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Capture-recapture abundance and survival estimates of three cetacean species in Icelandic coastal waters using trained scientist-volunteers

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A B S T R A C T

Knowledge of abundance and survival of humpback whales, white-beaked dolphins and minke whales are essential to manage and conserve these species in Icelandic coastal shelf waters. Our main goal was to test the feasibility of employing inexpensive research methods (data collected by trained-scientist volunteers onboard opportunistic vessels) to assess abundance and apparent survival. No previous studies in Iceland have investigated these two demographic parameters in these three cetacean species using open capture-recapture models accounting for imperfect and possibly heterogeneous detection. A transient effect was accounted for whenever required to estimate the population of resident individuals. Identification photographs were collected by scientist-trained volunteers for 7 years (2006–2013) from onboard commercial whale-watching vessels in the coastal waters of Faxaflói (southwest coast, ~4400 km^2) and Skjálfandi (northeast coast, ~1100 km^2), Iceland. We estimated an average abundance of 83 humpback whales (Mn; 95% confidence interval: 54–130) in Skjálfandi; 238 white-beaked dolphins (La; [163–321]) in Faxaflói; and 67 minke whales (Ba; [53–82]) in Faxaflói and 24 (14–31) in Skjálfandi. We also found that apparent survival was constant for all three species (Mn: 0.52 [0.41–0.63], La: 0.79 [0.64–0.88], Ba-Faxaflói: 0.80 [0.67–0.88], Ba-Skjálfandi: 0.96 [0.60–0.99]). Our results showed inter-annual variation in abundance estimates which were small for all species, and the presence of transience for minke whales. A significant increase in abundance during the study period was solely found in minke whale data from Skjálfandi. Humpback whales and white-beaked dolphins showed lower apparent survival rates compared to similar baleen whale and dolphin populations. Our results show data collected by trained-scientist volunteers can produce viable estimates of abundance and survival although bias in the methods we employed exist and need to be addressed. With the continued increase in anthropogenic pressures on our three target populations in Iceland our results can be used by relevant stakeholders to develop appropriate conservation strategies in the region.

1. Introduction

For management and conservation purposes, it is crucial to gather information about abundance, survival, movement and distribution of free-ranging cetacean populations (Silva et al., 2009; Dick and Hines, 2011). As it has been suggested in other studies (e.g. Parra et al., 2006; Papale et al., 2016), estimates of abundance and survival as well as existing information on movement patterns can be also used to start managing all sources of anthropogenic pressure cetacean species confront. To obtain these estimates it is paramount that a large amount of data is collected across many years, which can be costly (Kaufmann et al., 2011; New et al., 2015). Several research projects monitoring cetaceans around the world have opted for citizen science as an inexpensive way to collect and analyze data relying on the help of 'non-scientific members' (Silvertown, 2009) of the general public, or 'non-specialist volunteers' (Bruce et al., 2014). For cetacean research, citizen science has been used in several studies investigating occurrence, habitat use (Bristow et al., 2001), abundance and distribution (Bruce et al., 2014), with data collected from land or from boats, either research or opportunistic. Data have also been collected by 'experienced volunteers' (Newman et al., 2003) and 'trained scientists' (Higby et al., 2012) who both have a scientific background and to whom training is

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provided, which were both found to reduce bias during data collection and analysis (summarized in Thiel et al., 2014). Volunteers are asked to photograph animals using the photo-identification technique (Würsig and Würsig, 1977) and the photos are processed in order to get individual resightings using natural markings. These data are then analyzed using standard capture-recapture (CR) methods to estimate abundance and demographic parameters.

Minke (*Balaenoptera acutorostrata*) and humpback whales (*Megaptera novaeangliae*) are commonly sighted in Icelandic waters from March to November and occasionally in the winter (Bertulli et al., 2013; Magnúsdóttir et al., 2014) while white-beaked dolphins (*Lagenorhynchus albirostris*) occur all year long (Víkingsson and Ólafsdóttir, 2004). Previous studies also revealed that all species display site fidelity, although the majority of individuals are highly mobile, sighted only once, and spend part of their time travelling outside of our study areas (Bertulli et al., 2013, 2015). Using aerial surveys conducted during the month of July and covering coastal waters ≤ 600 m (Gunnlaugsson et al., 1988), the abundance of minke whales was estimated to be 43,633 (95% confidence interval [CI]: 30,148–63,149) in 2001, 18,262 (7381–24,919) in 2007, and 9588 (5274–14,420) in 2009 using cue-counting procedures (Pike et al., 2009, 2011; Borchers et al., 2009). The only abundance estimate for white-beaked dolphins in Icelandic waters using aerial line transect methods dates back to 2001 (North Atlantic Sighting Surveys conducted from 1986 to 2001), resulting in an estimated 31,653 animals (17,679–56,672) (Pike et al., 2009) although a small number of other dolphin species may be included in this count. Additionally, in 2001 4928 (1926–12,611) humpback whales were estimated (Pike et al., 2009) with 586 individuals recorded in the coastal waters of the northeast shelf that includes Skjálfandi (Block 4, 175–1956). In Icelandic waters, humpback whales, white-beaked dolphins and minke whales are also subject to various pressures related to whale-watching (Christiansen et al., 2015), fishery (Víkingsson and Ólafsdóttir, 2004; Basran, 2014), whaling activities (Marine Research Institute, 2014) as well as changes in the marine coastal environment (Víkingsson et al., 2015), all of which have been reported in both our study areas (see Discussion below).

Previous studies have shown that photo-identification is a suitable method to identify our three Icelandic cetacean species (Bertulli et al., 2013, 2015), but to date no other studies presenting abundance and survival estimates using CR methods and trained-scientists volunteers exist for this area. We wish to address these knowledge gaps by answering the following questions: (1) Can data collected by trained-scientist volunteers onboard opportunistic vessels be used to estimate cetacean abundance and survival? (2) How do our estimates of apparent survival compare with those of humpback whale, white-beaked dolphin and minke whale found outside of Iceland? 3) What is the short term stability of the three Icelandic populations? 4) Do these populations show any evidence of 'transience'? (i.e. 'transience' occurs when whales are traversing an area only once with no further chances to be encountered or sighted again (Pradel et al., 1997) This is the first study presenting capture-recapture abundance and survival estimates of humpback whales, white-beaked dolphins and minke whales from Iceland, using data collected by trained-scientist volunteers onboard opportunistic vessels. Our goal here was to study the feasibility of capture-recapture abundance and survival estimation using a new inexpensive method involving these volunteers.

2. Material and methods

2.1. Study area

The study areas including the coastal waters of Faxaflói (64°24′N, 22°00′W; ~4400 km^2) and Skjálfandi (66°05′N, 17°33′W; ~1100 km^2) have been previously described by Bertulli et al. (2012). Both bays are approximately 600 km apart and located in the southwest and northeast of Iceland, respectively (Fig. 1).

2.2. Sampling methods

From 2006 to 2013, non-systematic and opportunistic boat surveys were conducted onboard motor whale-watching vessels (20–26 m in length) in sea state of zero to three on the Beaufort scale. Each boat survey lasted approximately 3 h and covered morning, afternoon or evening hours due to the high latitude of the study sites. When possible, vessels would run parallel to whales and dolphin groups, allowing researchers to systematically shoot the entire surfacing pattern of each randomly encountered individual, with no preference given to marked animals over unmarked animals.

2.3. Photo-identification

One to a maximum of four observers, usually the principle investigator and three scientist volunteers, were part of the photo-identification team onboard survey vessels in Faxaflói and Skjalfandi. Volunteers underwent a selection process, and individuals with scientific background, preferably with previous cetacean research and good photographic skills were chosen. Training was provided by the principal investigator (CGB or MHR) on board, to teach scientist volunteers individually how to collect photo-id images. Volunteers were also followed in data entry and given lectures and materials (e.g. publications, reports) on studied species and field techniques used. A range of DSLR cameras was used in both study areas, with zoom lenses ranging from 55 to 200 mm to 70–300 mm for Faxaflói and 28–135 mm to 40–150 mm for Skjálfandi. Images were taken in both JPG (300 pixel/in.) and RAW formats.

A grading system of quality (Q1–Q6; Fig. 1 in Gowans and Whitehead, 2001; Fig. 1 in Rosso et al., 2011) and distinctiveness (D1–D4; Table 1 in Zaeschmar et al., 2014) was used to evaluate photographs. Images rated Q ≥ 5 of *adult* only, and with 'distinctive' and 'very distinctive' fins were considered suitable for the analysis (Gowans and Whitehead, 2001; Zaeschmar et al., 2014). *Adults* were defined based on the estimated body length of each individual and their behaviour towards conspecifics (humpback whale: length at maturity of 11.6–12 m, Víkingsson, 2004b; white-beaked dolphin: 2.6–2.8 m, Víkingsson and Ólafsdóttir, 2004; minke whale: 6.5–7.5 m, Víkingsson, 2004a). In order to avoid misidentifications (e.g. false negatives) with minke whales and white-beaked dolphins, dorsal fin outline marks and injury marks were used as the only primary features as they were found to be both stable and long-lasting identification marks for each species (Bertulli et al., 2016). Linear marks for white-beaked dolphins and bite marks for minke whales were used as secondary features, since they were found to be reliable marks for recaptures spanning 5 and 8 years respectively (Bertulli et al., 2016). Humpback whales were primarily identified using pigmentation patterns on the ventral side of their flukes (Katona et al., 1979) and the presence of notches in the dorsal fin edge, and injury marks on flukes, flanks, and/or dorsal fin as secondary features. Photo-id images were matched in chronological order of collection to detect any change of outline and body marks over time. Using the 2008–2013 data sets, proportions of identifiable individuals per group were calculated to estimate coverage.

2.4. Capture-recapture analysis

We used the year as a time unit utilizing 2008–2013 for white-beaked dolphins and minke whales in Faxaflói, 2006–2013 in Skjálfandi for humpback whales and 2008–2013 for minke whales. Each year was made of 5 months in each bay (April to August in Faxaflói, May to September in Skjálfandi; see Table 1 for total number of days and associated sighting frequency for each species), which for each species corresponded to the period with the highest number of captures (e.g. Alves et al., 2014). By doing so, an occasion (a year made of a 5-month period) was relatively short compared to the interval between occasions, which however made it impossible to define secondary occasions