of Malaspina Reach, around Seymour Island and Bradshaw Sound.

Of the 56 dolphins that were present in the summer, we observed 53 in the winter. Three of the four calves that were born in the summer of 2008 were re-sighted. One calf was missing, and due to repeated observation of its mother, we assume it has died. The other two missing individuals were a 2 year-old and a 3 year-old. The mother of the 2 year-old was repeatedly sighted, and as the 2 year-old would still be dependent, we presume it has died. The mother of the missing 3 year-old had a calf this summer, so the missing dolphin would no longer be dependant but would be expected to closely associate with its mother. Because the mother was repeatedly sighted we presumed the 3 year-old has died, but sightings of the mother during future field trips are needed to confirm this.

Dusky Sound

We conducted fieldwork in Dusky Sound between 14th and the 27th July 2008. We searched for dolphins on 14 days (totalling 87 hours) surveying a distance of 964 nautical miles. All regions of the fiord were searched at least once during the field trip. We encountered dolphins on 13 days, recorded 39 dolphin groups, observing them for 42 hours and made 166 behavioural and spatial observations. We found dolphins groups throughout the fiord system, except the areas westward of Cooper Island in Dusky Sound and westward of Oke Island in Wet Jacket Arm. Compared to surveys in the summer, dolphin groups were more frequently sighted around Anchor Island, and between Anchor Island and Five Fingers Peninsula.

We observed 105 dolphins, 96 of which were sighted in the summer, and 9 were new individuals. The nine new individuals comprised the three new calves, two mother and sub-adult pairs and two adults. Seven of the nine calves that were observed in the summer were re-sighted in the winter. One of the missing calves is presumed dead due to repeated observation of its mother without the calf. Another calf was not sighted, but neither was its mother, so it is uncertain whether they have both died or have migrated elsewhere.