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How much effort is enough? The power of citizen science to monitor trends in coastal cetacean species

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ABSTRACT

Citizen scientists provide a cost-effective means of carrying out broad scale, long-term monitoring of the environment while fostering earth stewardship. In this study we investigate how much effort is required by citizen scientists to detect trends in the occurrence of a protected population of bottlenose dolphins (*Tursiops truncatus*). We analyse the WDC citizen science shore-based data collected over nine years (2005–2013) between April to October from within and in the vicinity of a Special Area of Conservation (SAC) for bottlenose dolphins in the Moray Firth, Scotland. Watches comprised a continuous 10 minute scan of the survey area in an hour. During peak season, around 5 watches per day were required to detect annual or between-site trends of 50% in dolphin occurrence in locations where dolphins were sighted reliably (0.1 sightings per hour). Less effort was required at higher sightings rates, and it was not possible to statistically detect trends of <30%. This study highlights the importance of power analysis in designing citizen science programmes and demonstrates their effectiveness in carrying out long term shore-based monitoring of coastal cetacean species, providing a cost-effective early warning system for changes in the marine environment.

1. Introduction

Citizen science is the use of volunteers or non-scientific members of the public to carry out scientific research (Silvertown, 2009). In recent years, the use of citizen scientists in ecological and environmental research has exploded, particularly with the advancement in mobile technology (e.g. Sullivan et al., 2009: eBird citizen science online bird surveys). In a world of growing concerns about human impacts on the environment, alongside financial constraints on research, citizen science is of increasing importance not only as a means of collecting data cost-effectively, but for fostering Earth stewardship (Dickenson et al., 2012). Citizen science takes many forms, from large-scale reporting of opportunistic sightings of species (e.g. jellyfish; Pikesley et al., 2014), to more directed broad-scale surveys carried out by volunteers (e.g. Breeding Bird Survey; Sauer et al., 2003), and narrower focus hypothesis-driven volunteer-led monitoring (e.g. investigating leaf-minor attack on horse chestnut trees; Pocock and Evans, 2014). Such data has proven to be invaluable in conservation biology by informing policy and conservation management practices, for example, the UK volunteer Seasearch underwater surveys of the waters

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around the UK informed the selection of the Marine Conservation Zones for conserving biodiversity in England (POST, 2014). In our study, we investigate the use of citizen scientists to monitor a population of bottlenose dolphins, *Tursiops truncatus*, protected within a Special Area of Conservation (SAC), and consider in particular how much effort is needed to allow for the calculation of statistically robust measures of trends in species occurrence within and outside the SAC.

Citizen scientists have been used to monitor cetacean populations for decades, within organisations such as Sea Watch in the UK (www.seawatchfoundation.org.uk; Evans, 1980, 1992 and Evans et al., 2003), and through events such as the 'Great Whale Count' carried out by the Pacific Whale Foundation in Hawaii (www.pacificwhale.org; Tonachella et al., 2012). These primarily shore-based observation programmes have been used to monitor a range of species from bottlenose dolphins (Bristow et al., 2001) and harbour porpoises (*Phocoena phocoena*) (Bailey et al., 2012; Camphuysen, 2011) to humpback whales (*Megaptera novaeangliae*) (Tonachella et al., 2012). The large spatial and temporal scales achievable by using citizen scientists for shore-based cetacean monitoring have shown to be beneficial for conservation management by identifying the spatial extent (Pierce et al., 2010), and temporal trends (Tonachella et al., 2012) of species close to shore. For example, the 'Great Whale Count' carried out by citizen scientists in Hawaii was able to detect a 5% increase in humpback whales which was matched by scientific estimates of their populations (Tonachella et al., 2012).

Shore-based surveys provide a number of benefits as a platform for coastal cetacean research, to supplement more research-intensive methods such as boat-based or aerial surveys (Cheney et al., 2013). Although shore-based surveys are limited spatially to areas close to land, they are a cost-effective means of gathering habitat use and temporal data to assess variation in occurrence of marine mammals at key coastal sites of interest (Evans and Hammond, 2004; Pierpoint et al., 2009). Data collection is also non-invasive and does not cause disturbance or affect the behaviour of the study animals as boat-based surveys have the potential to do. Due to the cost-effectiveness of shore-based surveys it is possible to carry out monitoring over more extended time periods than boat-based surveys, allowing for long-term monitoring to be carried out. For example, 40 years of shore-based surveys off California showed an increase in the diversity of cetacean species sighted in line with warming sea temperatures and an implied regime shift (Shelden et al., 2004; Shelden and Rugh, 2010). Longitudinal studies such as these have been identified as one of the most effective ways of using citizen scientists to measure change and therefore to quantify the impact of conservation policy and measures (Tulloch et al., 2013).

Using citizen scientists in scientific studies has been shown to produce data of similar reliability as using specialists if sufficient training is provided (Newman et al., 2003), and in shore-based studies, if a high enough vantage point is used (Young and Peace, 1999). To ensure that volunteer-collected data can be used to monitor trends in occurrence, it is vital that volunteer programmes understand how much data (volunteer effort) is required to ensure sufficient statistical power to detect these trends (e.g. Jackson et al., 2008). Volunteers are motivated to participate in science for a variety of reasons including environmental stewardship and education (Ryan et al., 2001), but if we are to maintain motivation for participation, monitoring programmes should not overload volunteers and result in burnout (Measham and Barnett, 2008). A target level of effort can help guide the volunteer programme, ensuring sufficient statistical power to detect trends for conservation purposes, while maintaining volunteer motivation. Therefore in this study we explore two main questions:

1. *How much effort is required to detect inter-annual trends in bottlenose dolphin occurrence at a single location*? Using data from a single site for which there is a long-term monitoring programme, we explore the impact of decreasing the number of days monitored on the statistical power to detect an inter-annual trend in bottlenose dolphin occurrence. This is used to evaluate the trade-off between monitoring effort and the magnitude of inter-annual trend that we are able to detect.
2. *What impact does detection rate have on the amount of effort required to detect trends*? Widening the study to include all the sites monitored within the vicinity of the bottlenose dolphin Special Area of Conservation (SAC) we explore the impact of detection rate and rarity on the amount of effort required to reliably assess occurrence at a site. Other studies have shown that species with lower detection rates require more effort to have the power to detect trends (de Solla et al., 2005), so we hypothesise that more effort will be required in those locations with low detection rates.

1.1. Moray Firth Shorewatch programme

Our citizen science project is based on the WDC Shorewatch programme which supports volunteers to monitor the presence and absence of coastal cetaceans over time by conducting effort-based watches from shore at specified local sites around Scotland. Volunteers have been carrying out Shorewatches from the Scottish Dolphin Centre in Spey Bay since 2005, and consistently from sites around the wider Moray Firth since 2010. The Inner Moray Firth is an SAC for a small population of bottlenose dolphins estimated at around 195 individuals and is considered to be a stable or increasing population (Cheney et al., 2013, 2014). The SAC boundary was originally based on the animals' core range during the 1980s and 1990s (Wilson et al., 2004). The population range has since expanded to include core sites outside the SAC, including the wider southern Moray Firth coast (Culloch and Robinson, 2008) and Aberdeen Harbour (Weir et al., 2008). Although the population are still encountered within core areas of the SAC throughout the year, with at least 60% of the population having been encountered within the SAC in 16 of the last 21 years (Cheney et al., 2012), dolphins are observed here at higher levels during the summer months (Cheney et al., 2012). Over half of the known individuals from the SAC have also been photo-identified in Aberdeenshire, some of them regularly (Weir et al., 2008). Extensive surveys in recent years have determined that the bottlenose dolphins are rarely encountered offshore in the Moray Firth (Culloch and Robinson, 2008; Eisfeld et al., 2009). SAC protection extends beyond the SAC boundary to include the full range of the population.

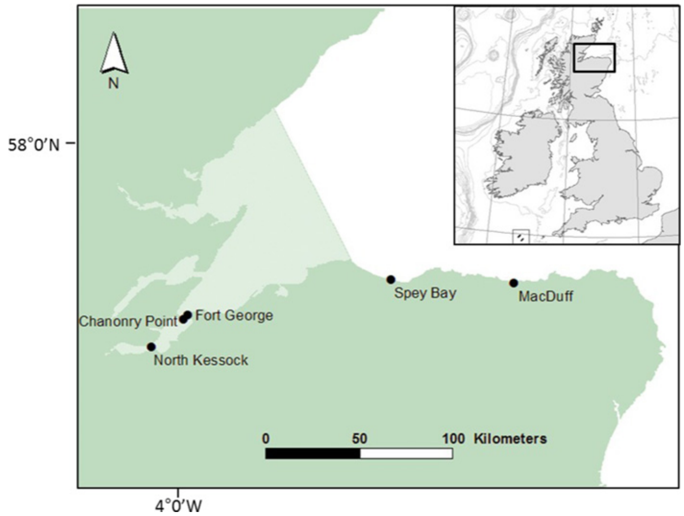

Fig. 1. Map of the Moray Firth in relation to the UK, location of shore-based survey sites (Spey Bay, MacDuff, Fort George, Chanonry Point and North Kessock). The grey shaded area shows the location of the SAC for bottlenose dolphins.

Coastal cetaceans face increasing development in their environment, including for harbour developments, oil and gas, and marine renewable energy, associated transmission and harbour infrastructure, as well as other pressures such as fisheries and military activities. Individually and cumulatively, these developments may impact cetacean habitat quality spatially and temporally at both localised and wider scales. Our overall objectives are therefore not only to determine the amount of effort required to have the statistical power to detect trends, as earlier stated, but also to investigate the potential for using citizen scientists to help monitor a protected cetacean species in and around an SAC to help inform conservation management of the species. This will have impacts for our study in Scotland and for the design of shore-based citizen science monitoring programmes globally.

2. Methods

2.1. Study area

The Moray Firth is a large, triangular estuarine embayment in northeast Scotland from Helmsdale in the north of the inner Moray Firth to Lossiemouth in the south, covering an area of approximately 5230 km^2 (Thompson et al., 2011). The general topography of the sea floor of the wider Moray Firth is smooth with a gradual deepening to the east (Foster-Smith et al., 2009). This analysis focuses on data collected from three sites within the SAC designation: North Kessock, Chanonry Point, Fort George; and from two sites immediately adjacent to the southern boundary of the SAC: Spey Bay and Macduff (Fig. 1).

2.2. Data collection

Surveys were conducted throughout the year in sea states of four or less when visibility was at least 2 km. However, this analysis concentrates on the peak effort and sightings months between April and October for Spey Bay inter-annual trend analysis, and June–September for the inter-site trend analysis. During these months, surveys were predominantly conducted between 8 am and 5 pm (GMT) but with watches occurring from 6 am to 8 pm (GMT).

Data were collected in the form of 10 min scans (‘Shorewatches’) carried out once per hour from a given dedicated site. Shorewatches were conducted by trained observers using issued 7 × 50 Opticron Marine-3 binoculars (with internal compass and reticules) mounted on a monopod. A survey area of approximately 180° was divided into four quadrants from left to right. Each quadrant was scanned with binoculars for one minute and then the entire survey area was scanned with the naked eye. This process was repeated to complete the 10 min watch. At North Kessock, watches lasted only 3 min due to the significantly smaller area of water covered.

Basic information including date, time and observer name, environmental data including sea state and visibility as well as presence/absence of cetaceans were recorded for each Shorewatch. During a dolphin encounter, data relating to sighting time, species ID, ID confidence, sighting location (using bearings, reticules and estimates), number of adults and calves (minimum group estimates) and basic behaviour/activity level were recorded.

At Spey Bay effort was fairly consistent from April to October with watches carried out in several hours of each day, effort is more variable at the other sites around the Moray Firth. At Spey Bay there were a minimum of 682 watches between April and October in 2006 and a maximum of 1957 in 2008 (Table 1). This represented from 31 to 363 watches a month, with the

Table 1
Spey Bay number of watches per year (April–October) with associated bottlenose dolphin sightings rate and normal approximated confidence intervals.

Year	Number of watches (April–October)	Number of segments	Sightings rate ± CI
2005	1460	353	0.036 ± 0.010
2006	682	217	0.040 ± 0.015
2007	855	236	0.081 ± 0.018
2008	1957	273	0.106 ± 0.014
2009	1287	308	0.141 ± 0.019
2010	1737	229	0.169 ± 0.018
2011	1588	328	0.194 ± 0.019
2012	1178	333	0.168 ± 0.021
2013	1728	407	0.193 ± 0.019

Table 2
Number of watches and segments for each Moray Firth shore-based survey point for 2012 with associated bottlenose dolphins sightings rates and normal approximated confidence intervals.

Watch site	Number of watches	Number of segments	Sightings rate (SE)
MacDuff	741	584	0.063 ± 0.017
Spey Bay	1333	441	0.156 ± 0.014
Fort George	202	182	0.198 ± 0.055
Chanonry Point	180	58	0.500 ± 0.073
North Kessock	1218	796	0.104 ± 0.017

maximum of 14 h monitored in any day (Table 1). Effort was reasonably consistent, with only 2 months over the 9 years of monitoring having less than 100 watches. Effort was much more variable at the other sites, with as few as 180 watches at Chanonry Point and 202 at Fort George and as high as 1218 watches at North Kessock in 2012, with effort relatively evenly distributed throughout the summer season (June–September) (Table 2).

2.3. Data analysis

All inter-annual analyses were carried out on the Spey Bay dataset since this was the only dataset to have watches over nine years. This dataset consisted entirely of bottlenose dolphins, with no sightings of any other species. Since winter monitoring only started in more recent years with effort varying between months, only data from April to October were included in the analysis.

Dolphins were considered to be either present (1) or absent (0) in an hour dependent on whether they were seen in the watch period. Use of presence and absence (effort-based) rather than counts (or at least using minimum counts) for analysis is less likely to be impacted by detection skill (Pierpoint et al., 2009; Thompson et al., 2000). The data were temporally autocorrelated, so observers were more likely to see dolphins in any given watch if they had been seen in the previous hour's watch. To compensate for this autocorrelation, surveys were divided into 'segments' of continuous watches within which there was autocorrelation but little between segments. Autocorrelation was addressed using two different methods: (1) random resampling of segments of watches to calculate the statistical power of being able to detect a difference between years or sites with different levels of watch effort while retaining the autocorrelation structure; (2) using Generalised Estimating Equations (GEEs) to model the autocorrelation structure, and using this within a GLM to test for trends between years or sites (Liang and Zeger, 1986; Zuur et al., 2009). GEEs have been increasingly used within ecology to model autocorrelation structures (e.g. Bailey et al., 2012, Embling et al., 2013, Pirotta et al., 2011, 2013). Since the data within each segment were temporally autocorrelated, an ar1 correlation structure was used to model the occurrence of bottlenose dolphins, using a binomial distribution and a logit link function within the GLM. The analysis was carried out using the 'geepack' library (Halekoh et al., 2006) in R version 2.15.1 (R Core Team, 2012). GLM–GEEs were used to determine the significance of year and watch site on bottlenose dolphin occurrence, while compensating for sea state (by including sea state in the model).

To determine how many watches are required to detect trends, datasets of varying length were reconstructed from random combination of segments (to retain the autocorrelation structure). The number of watches was increased from 25 watches (which is considered to be an extremely low level of effort since it represents <4 watches per month) up to 2000 watches per year (equivalent to around 9–10 watches per day), and 1000 resamples were carried out for each level, and for each site and year of data. For each 1000 resamples, the GLM–GEE was run on the randomly generated datasets to determine if year or site was significant for the resampled datasets. The power was calculated as the proportion of watches that trends (between years or sites) were detected as significantly different from zero based on a significance level of $p < 0.05$ (as per Maclean et al., 2012). Coefficients of Variation (CVs) were also calculated on the resampled data to determine the effect of sample size on the precision of sightings rate.

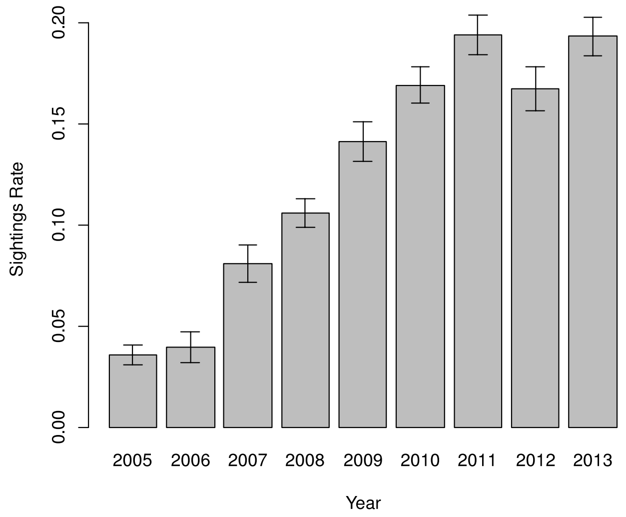

Fig. 2. Bottlenose dolphin sightings rates (sightings per watch) for Spey Bay in relation to year with error bars showing the standard error around the mean.

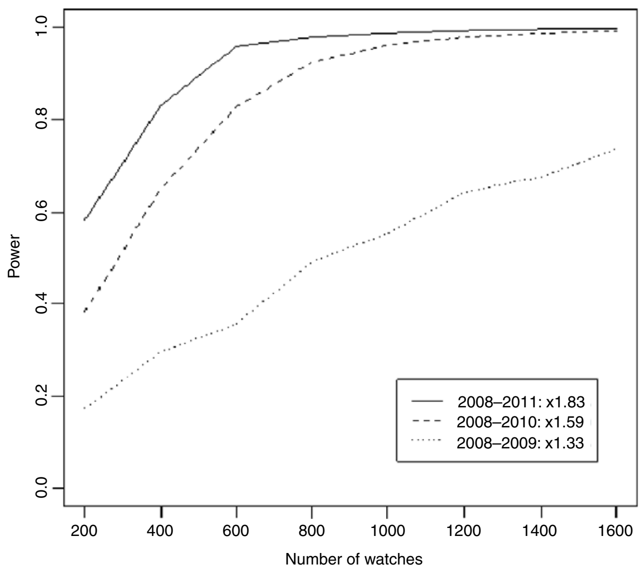

Fig. 3. Power of detecting increases in sightings rates between 2008 and subsequent years at Spey Bay with the number of watches per year (April–October) based on resampling the original datasets.

3. Results

3.1. Effort required to detect inter-annual trends

Bottlenose sightings rates increased at Spey Bay from 0.036 sightings per watch in 2005, to a peak of 0.194 sightings per watch in 2011, since when sightings have levelled off (Table 1, Fig. 2). This increase was shown to be statistically significant between all years and combinations of years except 2005–2006, 2007–2008, 2009–2010/2012, with no significant trends since 2010 (Table 3). The lowest detectable trend was an increase of 34% in sightings rate between 2008 and 2009, smaller trends could not be detected statistically.

The power to detect an increase in sightings rates between years is shown in Fig. 3. This demonstrates that more watches are required to detect smaller trends. For example, the number of watches to achieve power > 0.8 (Cohen, 1988) for an 83% increase in sightings rates between 2008 and 2011 required around 350 watches, while the 59% increase between 2008 and 2010 required around 600 watches, and the 33% increase between 2008 and 2009 did not reach the 0.8 power threshold even after 1600 watches (Fig. 3). Similarly, smaller trends based around lower sightings rates are harder to detect than the same trend at a higher sightings rate.

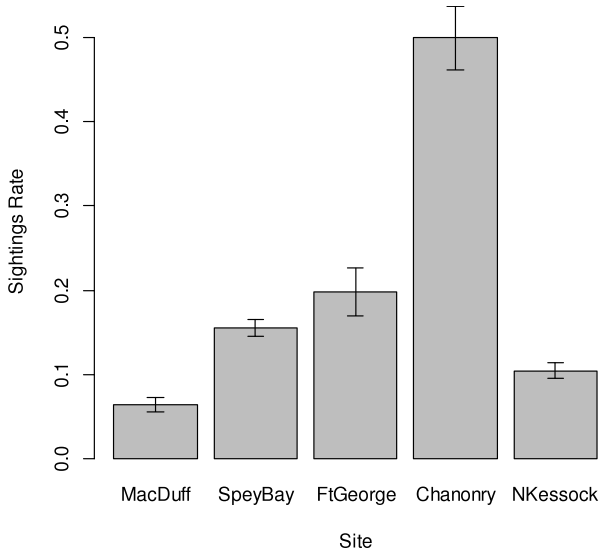

Fig. 4. Bottlenose dolphin sightings rates (sightings per watch) for each Moray Firth shore-based watch site for 2012, with error bars showing the standard error around the mean.

Table 3
Results of the GLM-GEE model testing the significance of yearly differences in bottlenose dolphin sightings rates at Spey Bay (top), and observed increases in sightings rates (bottom), in bold where significant.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
2005		NS	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
2006	1.11		$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
2007	**2.27**	**2.04**		NS	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
2008	**2.97**	**2.67**	1.31		$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
2009	**3.97**	**3.57**	**1.75**	**1.34**		NS	$p < 0.01$	NS	$p < 0.05$
2010	**4.75**	**4.28**	**2.10**	**1.60**	1.20		NS	NS	NS
2011	**5.45**	**4.90**	**2.40**	**1.83**	**1.37**	1.15		NS	NS
2012	**4.70**	**4.23**	**4.23**	**1.58**	1.18	0.99	0.86		NS
2013	**5.43**	**4.88**	**2.40**	**1.83**	**1.37**	1.14	1.00	1.15	

Table 4
Bottlenose dolphin sightings rates for each monitored site around the Moray Firth for 2012, detected trends (top), in bold where the GLM-GEE showed a significant difference in sightings rates between sites. The bottom part of the table shows the estimated number of watches required to have power > 0.80 for detecting the between site differences based on resampling the original datasets.

	Rate	MacDuff 0.063	Spey Bay 0.156	Fort George 0.198	Chanonry 0.500	N Kessock 0.104
MacDuff	0.063		↑**2.45**	↑**3.12**	↑**7.88**	↑ 1.64
Spey Bay	0.156	≈170		↑**1.27**	↑**3.21**	↓**1.49**
Fort George	0.198	≈80	>2000		↑**2.53**	↓**1.90**
Chanonry	0.500	<25	≈40	≈50		↓**4.80**
N Kessock	0.104	NS	≈1000	≈230	≈40	

3.2. Effort required to detect between-site trends with different detection rates

Sightings rates were lowest at the site furthest from the SAC boundary in MacDuff (0.063 sightings/watch), increasing to 0.156 at Spey Bay, to 0.198 at Fort George and peaking at 0.5 sightings per watch at Chanonry Point before dropping down to 0.104 at North Kessock (Table 2, Fig. 4). All differences between sites were significant to $p < 0.05$ except between MacDuff and North Kessock (Table 4). The smallest difference that could be detected was the 27% increase in sightings rate between Spey Bay and Fort George (at relatively high sightings rates), however the larger increase of 64% between MacDuff and North Kessock (at a lower sightings rate) was not detectable (Table 4, Fig. 4).

Similar to the power analysis for the yearly data at Spey Bay, the power analysis for the site data showed that more effort was required to detect smaller trends, and more effort was required to detect trends at low sightings rates (Fig. 5). For example, an increase of 90% in sightings rate between North Kessock and Fort George was detectable with around 230 watches to achieve power > 0.8, whereas an increase of 50% sightings rates between North Kessock and Spey Bay required around 1000 watches, and >2000 watches was required to achieve power > 0.8 for the 30% increase in sightings rate

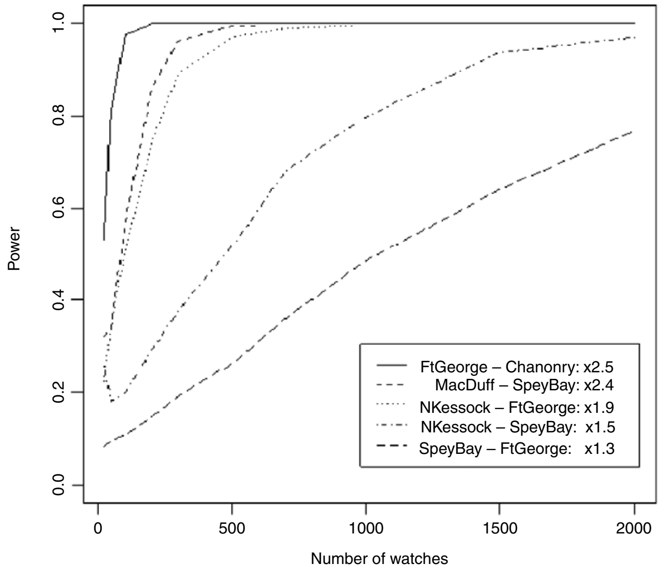

Fig. 5. Power to detect a trend in sightings rates with increasing numbers of watches in a year.

between Spey Bay and Fort George (Fig. 5). Similar to the resampled yearly data, the coefficient of variation decreased with increasing amount of effort, and required fewer watches to achieve a CV < 0.1 at higher sightings rates (e.g. around 200 watches at Chanonry Point with a sightings rate of 0.5 sightings per watch) than at a lower sightings rate (e.g. 2000 watches at MacDuff with a sightings rate of 0.063) (Fig. 6).

4. Discussion

This paper demonstrates the effectiveness of a citizen science project to monitor bottlenose dolphins from shore-based watch points in and around an SAC in the Moray Firth, generating data with the power to detect inter-annual and inter-site trends in occurrence.

4.1. How much effort is enough?

We have shown that the amount of effort (number of watches) required to detect a certain trend in the occurrence of bottlenose dolphins depends on the detection (sightings) rate. At Spey Bay, a known bottlenose dolphin hotspot, an inter-annual (2008–2010) increase in sightings rate of 59% from 0.106 to 0.169 sightings per hour could be detected with around 600 watches between April and October, which equates to around 86 watches per month or 3 watches per day. If we take a threshold of a 50% difference between years or sites, which was the difference between North Kessock and Spey Bay in 2012 from 0.104 to 0.156 sightings per hour, 1000 watches were required over the same peak months. This equates to 143 watches per month or 5 watches per day. At higher sightings rates, lower numbers of watches were required to detect the same trend, and trends are virtually impossible to detect at sites with very low sightings rates. Trends lower than 30% could not be detected even with very high levels of effort (up to 2000 watches between April and October). This finding is supported by similar studies examining the power to detect trends (Gerrodette, 1987), particularly in environmental impact assessment (EIA) studies (e.g. Maclean et al., 2012). For example, in the Maclean et al. (2012) study it was difficult to detect trends of seabird abundance of <50%, and increasing effort did not yield much benefit in terms of statistical power.

How feasible is this level of effort? The WDC Shorewatch programme has already been able to coordinate this level of effort from a team of citizen scientists at Spey Bay and many of the other sites around the Moray Firth. Our analysis shows that in order to detect inter-annual trends, high numbers of watches should be carried out from sites with reliable dolphin presence (0.1 sightings per hour). Regular occurrence of dolphins is also more likely to motivate volunteers to participate in the longer term. Conducting up to five watches per day may not be an efficient use of time at sites which only get occasional visits from bottlenose dolphins, and is unlikely to generate enough data to be able to statistically detect inter-annual trends. However, the effort required to detect large inter-site differences in occurrence is more manageable and was achieved at all of the sites used in our analysis, despite relatively low effort at some of the sites. Strategic monitoring at sites considered to be important to the animals, for example, those that are in the vicinity of protected areas and/or overlooking potential coastal development sites (e.g. marine renewable energy (wind, wave and tidal), harbour developments or aquaculture facilities) is necessary. Required effort can be achieved by consolidating volunteer effort at these sites. Different levels of effort can therefore be recommended dependent on site and conservation requirements, with highest levels of effort (5 watches per day minimum) recommended for relatively immediate (inter-annual) trends in dolphin occurrence, medium levels of effort

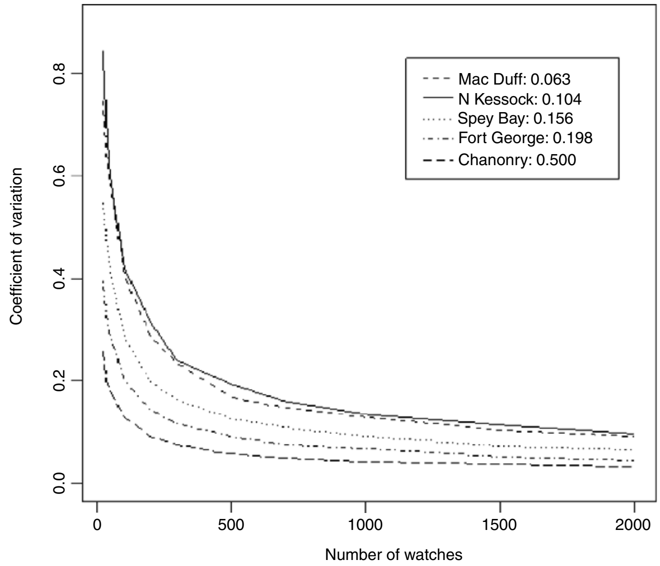

Fig. 6. Change in coefficient of variation with increasing numbers of watches and different bottlenose dolphin sightings rates resampled from the 2012 data from each watch site in the Moray Firth.

(2–3 watches per day) for detecting temporal changes over a longer period of time (e.g. between 6-yearly reporting of SAC status), and low levels of effort for monitoring trends in spatial range over larger scales.

How should the watches be distributed throughout the day? From a theoretical point of view, it is better to break watch periods into smaller continuous bouts of watches, with breaks between bouts, where bouts should consist of no more than 4 continuous watches (Bailey et al., 2012). GEEs were shown to perform best (fewer type I errors, i.e. rejection of the null hypothesis when it is true) if segments comprised 4 watches (Bailey et al., 2012). There are also other factors that should be considered in shore-based surveys of cetaceans which are aspects such as time of day, tidal state, or other variables that may impact sightings rate. For example, sightings rates of bottlenose dolphins were shown to vary both diurnally and tidally at Chanonry Point (Bailey et al., 2012). If effort was biased to times when dolphins were more likely to be present, such as early morning and low tides at Chanonry Point (Bailey et al., 2012), sightings rates would be overestimated leading to false statistical inter-annual or between-site trends. Effort should therefore be carefully distributed so that there is even effort both with time of day and tidal state, and any other factors that may be important to the animals at the site being monitored. Similarly, effort should be distributed evenly over the survey period to allow for the natural fluctuations of dolphin habitat use (e.g. Bailey et al., 2012). Without these considerations sightings rates could be biased and could result in false detection of trends.

4.2. How has citizen science helped monitor bottlenose dolphins in the Moray Firth?

Our data showed an increase and then stabilising in bottlenose dolphin occurrence at Spey Bay between 2005 and 2013. The data from the wider Moray Firth area also show clear spatial differences in habitat use around the Moray Firth coast. What do these differences actually mean? Although shore-based surveys cannot be used to make inferences at the population level, they can be used to assess habitat usage and signal changes in the marine environment that may be impacting the dolphins, such as changes in prey availability or anthropogenic disturbance (Pirotta et al., 2015). The increase in dolphin occurrence at Spey Bay may be in response to temporal changes in prey availability at a local level (Wilson et al., 2004; Knight and Laughton, 2012; Bailey et al., 2012). For example the 2012 Spey Fisheries Board Annual Report reported an increase in rod and line catches of salmon on the River Spey between 2004 and 2008 that may explain the changes in bottlenose dolphin occurrence at Spey Bay during this time. Studies carried out on the wider population of bottlenose dolphins based on predominantly boat-based surveys have shown that the population of bottlenose dolphins has expanded its range outside the SAC (SNH, 2011; Cheney et al., 2012, 2014), as backed up by our volunteer-led watch data, showing increasing sightings rates at Spey Bay. Bottlenose dolphins have shown an ongoing preference for the Spey Bay habitat (Culloch and Robinson, 2008) and such long term site fidelity may well indicate a unique relationship with this particular piece of the coastline (Miller and Baltz, 2010). Spey Bay is an ideal location for monitoring with shore-based observations because bottlenose dolphins occur regularly and close into shore. It is also an area of key habitat which may act as an indicator of influences on the wider population but is also important in its own right.

The trends detectable by these large scale citizen science shore-based monitoring programmes can provide a cost-effective warning system about changes in the marine environment. This is particularly important in the Moray Firth towards monitoring the status of the bottlenose dolphins protected by the SAC, and complements more spatially-extensive boat or aerial based surveys carried out to monitor population level trends and wider scale habitat preferences. The east coast of Scotland population of bottlenose dolphin are not immune to anthropogenic threats despite being protected by the SAC. The Moray Firth is subject to oil and gas exploration, resulting in seismic air-gun surveys within the outer Firth, with the potential for disturbing cetaceans that use the SAC (Thompson et al., 2013; Pirotta et al., 2014). The Scottish Government has also recently consented large offshore wind farm developments in the Moray Firth and a further five throughout the wider east coast (off Aberdeen and the Forth and Tay area), as well as numerous associated harbour expansions. The short and long-term impacts of construction and operation of these developments on bottlenose dolphins and other marine mammals are currently uncertain but may be significant (Lusseau, 2013). Shorewatch data is well placed to provide valuable long-term baseline data, to assist with government planning and decision making, and to contribute to monitoring any changes in dolphin occurrence due to anthropogenic influences. Alongside the boat-based surveys which are also critical for determining population level trends, these shore-based volunteer-led watches can help understand potential impacts and to ensure that the conservation objectives of the bottlenose dolphin SAC are being met.

4.3. Benefits of citizen science projects

We have demonstrated the benefit of shore-based citizen science surveys for monitoring coastal species, and in acting as a warning system for changes in the marine environment. However, there is a need for statistical rigour, experience and a large amount of effort to provide data that is useful for conservation outcomes such as identification of trends. Ensuring even temporal effort throughout the day and from month to month increases the value of the data. A high level of commitment is necessary from volunteers and the project co-ordinator to achieve the quality and quantity of effort required for robust trend analysis (Thompson et al., 2011). In order to collect the quantity of data required to produce statistically reliable data for monitoring changes in occurrence of bottlenose dolphins, the Shorewatch Programme was designed to target, support, motivate and maintain volunteer effort. The 10 min protocol is relatively short so that it is accessible by a wide range of volunteers and feasible throughout the year and in variable weather. Ongoing training and support of volunteers is essential to provide confidence and ability but with increasing number of sites can come at a considerable financial cost. We have found that the considerable time commitment can most easily be overcome by bolstering effort with staff and residential volunteers who are regularly present on site and also by working with ‘partner groups’ (such as Historic Scotland at Fort George) who can include Shorewatch as part of their daily role.

The benefits of involving citizen scientists in scientific projects extend beyond the cost-effective science itself, and have been shown to be important in fostering ‘earth stewardship’ (Dickenson et al., 2012). At a high level, the public can have a large influence on scientific policy, and one way of achieving this is to engage them in science: ‘science by the people’ (Silvertown, 2009). At a local level, engaging communities in local conservation projects is likely to result in better understanding and management to the benefit of both the ecosystem conserved and the local communities. In the Moray Firth, the Shorewatch programme engages local people in collecting data about the bottlenose dolphins within and around the SAC, and therefore as a secondary consequence educates and involves local communities in their local conservation project. Alongside this, the WDC Scottish Dolphin Centre at Spey Bay provides education and outreach to inspire local communities and tourist visitors. Shorewatch data is also used for wider outreach purposes for example, including reporting sightings using social media and to enthuse communities and tourists towards awareness and stewardship of the dolphins and the wider marine environment. Ultimately, the use of citizen scientists not only allows for cost-effective, broad and long-scale monitoring of coastal bottlenose dolphin populations, but also enhances engagement with the local environment, feelings of earth stewardship, and facilitates participation in democratic decisions about the environment (Dickenson et al., 2012; Greenwood, 2007; Silvertown, 2009).

5. Conclusion

We have demonstrated the value of citizen science shore-based surveys in understanding the localised temporal and spatial trends in bottlenose dolphin occurrence in the Moray Firth. Shore-based surveys are particularly useful for coastal bottlenose dolphins, as they often demonstrate site fidelity and are relatively easy to observe in suitable sea states. Required effort will vary in other regions or with different species demonstrating different movement patterns. At sightings rates between 0.10 and 0.15 sightings per hour, around 5 watches per day (10 min scans in an hour) were required to detect a 50% trend in occurrence between years or sites. This level of monitoring would be required to detect rapid changes due to anthropogenic disturbance, such as impacts of pile driving during the wind farm construction phase (e.g. Bailey et al., 2010). Lower levels of effort can still be useful to detect slower trends in occurrence, large inter-site differences in occurrence, or species ranges when carried out over larger scales (e.g. Sauer et al., 2003). Strategic decisions should be made to monitor from sites where sighting rates are greatest or at sites considered to be important to the animals and where conservation objectives are of greatest interest. Consolidating volunteer effort at these locations will help to ensure sufficient survey data to achieve statistical rigour in identifying trends.

This study calculated a clear increase in occurrence of bottlenose dolphin at Spey Bay over the study period, although the reasons for this increase are unknown. Regardless, there will be a dramatic increase in large-scale industrial development associated with marine wind farms in offshore waters in future, including pile driving for several years, that we anticipate will be audible throughout the range of the bottlenose dolphins. This data may provide a critical baseline to assist our understanding of any impacts that result from activities associated with these developments, i.e. displacement from core foraging habitats. In its decision making surrounding all marine activities, Marine Scotland needs to ensure that the conservation objectives of the bottlenose dolphin SAC are maintained.

In places such as the Moray Firth, concerns about the health of the marine environment continue to grow. There are clear benefits in involving local people in monitoring efforts which both enhances management of the local SAC and fosters earth stewardship within the community. Using citizen scientists to collect shore-based observations of coastal cetaceans provides an achievable and cost-effective means of carrying out broad and long-scale monitoring. With sufficient survey effort, data can be rigorously analysed to detect trends in occurrence, offering an early warning system about changes in the marine environment and informing conservation management of the species.

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