Abundance and population structure of bottlenose dolphins in Doubtful and Dusky Sounds

Population monitoring in Summer 2007/2008

2008

Department of Conservation
Te Papa Atawhai

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Executive Summary

1. The bottlenose dolphin of Dusky Sound (*Tursiops* sp.) are a little studied group at the southern limit of the species range, while the neighbouring bottlenose dolphins of Doubtful Sound have been declining, and are subject to potential impacts from tourism and habitat change.
2. We applied photo identification census and capture-recapture techniques to estimate dolphin abundance in both Doubtful and Dusky Sounds. Further we applied laser photogrammetry and a sex prediction model derived from the population in Doubtful Sound to assess the likely sex ratio in Dusky Sound.
3. In Doubtful Sound, there were 56 (CV=1.3%) bottlenose dolphins, representing no net change in population status over the past 12 months. Four of five individuals missing from last year were under 4 years of age. Survival of newborns in the first year of life was 50%, confirming the importance of calf survival in population health.
4. In Dusky Sound, there were 102 (CV=0.9%) bottlenose dolphins, the first abundance estimate for this population. We did not encounter any individuals from Doubtful Sound in Dusky Sound (or vice versa) suggesting little or no interchange between populations.
5. We predicted the sexes of 79 individuals (representing 98-99% of adults and sub-adults) in Dusky Sound. When our predictions were corrected for animals of known sex, the resulting sex ratio was 35 males to 44 females, not significantly different to an expected 1:1 ratio ($G = 1.02$, d.f. = 1, $P = 0.312$).
6. High resighting rates of individual dolphins suggest the population may be resident, similar to Doubtful Sound. However the clear seasonal shift in distribution observed in Doubtful Sound was absent from Dusky Sound. We discuss the consequences of our findings for the future management of the Fiordland bottlenose dolphins.

Introduction

Bottlenose dolphins, while globally abundant (Wells & Scott 1999), are frequently found in isolated populations that range along discrete areas of coastline (e.g. Wells et al. 1987; Wilson et al. 1999; Connor et al. 2000). The bottlenose dolphins of Fiordland (44°30', 168°E; 46°10'S, 166°40'E) are thought to be the World's southern-most resident groups of bottlenose dolphins (Brāger & Schneider 1998). They are found in three separate populations within Fiordland (Brāger & Schneider 1998; Lusseau & Slooten 2002). One population ranges among the fiords and bays of the northern Fiordland coast. Another is restricted to the Doubtful/Thompson Sound complex (referred to as Doubtful Sound). While the third appears to be restricted to the Dusky/Breaksea Sound complex (referred to as Dusky Sound).

Of the three Fiordland populations, the Doubtful Sound population is the most accessible and has been extensively studied since 1990 (Williams et al. 1993). The population shows adaptations to living in a cool water habitat, such as rotund body shape (Chong & Schneider 2001), seasonal calving (Haase & Schneider 2001) and seasonal changes in habitat use (Schneider 1999). The Doubtful Sound dolphins have an unusual social structure that has been attributed to geographic isolation and ecological constraints (Lusseau et al. 2003). Recently Currey et al. (2007) analysed photo-identification data spanning a 17-year period and detected that the population had declined by 34-39% over the last 12 years to 56 individuals (CV=1.0%) in 2007. Coincident with the population decline, the survival of newborn calves decreased from 0.800 prior to 2000 (Haase & Schneider 2001), to 0.569 (CV=30%) between 2004 and 2007 (Currey et al. 2007). Preliminary modeling from a long-term dataset suggests that this decline occurred around 2002 and that current levels of calf survival are among, if not the lowest, calf survival rates reported in the literature (Currey et al. in prep). The rate of decline in abundance and survival is unsustainable and long-term viability of the population is threatened (Lusseau et al. 2006; Currey et al. 2007).

The detection of a decline in Doubtful Sound now prompts the question: is the decline in bottlenose dolphin abundance limited to Doubtful Sound, or is a similar decline occurring across Fiordland? The other bottlenose dolphin populations in Fiordland are far less accessible than Doubtful Sound, and consequently, are less studied. While some research has been conducted on the northern population, principally concerning tourism impacts (Lusseau 2005), data were only collected in Milford Sound, which represents a fraction of the population's range. Dusky Sound is the most remote and the most data deficient of the three Fiordland populations. Currently, published information concerning the population is limited to opportunistic surveys of the southern fiords that suggest bottlenose dolphins are resident in the fiord, at least in spring and summer (Brāger & Schneider 1998; Lusseau & Slooten 2002).

The aims of our present study were to provide an updated abundance estimate for the Doubtful Sound bottlenose dolphins and to determine the survival rate of calves born during summer 2007. We also aimed to produce the first abundance estimate for the Dusky Sound bottlenose dolphin population by conducting a photo-identification census and capture-recapture analysis. Our systematic photo-identification surveys in Dusky Sound allowed us to gather the first data on dolphin distribution within the fiord system. Further, we applied a non-invasive morphometric technique to obtain sex information for the dolphin population. Rowe and Dawson (in press) used morphometric data from laser-metric dorsal fin photographs to predict the sex of dolphins in Doubtful Sound with 93% accuracy. Here we applied their sex prediction model to laser-metric dorsal fin photographs of individuals from Dusky Sound to provide sex information for the population.

Methods

Survey Methods

We conducted daily systematic surveys and obtained dorsal fin photographs during field trips to Doubtful Sound (45°30' S, 167°00' E), and Dusky Sound (45°45' S; 166°35' E) visiting both sites in November-December 2007 and February-March 2008. Our survey craft was a 5.5m aluminium-hulled vessel, *Patio 1*, powered by a 90hp two-stroke outboard engine. The survey vessel was airlifted into Dusky Sound by helicopter. Surveys encompassed the entire inner fiord waters and as such, rarely included all areas in a given day. However, all areas of the fiords were surveyed at least once per trip in order to locate any persistently isolated groups of dolphins. In Doubtful Sound, surveys departed from Deep Cove (45°28'S, 167°09'E) and followed a pre-determined route established by Schneider (1999) to include all inshore waters (Fig. 1). In Dusky Sound, we established a survey route departing from Anchor Island Harbour (45°45' S, 166°31.5' E) that included all inshore waters (Fig. 2).

Surveys usually began an hour after dawn, weather permitting, and the survey route was followed until a group of dolphins was encountered. A Garmin GPSMap 60CSX was used to record survey effort, logging track points each minute the vessel was in operation. Once dolphins were encountered, the survey route was suspended and the research vessel approached the dolphins in accordance with the Marine Mammal Protection Regulations and the code of practice developed by Schneider (1999). Photographic effort began when the vessel was within approximately 15m of a dolphin group. Once we believed we had photographed every individual in the group (when we had taken >4 photos of each individual, c.f. Wūrsig & Jefferson 1990), we broke contact and continued with the survey until the route was completed, conditions deteriorated (i.e. Beaufort 4 and/or heavy rain) or daylight diminished.

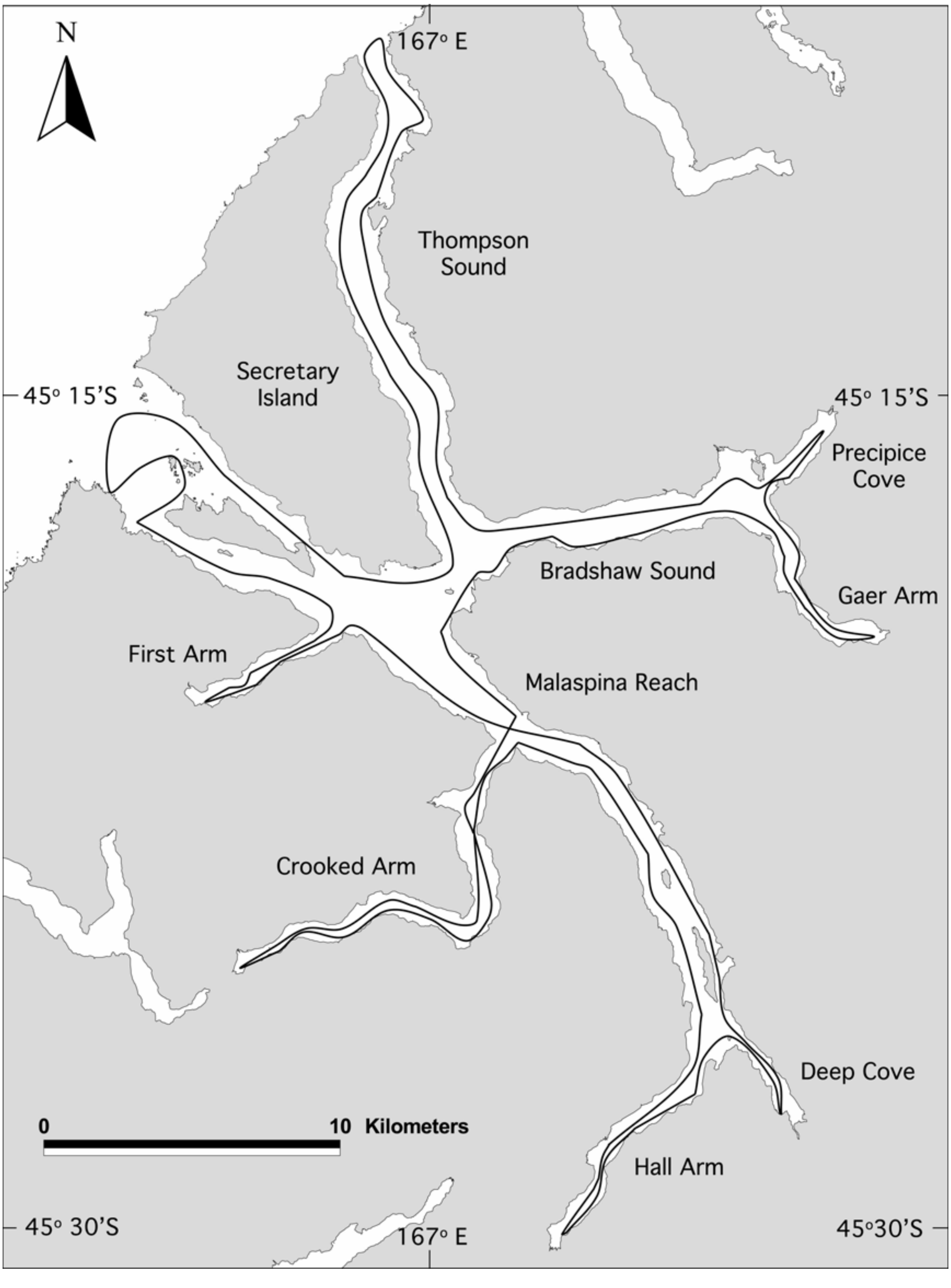

FIG. 1 SURVEY ROUTE IN THE DOUBTFUL-THOMPSON SOUND COMPLEX (SCHNEIDER 1999).

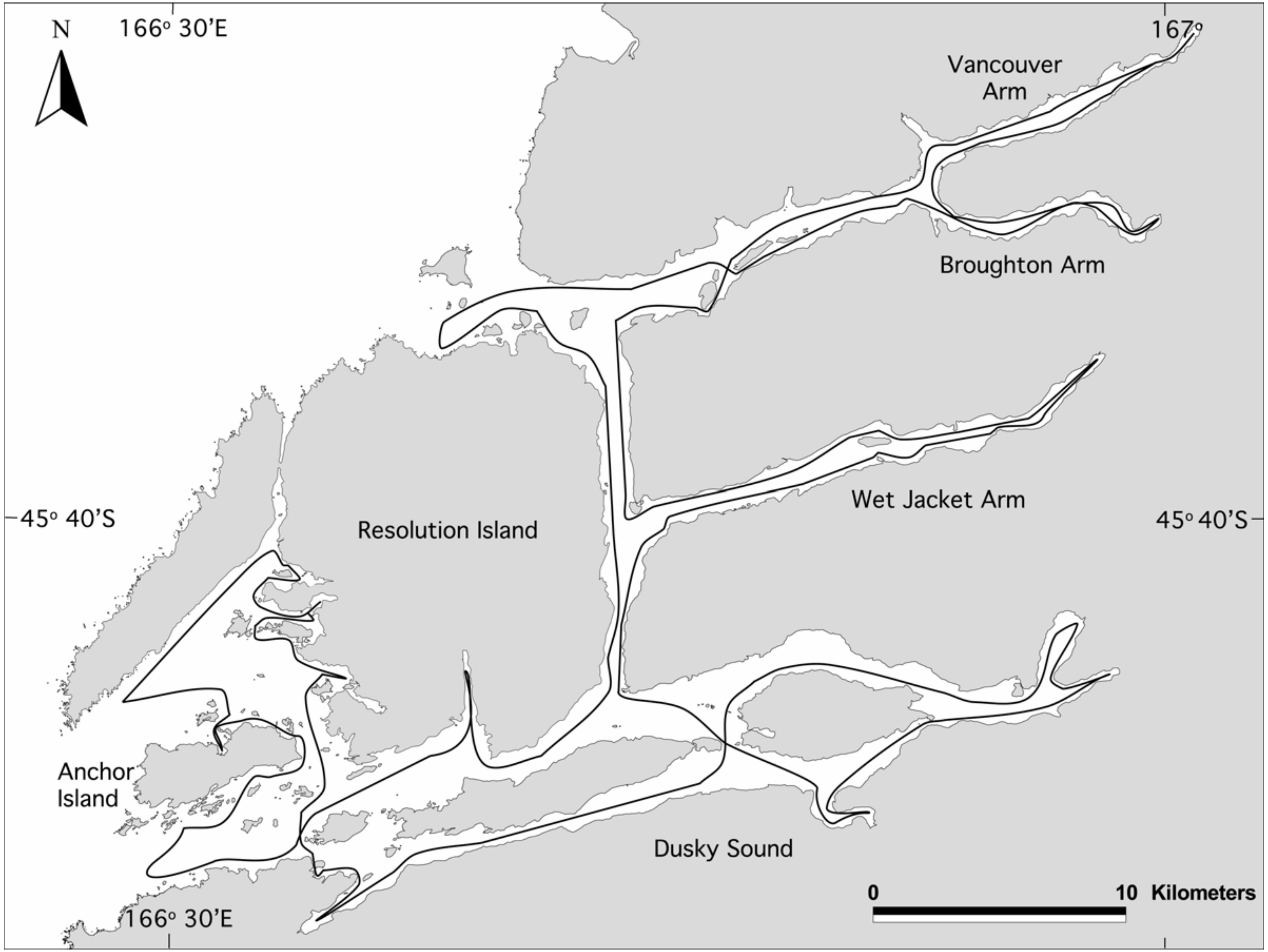

FIG. 2 SURVEY ROUTE IN THE DUSKY-BREAKSEA SOUND COMPLEX.

Photo Identification

Dorsal fin photo-identification (photo-ID) allows individual dolphins to be identified by unique patterns in naturally occurring marks (Wūrsig & Wūrsig 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. 1999).

Dorsal fin photographs were taken of individuals irrespective of their marks to enable an unbiased estimation of the proportion of nicked individuals (termed mark rate). Identification photographs were classified into four mark classes according to the presence of tooth rakes, a single nick, a double nick, or multiple nicks in the dorsal fin (following Williams et al. 1993). High intensity photo-ID effort allowed even subtly marked individuals to be uniquely identified and consistently re-sighted. Photographic re-sightings of individually identifiable dolphins were made with reference to a photo-ID catalogue that included all known individuals. In Dusky Sound, this required the construction of a new catalogue, while in Doubtful Sound photographic re-sightings were used to update the existing catalogue (Williams et al. 1993; Currey et al. 2007).

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 Nikon digital SLR cameras (Nikon D70s) equipped with AF Nikkor lenses (80–200 mm f2.8 and 70–200 mm f2.8 VR). We operated two cameras concurrently, with one set of photographs used to produce the photo-ID census and capture-recapture abundance estimates, and the other to make measurements of dorsal fin morphometry using laser photogrammetry.

Abundance Estimation

We estimated dolphin abundance using both capture-recapture and census techniques; an approach that has yielded precise estimates of dolphin abundance in Doubtful Sound in the past (Currey et al. 2007). A photographic census was conducted by recording the number of identified individuals sighted over the period of fieldwork. This serves as a direct measure of minimum abundance. Our census included adults, sub-adults and calves, representing all subgroups within the population. We identified calves by the presence of marks (primarily tooth rakes), the shape of their dorsal fins and continued association with the (presumed) mother.

We calculated capture-recapture abundance estimates using the Chapman modification of the Lincoln-Petersen estimator (Chapman 1951):

$$N = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \qquad (1)$$

Where N is the estimate of abundance, n_1 is the number of individuals captured (i.e. photographed) in the first period, n_2 is the number of individuals captured in the second period and m_2 is the number of individuals captured in the first period and recaptured in the second period.

We estimated abundance under two scenarios: (i) assuming all individuals in the population were marked (termed LP all marked), and (ii) using only individuals with dorsal fin nicks, and then scaling this estimate by a mark rate (termed LP nicked marked). In each scenario, we considered the fieldwork conducted in early summer as the "capture" period, and the fieldwork conducted in late summer as the "recapture" period. The second scenario is more conservative as it assumes only long-lasting marks (dorsal fin nicks) can be reliably resighted. We estimated mark rate by counting the number of high-quality photos of individuals with dorsal fin nicks and dividing by the total number of high quality dorsal fin photos taken (Williams et al. 1993; Currey et al. 2007). We calculated log-normal confidence intervals as these better reflect the uncertainty in abundance estimates (Buckland et al. 1993).

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 (Durban & Parsons 2006). 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-metric photography has been used to obtain measurements of the dorsal fins of killer whales (Durban & Parsons 2006) and bottlenose dolphins (Rowe & Dawson in press). Here, laser pointers were fixed 100mm apart inside a rectangular plastic mounting block attached directly to the camera. The system was calibrated daily to ensure lasers were parallel, and checked regularly during photographic effort by projecting the lasers on to a measurement grid onboard the boat. Laser-metric photographs were subject to the same quality grading procedures at described above for photo-ID, with the addition that the laser dots were required to be clearly visible in each photograph.

We selected the highest quality laser-metric photograph of each individual's dorsal fin for analysis. In *Intaglio* (version 2.9.4, Purgatory Design) the dorsal fin base line (DBL) 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. The distance between the laser dots on each photograph was calibrated to equal 100mm and DBL measured. The image of the dorsal fin was extracted from the background and cropped at DBL using *Adobe Photoshop* (version 7.0, Adobe Systems Inc, California). To ensure consistency, all image selection, manipulations, and measurements were made by the same person.

Sex Prediction

A sex classification model derived from 43 known-sex adult and sub-adult bottlenose dolphins from Doubtful Sound correctly classified the sex of 93% of individuals (Rowe & Dawson in press). Here we apply this model to predict the sex of adult and sub-adult bottlenose dolphins in Dusky Sound. This method is only applicable to adult and sub-adult dolphins (>4 years of age), thus we excluded calves from the data set. In Doubtful Sound, all dolphins less than 4 years old had dorsal fins less than 34cm in base length, allowing these individuals to be excluded from the sex classification model (Rowe & Dawson in press). We applied the same measurement threshold in Dusky Sound and only included individuals whose DBL exceeded 34cm to ensure the model was applicable.

The model to predict the sex of adults and sub-adults in Dusky Sound required specific morphometric data: dorsal fin surface area, proportion of the dorsal fin covered in scarring and the mark class. In *ImageJ* (version 1.37, National Institute of Health, USA), a scale was set for each photograph by calibrating the distance between the laser dots to equal 100mm. The fin area was selected by a threshold technique and the area measured and expressed as cm^2. To provide a measure of scarring severity, the perimeter of individual scars was traced using the paintbrush tool in *Photoshop*. In *ImageJ* the threshold technique allowed the area of the traced scarring to be expressed as a percentage of the total area of the dorsal fin. Photo-identification mark classes were assigned a value from 0 to 3 respectively and were recorded as a categorical variable for each individual.

The following sex classification model from Rowe and Dawson (in press) was applied to the morphometric data to predict the sex of the Dusky Sound dolphins:

$$\pi_i = \frac{e^{(-25.640+0.038(\mathrm{a}_i)+0.460(\mathrm{b}_i)+\alpha_i)}}{1+e^{(-25.640+0.038(\mathrm{a}_i)+0.460(\mathrm{b}_i)+\alpha_i)}} \qquad (2)$$

Where a_i, b_i and α_i are morphometric measures for individual i and π_i is the probability of being male. Specifically, a = dorsal fin surface area, b = proportion of the dorsal fin that is scarred and α is a numerical coding of mark class such that $\alpha = 0$ when mark classification is tooth rakes; $\alpha = -3.006$ when mark classification is single nick; $\alpha = -2.326$ when mark classification is double nick; $\alpha = 1.668$ if mark classification is multiple nick. The logistic regression model will give the probability (π_i) of being male, meaning if π_i is greater than 0.5, then the individual is considered male. If π_i is less than 0.5, the individual is considered female. For example, if $\pi_i = 0.84$, there is an 84% probability that the individual is male and a 16% probability ($1-\pi_i$) that the individual is female. In this case, we would predict the individual is male.

When using sex determination methods, it is as important to know when a method may fail as when it may provide useful information (Albanese 2003). During photo-ID field effort in Dusky Sound opportunities arose to sex some individuals. Females were identified by observation of their genital region and the presence of mammary slits. Individuals were also assumed to be female if they had consistent association with a calf or sub-adult. Males were identified by observation of genital region or an erect penis. We compared the assigned sex from the classification model to that known sex for individuals for which data was available. We compared the ratio of males and females using the sexes assigned from the classification model, and also the ratio of males and females after erroneous classifications were corrected. The statistical significance of the departure of the ratio males to females from the expected 1:1 ratio was tested by means of a goodness-of-fit *G*-test.

Results

Field Effort and Dolphin Distribution

Our field effort in Doubtful Sound was divided into two sampling periods, the first in late spring 2007 and the second in late summer 2008. We spent 14 days (totalling 104 hours) on the water, encountering dolphins on 13 days, observing them for 53 hours and surveying a distance of 1144 nautical miles on effort. All regions of the fiord were searched at least once in each sampling period. We encountered 29 dolphin groups, made 225 spatial observations at 15-minute intervals and took 2997 dorsal fin identification photographs to estimate dolphin abundance. Dolphin distribution varied between sampling periods, with late spring sightings primarily in the outer fiord, followed by an inshore shift with late summer sightings primarily in the inner fiord (Fig. 3).

Our field effort in Dusky Sound entailed two periods of fieldwork in early and late summer 2007/08, resulting in 17 days (113 hours) spent on the water. We surveyed 1472 nautical miles on effort, with all regions of the fiord searched at least once in each sampling period. We encountered dolphins on 15 days, spent 43 hours with them and made 188 spatial observations at 15-minute intervals. We took 3623 dorsal fin identification photographs for abundance estimation and 1537 dorsal fin photographs for morphometry and sex prediction. The 29 dolphin groups we encountered were distributed throughout the entire fiord system in both fieldwork periods, with sightings in the inner fiord regions as well as the entrances of both Dusky and Breaksea Sounds (Fig. 4).

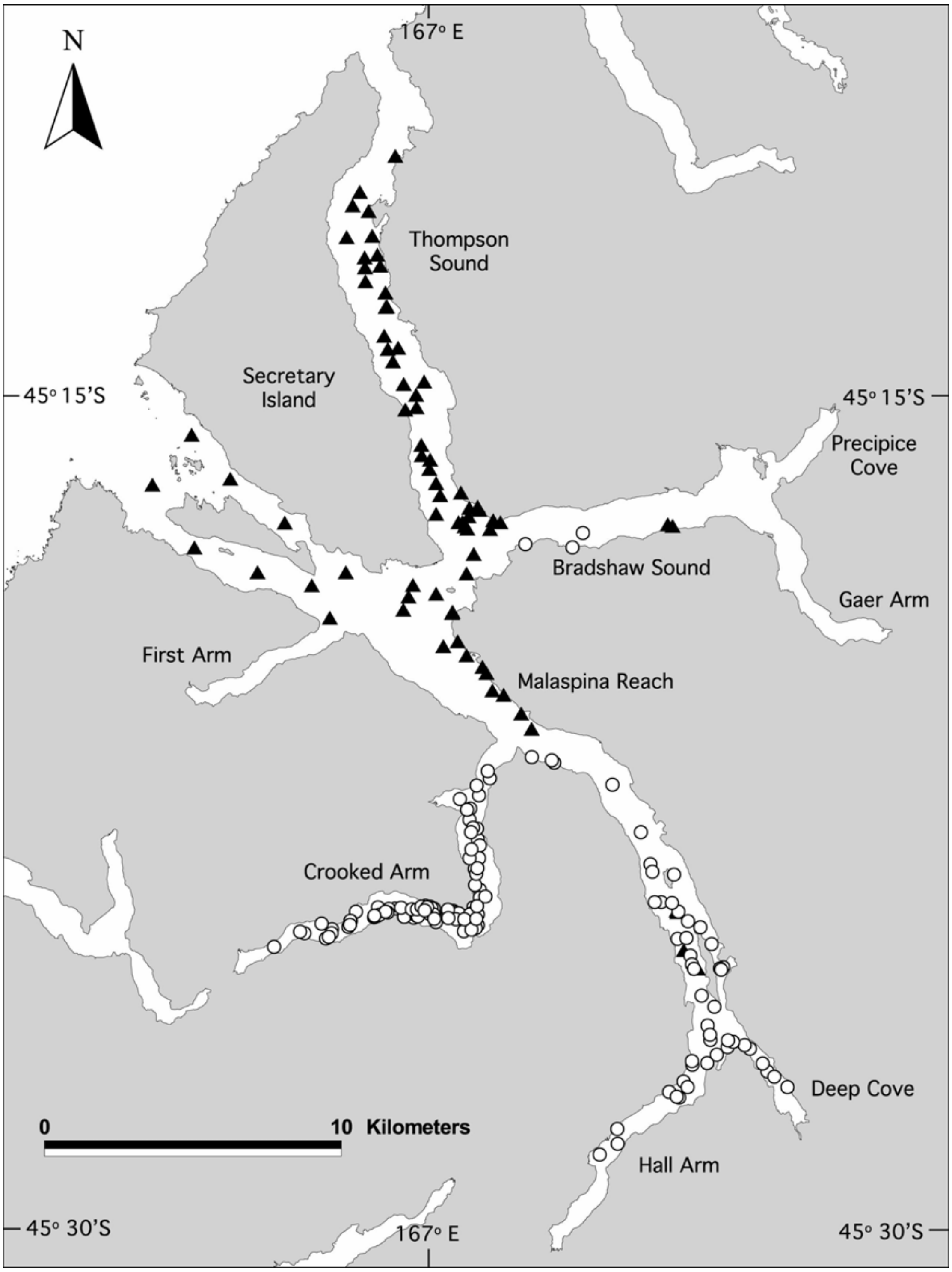

FIG. 3 DISTRIBUTION OF DOLPHIN GROUPS RECORDED AT 15-MINUTE INTERVALS IN DOUBTFUL-THOMPSON SOUND COMPLEX. SIGHTINGS FROM SURVEYS IN NOVEMBER AND DECEMBER 2007 ARE DENOTED BY ▲ AND SIGHTINGS FROM FEBRUARY 2008 ARE DENOTED BY ○.

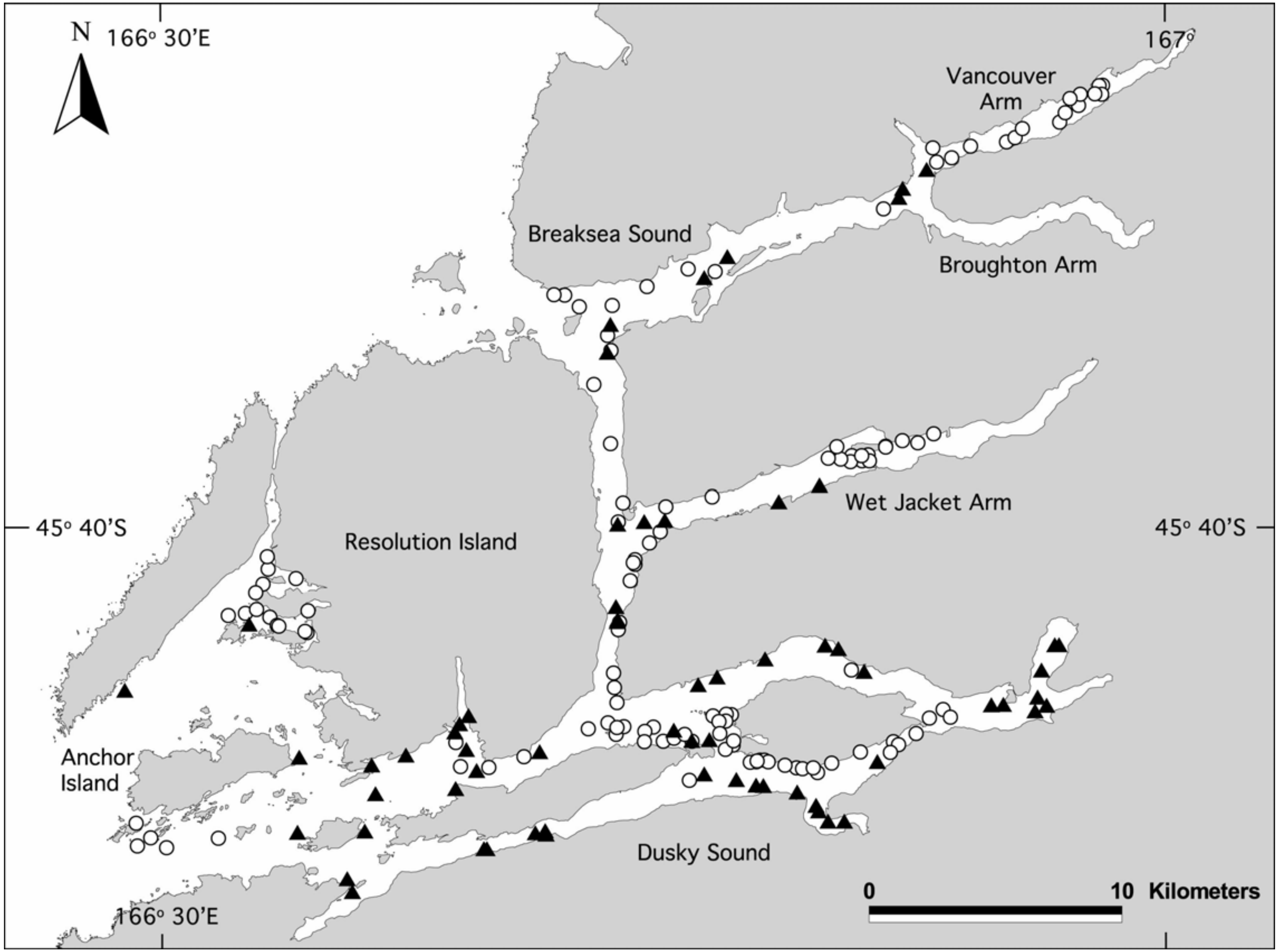

FIG. 4 DISTRIBUTION OF DOLPHIN GROUPS RECORDED AT 15-MINUTE INTERVALS IN DUSKY-BREAKSEA SOUND COMPLEX. SIGHTINGS FROM SURVEYS IN DECEMBER 2007 ARE DENOTED BY ▲ AND SIGHTINGS FROM FEBRUARY AND MARCH 2008 ARE DENOTED BY ○.

Population Demographics

In Doubtful Sound, we observed and identified 56 individually marked bottlenose dolphins. These individuals included 51 adults, sub-adults and calves (>1 year old) that had been sighted in the fiord in prior years, one calf born between February and November 2007 and four calves born between November 2007 and February 2008. Since February 2007, five previously identified individuals have disappeared: one mature female and four calves in the first three years of life, resulting in no net change in the population in the last 12 months. Two of the four calves born last summer survived to this summer, resulting in an apparent annual survival rate of 50% over the past year for calves in the first year of life.

In Dusky Sound, we observed and identified 102 individually marked bottlenose dolphins. These individuals consisted of 93 adults, sub-adults and calves (>1 year old) and nine newborn calves: three born just prior to December 2007 (based on size relative to the mother, depth of foetal folds and erratic surfacing behaviour) and six born between December and February 2008. There was no apparent overlap with the population in Doubtful Sound, with none of the individuals observed in Dusky Sound sighted in Doubtful Sound previously. In addition, we observed and identified a single individually marked common dolphin (*Dephinus delphis*), which was sighted on four separate days freely associating with the bottlenose dolphins. This individual was photographed in Dusky Sound 12 months earlier and hence may have joined the population.

All 93 adults, sub-adults and calves (>1 year old) exhibited some degree of marking, with 80 possessing dorsal fin nicks and toothrakes, while the remaining 13 had toothrakes on their dorsal fins. The nine newborn calves could be identified by their dorsal fin shape and mother-calf associations and in some cases were beginning to accumulate dorsal fin nicks and toothrakes by the end of the summer. Population composition appeared to be consistent over the summer with the majority of the population sighted on 5 or more occasions (Fig. 5). This consistency was reflected in the discovery curve, with all 93 adults, sub-adults and calves (>1 year old) observed within the first 10 days of field effort (Fig. 6). High resighting rates and a tapering discovery curve indicates the population was probably resident within the fiord system over the study period.

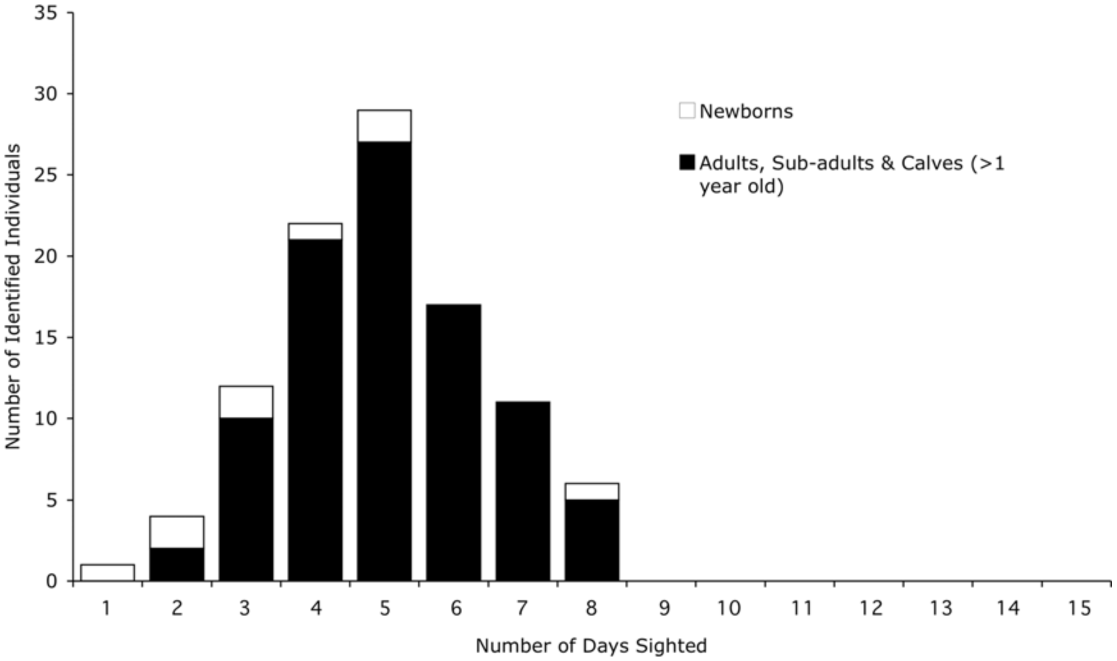

FIG. 5 SIGHTING FREQUENCY OF INDIVIDUALLY IDENTIFIED BOTTLENOSE DOLPHINS (N = 102) OBSERVED IN 15 DAYS OF PHOTO IDENTIFICATION ON DUSKY-BREAKSEA SOUND COMPLEX.

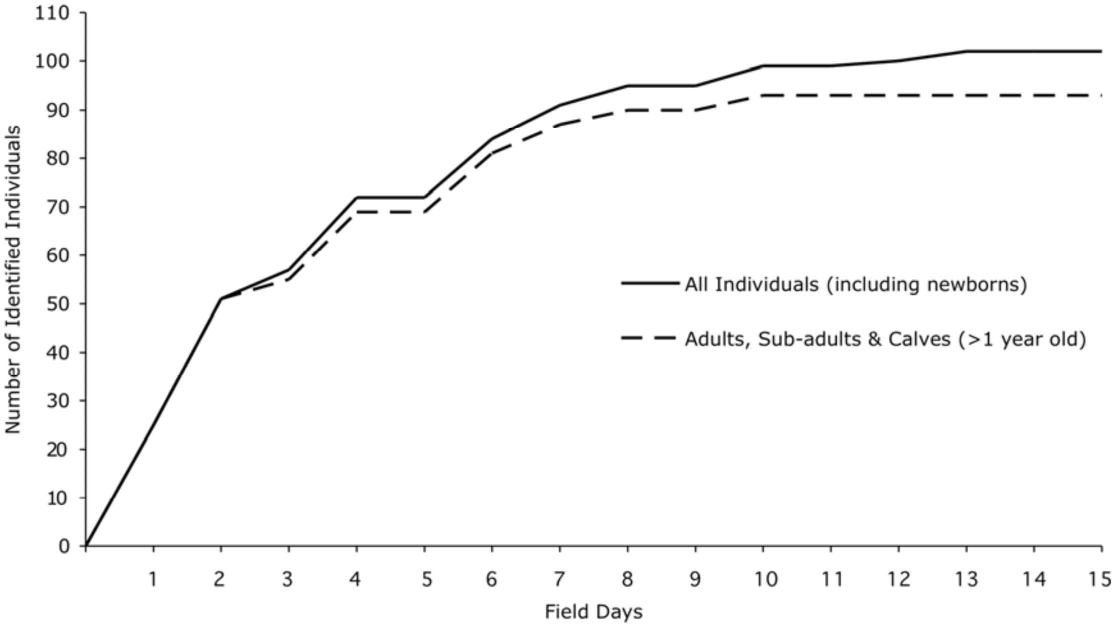

FIG. 6 DISCOVERY CURVE FOR 102 INDIVIDUALLY IDENTIFIED BOTTLENOSE DOLPHINS ACROSS THE 15 DAYS OF PHOTO IDENTIFICATION ON DUSKY-BREAKSEA SOUND COMPLEX.

Abundance Estimates

In Doubtful Sound, our capture-recapture abundance estimates were very similar to our population census of 56 bottlenose dolphins. The Lincoln-Petersen estimate that included all individuals as marked was exactly 56. Identifying all 56 individuals in the recapture period and the 100% mark rate resulted in a CV of zero for this estimate. The Lincoln-Petersen estimate that included only nicked individuals as marked was 55 (CV=1.3%). The precision of the abundance estimate results from the scaling effect of mark rate as we observed all the marked individuals in the recapture period. Further the 95% confidence intervals of this estimate overlap our population census of 56. Thus we interpret these results to indicate that there are 56 (CV=1.3%; 95% CI: 55-57) bottlenose dolphins in Doubtful Sound.

In Dusky Sound, both capture-recapture abundance estimates were identical to our population census of 102 bottlenose dolphins. The Lincoln-Petersen estimate that included all individuals as marked was exactly 102. The 100% mark rate in addition to identifying all 102 individuals in the recapture period resulted in a CV of zero for this estimate. The Lincoln-Petersen estimate that included only nicked individuals as marked was 102 (CV=0.9%). As in the case of the Lincoln-Petersen estimate that considered all individuals as marked, we observed all the marked individuals in the recapture period, thus the precision of the abundance estimate results from the scaling effect of mark rate. Thus we interpret these results to indicate that there were 102 (CV=0.9%; 95% CI: 100-104) bottlenose dolphins in Dusky Sound in February 2008.

Sex Prediction

High quality laser-metric dorsal fin photographs were obtained for 98 out of a possible 102 identified individuals, from which 79 dolphins had a dorsal fin base length exceeding 34cm. The sample represented 98-99% of the adult and sub-adult population, as two of the four unmeasured individuals were newborn calves. The classification model derived from 43 known-sex dolphins from Doubtful Sound was applied to predict the sexes of the 79 dolphins from Dusky Sound. Based on a 0.5 probability threshold, the model predicted that 42 dolphins were female and 37 dolphins were male.

The sex of 24 of the dolphins in Dusky Sound was known and provided a sample to validate the predicted sexes. The predicted sex was correct for 75% (18/24) of the dolphins, with 4 females and 2 males being misclassified. Of the 24 known-sex individuals, 21 were female and 3 male. Females that were sexed by close association with a sub-adult or by direct observation were assigned the correct sex by the model. The four females that were misclassified as males were all sexually mature females. The two misclassified males were young, small sub-adults that only just exceeded the fin base length threshold to be included in the model.

The ratio of male to female dolphins was 37:42 which is not a statistically significant departure from the expected 1:1 ratio (goodness-of-fit G-test G = 0.31, d.f. = 1, P = 0.575). When the erroneous sex assignments were corrected with the known-sex data, the ratio of male to female dolphins was 35:44. Although this is more skewed towards females, it is not significantly different from the expected sex ratio (goodness-of-fit G-test G = 1.02, d.f. = 1, P = 0.312).

Discussion

Through the application of capture-recapture and census techniques, we have produced a current abundance estimate that includes all members of the population (i.e. adults, sub-adults and calves) and determined that there are currently 56 bottlenose dolphins resident in Doubtful Sound. The current abundance is identical to an abundance estimate obtained 12 months prior (Currey et al. 2007). Despite the addition of five calves during the intervening year, there has been no net population increase, due to the corresponding disappearance of five individuals. Four of the five animals that disappeared were young (< 4 years) and were still dependant on, or closely associated with, their mothers. As the mothers were either sighted without them (in three of four cases) or had disappeared more than 12 months ago (in one case), we conclude that these absent individuals have most likely died. This is consistent with an observed decrease in the survival of newborn calves (Currey et al. 2007). Preliminary modeling suggests that low calf survival may be the demographic cause of the population decline (Currey et al. in prep). Mortality of individuals in the first 3 years of life, particularly of newborns, appears to be the most important factor that management needs to address to ensure the long-term viability of the Doubtful Sound population.

This study provides the first estimate of bottlenose dolphin abundance in Dusky Sound and resulted in production of the first photo-ID catalogue of the population. Using capture-recapture and census techniques we determined that 102 bottlenose dolphins were resident in Dusky Sound over the study period. This abundance estimate includes all members of the population (i.e. adults, sub-adults and calves). As in previous studies of Fiordland bottlenose dolphins, we were able to produce a photo-ID census of the entire population that was comparable to the results of the capture-recapture abundance estimate (Currey et al. 2007). The congruence between the two abundance techniques is a by-product of a high mark rate and intensive photo-ID effort during the study period.

Dolphin abundance is far higher in Dusky Sound compared to the neighboring population in Doubtful Sound, for which there could be several reasons, including: (i) Dusky Sound is a larger fiord (approximately twice the surface area) and may have greater regions of suitable habitat enabling it to support a larger dolphin population; (ii) there may be fundamental ecological differences (i.e. different levels of local productivity) between the two fiords despite their close proximity, and (iii) that the higher level of anthropogenic impact in Doubtful Sound has a negative effect on dolphin abundance.

The bottlenose dolphin population of Dusky Sound is nearly twice as large as that of Doubtful Sound and it was expected that the number of newborn calves would reflect this. The birthrate in Doubtful Sound varies between 2 and 9 calves a year (Haase & Schneider 2001). Thus, in a population approximately double the size, it seems reasonable to expect between 4 and 18 births a year. Nine new season calves were sighted in Dusky Sound, which fits within the expected range based on the Doubtful Sound birthrate. We cannot assess if the low level of calf survival found in Doubtful Sound (Currey et al. 2007) is also occurring in Dusky Sound until the number of calves that survive to next summer is known. While it will be possible to calculate a survival rate for the year after next summer underlying trends in survival will not become apparent for several years. Continued photo-ID monitoring of the population will be essential to assess future trends in calf and adult survival.

Although declining survival of calves is most likely driving the population decline in Doubtful Sound (Currey et al. in prep), it is important to establish if emigration to other fiords is a contributing factor. Bottlenose dolphins are social animals and migrant dolphins could increase their chances of survival by joining an established bottlenose dolphin population (Connor & Norris 1982). The Dusky Sound population experiences the least human impacts of all the Fiordland bottlenose dolphins (Lusseau et al. 2006), which may mean that individuals immigrating to Dusky Sound have a higher chance of survival and successfully joining the new population, compared to those emigrating to join the northern population. Despite this, we did not sight any individuals in Dusky Sound that had been previously sighted in Doubtful Sound, either during the present study or during a previous 6-day survey of Dusky Sound in October 2006 (R. Currey and E. Slooten, unpublished data). The precision of the capture-recapture abundance estimate and the plateau of the discovery curve both give us confidence that we would have been likely to sight any Doubtful Sound individuals had they been present. To establish conclusively that members of the Doubtful Sound group are not migrating to either of the neighbouring populations, surveys of the northern fiords, and repeated surveys of Dusky Sound are required.

In Dusky Sound, dolphins were sighted throughout the entire fiord system, with no apparent shift in distribution between early and late summer. This contrasts with the well-established pattern of seasonal movements within Doubtful Sound, where dolphins use the outer fiord in winter and spring before returning to the inner arms of the fiord to breed in summer and autumn (Schneider 1999). The seasonal distribution in Doubtful Sound is thought to be a response to seasonal changes in water temperature, but may also reflect shifts in productivity or prey distribution (Schneider 1999). Given that the two populations are located just 25 nautical miles apart at the fiord entrances, it is surprising that we did not observe either a shift in distribution or a preference for inshore waters in Dusky Sound. This suggests that the seasonal distribution observed in Doubtful Sound may be due to oceanographic conditions specific to the fiord.

The freshwater input from the Manapouri hydroelectric power station is a major anthropogenic effect that alters the oceanographic regime of Doubtful Sound. The influx of freshwater from the power station tailrace amounts to two to three times the natural catchment run-off, augmenting a naturally occurring low salinity layer (LSL) (Gibbs et al. 2000). The thickness of the LSL is correlated with wind and rainfall events (Gibbs et al. 2000), but also corresponds to variability in tailrace discharge (Boyle et al. 2001). There is a seasonal pattern in tailrace discharge, with the highest flow rates occurring in spring due to snowmelt (Mabin 2008). In spring, when the LSL is thickest and most persistent, the temperature of the LSL is lower than the underlying marine layer (Gibbs 2001). Spring is also the period that corresponds with the dolphins' distribution being furthest from the tailrace. It may be that the dolphins reduce thermal stress by avoiding the colder temperatures of the inner fiord in winter and spring.

While the dolphin population in Dusky Sound is more abundant than the population in Doubtful Sound, it is still relatively small and hence is inherently vulnerable to stochastic changes in sex ratio since the effects of such changes are often magnified when abundance is low (Gilpin & Soule 1986). If the sex ratio of a population becomes skewed towards either sex, the viability of the population can be reduced due to Allee effects (Stephens et al. 1999) manifested through reduced reproductive rate (Saether et al. 2004) and changes in social structure (Lusseau & Newman 2004). The results of the sex prediction model suggest the ratio of males to females in Dusky Sound is close to 1:1, which is similar to findings from other bottlenose dolphin populations (Perrin & Reilly 1984; Hersh et al. 1990; Lusseau et al. 2003; Mann & Sargeant 2003; Krutzen et al. 2004). An approximately equal sex ratio in Dusky Sound indicates that the population is not currently facing the inherent problems related to stochastic sex-ratio fluctuations of small populations.

We made the assumption that the sex classification model derived from Doubtful Sound would be applicable in Dusky Sound due the close proximity of the populations and the fact that the characteristic we measured (i.e. dorsal fin morphology) is unlikely to vary over such a short range (see Bertellotti et al. 2002; Devlin et al. 2004; Shealer & Cleary 2007 for a similar approach). When the predicted sexes were compared to a known-sex sample from Dusky Sound the model's accuracy was 75%, not the expected 93%. While the lower performance of the classification model in Dusky Sound could be due to unexpected morphological variation between the populations, it is more likely a result of bias within the known-sex sample.

Male and female dolphins are not equally available to be sexed, and further, different age groups are more likely to be sexed than others. Both males and females can be sexed by direct observation. In addition, sex can be inferred in females from close association with a calf or sub-adult. Opportunities to sex males, particularly mature males, are infrequent. This is because mature males very rarely approach the boat to bow ride, which is when most sex observations take place. The result is that the known-sex sample is not only highly skewed towards females, but also towards older females and younger males. This age-related bias is of consequence because older females will have accumulated more marks over time (Würsig & Jefferson 1990), and in some cases, possess 'male typical' dorsal fins. The converse is true for some young males, who have yet to accumulate the scarring and nicks that characterise a male dorsal fin. In other words, these are the parts of the population in which the prediction approach works least well. Despite these biases, the sex classification model still predicted the correct sex for 75% of the individuals of known sex. We would expect that the model would predict the correct sex in more than 75% of individuals in an unbiased sample. It should approach the 93% accuracy that was achieved in Doubtful Sound (Rowe & Dawson in press).

An important outcome of this study is to provide sex ratio data for incorporation into future population viability analyses. Until now this information would have taken years of opportunistic observations to collect, or require invasive sampling for molecular sexing. Using the current sex information as a base line, future studies can monitor changes in sex ratio over time and adapt management accordingly. These sex data also facilitate the collection of sex-specific information, such as survival rate, reproductive rate and severity of epidermal lesions. Sex-specific comparisons of these factors may help diagnose differences between the Doubtful Sound and Dusky Sound populations to help resolve the cause of the population decline in Doubtful Sound.

Implications for Management

It should not be assumed that the bottlenose dolphin population in Dusky Sound represents a pristine and healthy population simply because dolphin abundance is high compared to Doubtful Sound. While our results provide a baseline estimate of dolphin abundance, they do not provide population trends. Provision needs be made to ensure the continuation of consistent population monitoring to enable trends in abundance and survival rates to be assessed over time. Clarifying the reasons behind the considerable differences in dolphin abundance and distribution between the Doubtful Sound and Dusky Sound is a priority for future research. A long-term comparative study between the two populations is required to help determine causes for these disparities, which in turn, will shed further light on the decline in dolphin abundance in Doubtful Sound. Towards this end, precautionary management of Dusky Sound is advised, not just for the welfare of the population, but also to ensure the population can provide a meaningful yardstick for comparison to Doubtful Sound in the long term. While there are almost certainly some human impacts in Dusky Sound, its isolation affords it a significant degree of protection. Hence the insights gained here may be closer to what we would expect to have seen in Doubtful Sound without current levels of impact. This will only remain true if any future impacts to the Dusky Sound population are managed with a precautionary approach.

The Doubtful Sound bottlenose dolphin population has been in precipitous decline for 12 years and urgently needs precautionary management of human impacts to ensure the dolphins' long-term survival (Currey et al. 2007). A voluntary Code of Management was introduced in January 2008 with the intent of minimizing the impact of tour boats on the dolphins. Protection measures include the creation of dolphin protection zones (DPZs), which are designed to reduce boat interactions within areas that include some of the population's most critical habitats (see Lusseau & Higham 2004). To be successful, the Code of Management requires stakeholder support. In other locations voluntary approaches to managing whale and dolphin tourism have suffered from issues of non-compliance (Scarpaci et al. 2003; Scarpaci et al. 2004; Whitt & Read 2006; Wiley et al. 2008). Hence, stakeholder compliance will be critical in this instance. Further, it will take several years to assess if the DPZs have a positive effect on calf survival and abundance, as these are lagging indicators of population health.

It is crucial to note that detection of a further decline in abundance must not be a necessary criterion for initiating further conservation measures. The efficacy of the Code of Management could be assessed in the short- to medium-term by assessing if the dolphins show increased or preferential use of the protected areas. Habitat use could be measured with passive acoustic monitoring with T-PODS (e.g. Philpott et al. 2007) and/or by dedicated spatial monitoring from boats (e.g. Wilson et al. 1997).

The steep decline of the Doubtful Sound population means we cannot afford to wait for an assessment of the Code of Management before considering other sources of potential impact upon the dolphins. Future studies are planned to enhance our understanding of these potential impacts. Increased freshwater input from the Manapouri power station has caused substantial ecological changes within the fiord (Boyle et al. 2001; Tallis et al. 2004; Rutger & Wing 2006), and may be a source of impact on the Doubtful Sound dolphins. There is a clear seasonal shift in dolphin distribution, which may be a response to colder water temperatures in the inner fiord consistent with the increased freshwater output from the tailrace. Such a seasonal shift is not apparent in surveys done to date in Dusky Sound. This raises the possibility that seasonal movements in Doubtful Sound could be a response to the tailrace discharge rather than a geographic adaptation to natural processes as previously thought. Future comparative studies of dolphin distribution and water temperature in both Doubtful and Dusky Sounds across seasons will clarify this. In the meanwhile, precautionary management that includes steps to control the effects of freshwater input into Doubtful Sound should also be considered. These steps could involve restricting future increases in output from the tailrace or limiting flow at times of the year when the dolphins are particularly vulnerable to impact (i.e. spring and summer when dolphins are in late pregnancy and calving). A precautionary management approach that includes all potential sources of impact is likely to be the most effective way to ensure the long-term survival of the bottlenose dolphins in Doubtful Sound.

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