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The combined use of visual and acoustic data collection techniques for winter killer whale (*Orcinus orca*) observations

R.E. Burham [a,*], R.S. Palm [b], D.A. Duffus [a], X. Mouy [c], A. Riera [d]

[a] *Whale Research Lab, Department of Geography, University of Victoria, Canada*
[b] *Strawberry Isle Marine Research Society, Tofino BC, Canada*
[c] *JASCO Applied Sciences, Victoria, BC, Canada*
[d] *Juanes Lab, Department of Biology, University of Victoria, Canada*

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ABSTRACT

Observations of cetaceans during the winter are difficult, if not impossible in some locations, yet their presence, habitat use, and behaviour during this period are important for conservation and management. Typically, observations come from vessel surveys, with citizen science networks increasingly adding significant sighting data. In compliment to this, acoustic data collection systems can be deployed to collect information remotely over long periods, and in almost any conditions. Here we describe how the combination of these data collection techniques works to fill knowledge gaps, with data from a well-established citizen science network, and a single passive acoustic monitoring (PAM) recorder integrated to identify killer whale presence during winter months in Clayoquot Sound, on the west coast of Vancouver Island.

Together these data show the overwinter use of Clayoquot Sound by killer whales is greater than previously thought. During the study period, February 21 to April 25, 2015, the citizen science network noted 14 visual encounters ranging from Amphitrite Point to Hot Spring Cove, Vancouver Island. The PAM recorded 17 acoustic encounters within the 10 km detection radius of the recorder, deployed off Siwash Point, Flores Island. This included 15 encounters not recorded by the visual network. Both resident and Bigg's (transient) transient whale groups were recorded, although analysis of vocalizations determined that the majority of the encounters recorded acoustically were of northern resident killer whales. This may be a function of life history, with Bigg's killer whales typically noted to be less acoustically active, or could represent greater site use by this group. This first use of acoustic monitoring over the winter, complemented with visual data, can establish a better understanding of year-round use of this area by killer whales and has broader application to other sites.

1. Introduction

Data on species distribution over long time periods or great spatial extents is difficult to collect in the marine environment. Observations of free-ranging cetaceans are hampered by high costs of field research, weather, and limited data collection periods, for example to daylight hours. Field research is more difficult, if not impossible, during the winter in many locations.

* Corresponding author.
E-mail address: burnhamr@uvic.ca (R.E. Burham).

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Typically, observations come from dedicated vessel-based surveys, with citizen science networks increasingly used to add significant to sightings data. These networks potentially have a wide spatial extent, but are dependent on the chance encounters of whales, and normal activities of vessels in any given area. Night or inclement weather observations are uncommon. Data, if garnered by an experienced observer may, however, provide more information than simple presence, such as group size, individual identity, or behavioural context.

Remote data collection devices, such as passive acoustic monitors (PAM) are being used to collect marine data over long periods, in areas and at times it might otherwise be problematic to survey. Once deployed, they can record data continuously without regard to sea-state or visibility, but are spatially restricted to a defined detection radius from its location. In the case of acoustically sensitive species, PAM may also offer a less intrusive alternative to vessel-based surveying.

Here we assess the input of the more traditional against the more technological data collection method to knowledge of whale presence, habitat use, and behaviour. Opportunistic visual observations from a well-established citizen science network are compared to underwater acoustic recordings to analyse the winter presence of killer whales (*Orcinus orca*) in Clayoquot Sound on the west coast of Vancouver Island, Canada. Together they form a novel examination of whales' use of the area, particularly adding knowledge during a time period where data collection is problematic.

Killer whales are common year-round inhabitants of coastal waters in the northeastern Pacific (Ford, 2014). In the near shore waters of British Columbia three sympatric and genetically distinct ecotypes have been described: resident, Bigg's (transient), and offshore (Ford et al., 2000). They differ in morphology, social structure, diet and foraging behaviour, and acoustic behaviour (Bigg et al., 1987; Ford, 1987; Baird and Stacey, 1988; Ford and Ellis, 1999; Ford et al., 2014). The resident killer whale ecotype is distinguished into a northern and southern cohort, with a number of pods or clans arranged into each. Each pod shares an acoustic dialect, with pods with similar calls collectively referred to as clans. Residents often utilize echolocation and communicate within and between hunting groups, with the seasonal presence of their salmonid prey strongly influencing the distribution of resident groups throughout their range (Nichol and Shackleton, 1996; Baird et al., 2005). A pod can have a repertoire of 7–17 discrete calls, whose use varies depending on the group dialect (Ford, 1987, Ford, 1991; Ford and Ellis, 1999). In contrast, Bigg's killer whales are mammal hunters, with much of their time devoted to foraging, markedly more than resident groups (Heimlich-Boran, 1988; Ford and Ellis, 1999). They tend to travel in smaller groups of 2–6 individuals, with a very dynamic social order (Ford and Ellis, 1999). Bigg's killer whales are believed to vocalize significantly less than residents, with calling predominantly limited to surface-active and post-feeding behaviours (Ford 1984; Morton, 1990; Guinet, 1992; Barrett-Lennard et al., 1996; Deecke, 2003; Deecke et al., 2005). Deecke et al. (2005) suggests that they remain silent as a strategy, so as to not incur extra cost to foraging from being heard by their prey on approach. Stealth and surprise are important elements of foraging success; therefore both vocalizing and echolocating are limited (Barrett-Lennard et al., 1996; Ford and Ellis, 1999; Deecke et al., 2002). When vocalizing they use a smaller repertoire of calls (4–6), demonstrating some regional distinction in use, but less distinctive dialect identity than residents (Ford and Ellis, 1999). The offshore killer whale ecotype are estimated to have diverged from the resident killer whale lineage approximately 200,000 years ago, and feed on fish, specializing on shark prey (Herman et al., 2005; Ford et al., 2011, 2014). Offshore groups have been noted in inside waters around Vancouver Island infrequently (Ford et al., 2014), and are predominantly sighted in waters off the coast between California and south-east Alaska (Herman et al., 2005). As such this group will not be considered further in this study.

Despite efforts to map abundance, distribution, and life histories of these groups spanning more than 40 years (Bigg et al., unpublished, 1990; Ford et al., 1998), questions still remain. For example, although the distribution and use of inshore waters around Vancouver Island by killer whales has been studied intensely, little is known about movement patterns outside of these areas and during winter months (Ford et al., 1998; Krahn et al., 2002, 2004; Ford, 2006; Riera et al., 2013). Similarly, their use of space and behaviour through the night remains poorly known. Previous studies have used passive acoustic monitoring for killer whale presence in the northern Pacific (e.g. Newman and Springer, 2008; Oleson et al., 2009; Široviæet al., 2011; Riera et al., 2013 and Hanson et al., 2013); in this study, we amalgamate visual and acoustic data sets to try to describe killer whale use of Clayoquot Sound during the winter. The data from a long-term citizen science network of observers provides the visual data. We compare this to a 64-day deployment of a bottom mounted acoustic recorder, as an assessment of passive acoustic monitoring for presence that may otherwise be impossible. Although the quantity and scale of data collected by each method differs, together these databases fill gaps in our knowledge of coastal killer whale habitat use, which is vital to species management plans.

2. Methods

2.1. Visual data set

Strawberry Isle Marine Research Society (SIMRS) and their reporting network recorded visual sightings of killer whales in Clayoquot Sound. The range of reporting for SIMRS between February and May 2015 extended from Amphitrite Point, Ucluelet, to Sharp Point/Hot Springs Cove, Vancouver Island. The daily sighting records are summarized into hourly reports, with observations of presence and behaviour of killer whales reported from an extensive network. They trace movements of whale groups through the network area for as long as possible, with observational data provided by private and recreational boaters, commercial vessels such as the whale-watching fleet and fishermen, as well as SIMRS scientists. Opportunistic photographs taken during a sighting are used to determine group size and identity, residency time and return rate.

2.2. Acoustic data set

An Autonomous Multichannel Acoustic Recorder (AMAR G3, JASCO Applied Sciences) was deployed on the ocean floor on February 21, 2015 and recorded continuously for 64 days. It was positioned approximately 5 nm southwest of Siwash Point, Flores Island at a depth of 51 m. Recorded ambient noise levels were used to estimate the killer whale detection range, calculated for every minute of the recording by summing the 1/3-octave-band levels, assuming a spherical spreading of sound from the source. The source level of killer whale vocalizations used were those reported by Holt et al. (2009) as 133–174 dB re 1 μPa at 1 m with a mean of 155.3 dB re 1 μPa at 1 m (±7.4 SD). Thus, the maximum detection range, given the lowest ambient noise levels and greatest killer whale call source levels, was 30 km, representing approximately 1% of the recording time. The median value (50%) was calculated at 1.8 km, with the upper quartile of killer whale detections extending to 3 km assuming high source levels of vocalizations (Fig. 1). Detection range is influenced by the frequency-specific propagation of calls, using the parameters defined by Holt et al. (2009) and known transmission parameters for the area (Mahoney et al., 2014; Mouy et al., 2015) as well as ambient noise quantifications. The AMAR was fitted with an M8E calibrated omnidirectional hydrophone (GeoSpectrum Technologies Inc) and set for a gain of 6 dB. The recorder sampled for 340 s (5 min and 40 s) at 16 ksps/0–8 kHz, alternating with 560 s (9 min 20 s) at 64 ksps/0–32 kHz, recording with equal sensitivity for all frequencies. The recordings were first passed through detection software that noted presence of killer whale clicks or whistles (Mahoney et al., 2014; Mouy et al., 2015). Presence–absence was then confirmed manually, selecting those clips shown to have killer whale presence and those temporally adjacent (directly before and after) to define the length of the acoustic 'encounter'. Each file, and respective spectrogram, was visually and aurally inspected to verify an acoustic encounter; with an acoustic detection noted when at least one killer whale call or whistle was heard. Echolocating clicks were not used as a reliable indicator of killer whale presence. A further percentage of the recordings, approximately 5%, were randomly selected for manual verification to determine confidence in the detection software and eliminate false negatives or positives from the data to be processed further.

Whistles, characteristic pulsed and tonal calls denoted killer whales presence. An 'encounter' was defined by a string of positive killer whale acoustic detections book-ended by recordings that did not have audible vocalizations. Although vocalization is not a continuous activity, acoustics are typically more consistently used by odontocetes. It is presumed that killer whales remain present between temporally adjacent sound files (those either directly before of after those confirmed to contain killer whale calls, and within a 15 min period), despite calls not consistently heard. The vocalizations were further analysed to determine the ecotype of the killer whale group, either resident, transient or unknown. This was determined by identification of stable, stereotypical discrete calls, which distinguishes the caller to ecotype, clan and in some cases pod, as categorized by Ford, (1987; 1991). In this case it is the type of vocalization, and its repetition rate that helps determine call characteristics and caller identity (Ford, 1987).

3. Results

Both data collection systems work at different scales and resolution, with only two occurrences of killer whales detected concurrently by both acoustic and visual means. The SIMRS network collected 14 visual encounters of killer whales throughout its larger spatial range (Hot Springs Cove to Ucluelet, Fig. 1) for the period of February 21–April 25, 2015. Network sightings within the maximum AMAR acoustic detection radius were noted on several different occasions (Fig. 1), however matching notations for visual and acoustic presence were only made on February 25 and March 17, 2015. All other on-water observations are beyond the limit of the recorder (Table 1). Analysis of acoustic data with its smaller range, but higher acuity, recorded 17 acoustic encounters, ranging from 9 min to 11 h 30 min. Thus the PAM recorded 15 encounters that were not located by the SIMRS network. The time of day of these encounters were determined as either 'day' (06.00–18.00), or 'night', (18.00–06.00) with several spanning both 'day' and 'night'. In this case it is counted as a single encounter and listed under the period the encounter begins determined by the time whale calls were first detected.

Although sounds made by vocalizing whales could suggest group number or animal density, in this study they were used solely as an indicator of presence and in further analysis to detect recognizable dialects of killer whale groups and identify ecotype, classifying calls in accordance with work by Ford (1987). Both resident and transient groups have been noted to the area, with the PAM recordings confirming both during the winter (Table 1).

4. Discussion

Clayoquot Sound is a significant habitat for several species of cetaceans. Killer whales and gray whales (*Eschrichtius robustus*) as well as harbor porpoise (*Phocoena phocoena*) are common and significant parts of the coastal ecosystem (Burnham, 2015; Burnham and Duffus, 2016, in press). The area is designated as a UNESCO Biosphere reserve, and holds several other marine area protective designations, as well as supports a thriving whale watching industry, both of which speak to the utility of detailed whale knowledge. However, we are only now grasping the importance of killer whales at the apex of the food webs in diversity and stability of local marine ecosystems (Estes et al., 1998).

In this study, passive acoustics collects killer whale data at times when it is otherwise difficult to gather information. Passive acoustic monitoring complements and extends the data from visual surveys, with long-term acoustic studies used to

Fig. 1. Location of AMARs deployment and likely range of acoustic detections. AMARs location is the centre of the detection circles, with the smaller circle representing the range of detection 50% of the recording time (1.8 km) and the larger circle the maximum extent (30 km). The extent of the SIMRS network extends from Hotsprings Cove to Ucluelet with arrows used to denote individual sighting events from the location they are first observed and the swimming direction.

Table 1
Presence of killer whales during AMARs deployment period. An '×' in PAM denotes acoustic presence, and in visual represents that a sighting was also recorded in the detection area. An '×' in Reported denotes a visual sighting recorded in the full range of SIMRS. Date and time of day represents when the observation was made, with this representing when whale vocalizations were first heard for acoustic encounters. For killer whale ecotype (KW type) NR = Northern Resident, SR = Southern Resident, T = Transient/Bigg's whales.

Date	Time of day	PAM	Duration	KW type	Visual	Reported
2015-02-21	Day					×
	Night	×	9 m	NR		
2015-02-23	Day	×	11 h 30 m	NR		
2015-02-25	Day	×	4 h 24 m	NR	×	×
	Night	×	6 h 53 m			
2015-02-28	Day					×
2015-03-01	Day					×
	Night	×	4 h 06 m	NR		
2015-03-02	Day	×	7 h 09 m	NR		
2015-03-03	Night	×	1 h	T		
2015-03-05	Day	×	6 h 09 m	NR		
	Night	×	1 h 51 m	T		
2015-03-06	Day	×	9 m	Unknown		
2015-03-07	Day					×
2015-03-08	Day	×	5 h 15 m	Unknown		
2015-03-11	Day					×
2015-03-12	Day					×
2015-03-16	Day	×	1 h 15 m	Unknown		
	Night	×	5 h	T		
2015-03-17	Day	×	15 m	T	×	×
2015-03-18	Day					×
2015-03-20	Day					×
2015-03-21	Day					×
2015-03-28	Day					×
2015-03-31	Day	×	3 h 39 m	NR		
2015-04-07	Day					×
2015-04-08	Night	×	6 h 09 m	NR		
2015-04-09	Day					×
2015-04-11	Night	×	15 m	Unknown		

refine knowledge on habitat use, and seasonal or diurnal patterns in a non-invasive way. The recordings from winter–spring 2015 provide several new insights into killer whale use of the area. This study records whale presence at one coastal location for one winter season, and so is a starting point to establish use of killer whales of Clayoquot Sound. This goes towards filling knowledge gaps in presence–absence, seasonal movements, distribution and behaviour for these whales. This study follows those conducted by Riera et al. (2013) and Hanson et al. (2013) examining year-round presence of killer whales in coastal waters and over the continental shelf respectively.

First, the consistent presence of killer whales during the winter was greater than previously thought. In the area of acoustic detection there was 17 encounters noted acoustically, of which two were reported visually, and on a number of occasions observations were made by the sightings network outside the spatial range of the PAM recorder. Considered together, these data sets demonstrate a high overwinter whale presence. Also, with 9 acoustic encounters during the day and 8 noted at night, in this data set there is no discernible diurnal patterning to the calling as you might expect from previous studies (e.g. Baird, 2001 and Newman and Springer, 2008). Second, the number of vocalizations recorded was also greater than expected, with acoustic analysis in most cases able to identify the ecotype of the individuals vocalizing. Both resident and Biggs' (transient) killer whale groups were noted, although the majority of vocalizations recorded were from the northern resident dialect, which are considered the least likely visitor from the local populations around Vancouver Island to be present due to presumed scarcity of prey resources (Ford et al., 2000; Palm, pers. obs.). Vocal detection rate may be a function of life history, with Bigg's whales less acoustically active to avoid 'eavesdropping' by mammal prey (Deecke et al., 2005), or could simply represent greater site use by resident whale groups. The acoustic data opens up the possibility that Clayoquot Sound may be an important overwinter foraging area for the resident ecotype, which focuses on salmon. However, call type and frequency has not been conclusively tied to behavioural context. During summer months resident whale habitat use is more predictable following salmon runs, which often form in narrow straits in the inside waters of Vancouver Island (Heimlich-Boran, 1986; Heimlich-Boran, 1988; Ford, 1989; Guinet, 1990; Nichol and Shackleton, 1996; Ford et al., 1998; Osborne, unpublished; Holt et al., 2013; Hanson et al., 2013). However, during the winter months distribution is tied to dispersed salmon populations, making the whales much more sporadic in space and time. This first look at winter presence using acoustics in addition to visual detections allows documentation of patterns of occurrence of killer whales in Clayoquot Sound, and has implications for both northern resident and transient eco-type foraging ecology.

Whale residency time is an important metric to inform management planning. Autonomous acoustic recorders, like the AMARs, can be deployed to collect data continuously and unobtrusively for long time periods, over known areas, and in all weather and light conditions. For the most accurate recording of marine mammal presence, however, we cannot yet rely solely on acoustic data. Little is currently known about vocalization rate of individual whales, or how this may be linked to circadian rhythms, activity state or the behavioural context (Ford, 1987; Deecke et al., 2005). Acoustic presence is an underestimate of both use of the area, and residency time. In addition, although recognition of acoustic signals can identify groups to ecotype, if not clan or pod level, this does not extend to the individual level, as photo-identification does, and so falters for data such as a whale's range, residency time, or return rate. An expanded array of recorders and/or more dedicated visual observations concurrent to acoustic recording could aid in annotating the calls heard with ecotype identity, whale number, and behaviour.

The detection of killer whales by the AMARs provides the minimum rate of presence, and over-winter site use. Whales may not be detected because they are not actively vocalizing, they are beyond the detection range of the hydrophone, or faint calls are not detected over ambient noise levels, so the absence of detection does not mean absence from the study site. The average swimming speed of a killer whale is between 3 and 10 km/h depending on behaviour (Ford, 1989; Barrett-Lennard et al., 1996) suggesting transition time through the area of detection could as little as 2 h if behaviour was purely travelling. As many of the acoustic encounters exceed this, it could be interpreted that the whales are foraging, resting or socializing.

Therefore, acoustic monitoring is complementary to more traditional research methods such as vessel or aerial survey, observation or tracking experiments. Passive acoustic data could, as visual observations do, inform habitat-based density models to allow the prediction of cetacean presence over space and time (Küsel et al., 2011; Harris et al., 2013). Acoustics can also inform us on conspecific or interspecific interactions, which may be unseen from the surface, particularly as the acoustic range of cetaceans far exceeds that of visual detection. This forms another interesting facet of acoustic data, with several sound clips of the recordings for this study indicating killer whale and either gray whale, humpback whale, or sea lion vocalizations co-occurring, possibly representing predator–prey contact between Bigg's whales and mammal prey (unpublished data). Killer whales are an influential apex predator. They may shape interactions through direct predation, as well as instigating avoidance behaviours in prey, reacting to fear of predation (Baird, 2011). As pack-hunters, they may be important in regulating prey populations, both fish and marine mammal species in this area.

Although beyond the scope of this report, the final useful observation is the potential for acoustic interaction between whales and vessels. Passive acoustic arrays are a tool to advise managers as to the vulnerability of cetacean species, such as killer whales, to the effects of increased underwater noise, particularly from anthropogenic sources. Thresholds of acoustic pollution, or mitigation measures to lessen the disturbance or potential acoustic masking effect can be derived from recordings such as those used in this study.

Although PAM methods are becoming feasible for measuring temporal and spatial distribution of marine mammals, they still remain expensive, require servicing, and have a limited battery life. Also, with many systems, such as the AMARs used here, the data is not accessible until retrieval of the recorder. Conversely, experienced citizen networks, that coordinate, compile and accurately log data provide information over wide spatial areas and in near real time. Citizen science groups can, therefore, accumulate large data sets at relatively low cost which, if complemented with photographs or notes on behaviour, can be analysed for relative change.

Complementary acoustic monitoring and visual observations fills knowledge gaps of presence and area use by cetaceans. This two pronged approach allows surveys to adapt to a range of species, from those commonly seen but rarely acoustically recorded, to those more vocal but elusive. Data from citizen science networks can support any other method that may be applied, and have been used to great advantage in many places with many species throughout the world (Dickinson et al., 2012). Not only do these groups provide information, they also provide a route where local communities can actively participate in research and conservation of species in their local waters. This investment pays off when new management action is proposed, and in events such as strandings and entanglements. Researchers working in coastal communities have relied on local boaters and in particular whale-watching fleets for support and value the addition of time tested local knowledge of waters and wildlife. In this example, the visual surface data from the citizen science network gives behavioural context to the acoustic data, which itself expands the accuracy of local habitat use estimates.

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