A reanalysis of historical population estimates of breeding European Storm Petrels *Hydrobates pelagicus* on Skokholm Island, Wales

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- Fe wnaethom goladu data arolygon a defnyddio pecyn cymorth a dull dadansoddol newydd (Padget et al., ar waith) i ailgyfrif amcangyfrifon poblogaeth hanesyddol ac, yn bwysig, eu terfynau hyder cysylltiedig. Felly rydym yn cyflwyno'r asesiad gwrthrychol cyntaf o dueddiad poblogaeth pedrynnod drycin ar Ynys Sgogwm.
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2. Executive summary

- Skokholm Island is home to the largest breeding colony of European Storm Petrels in Wales. Four census attempts have been made using call-playback; in 1995, 2001, 2003 and 2016. Similar approaches were used, but methodological differences have hindered objective estimates of population change.
- We collated survey data and applied a newly-developed analytical method and toolkit (Padget et al., in prep) to recalculate historical population estimates and, importantly, their associated confidence limits. Thus we present the first objective assessment of the population trend of European Storm Petrels on Skokholm Island.
- The recalculated whole-island population estimates of the number of Apparently Occupied Sites (AOS) on Skokholm Island are as follows:
  - 1995: 4567* (95% CL: 1723-8122)
  - 2001: 2391 AOS (95% CL: 1988-3268)
  - 2003: 1308* AOS (95% CL: 936-2003)
  - 2016: 2383 AOS (95% CL 2080-2589)
  - * Note: estimates in 1995 and 2003 are unreliable, issues discussed in the text
- As methods and analytical approaches have improved, the 2016 Skokholm whole-island estimate is judged to be reliable
- By combining the 2016 estimates for Skomer (201: 95% CL 155-389 AOS) and Skokholm islands and using our new technique to recalculate confidence limits, the revised 2016 population estimate for the Skomer, Skokholm and the Seas off Pembrokeshire Special Protection Area is thus 2584 AOS (95% CL: 2282 - 2885), excluding Grassholm and Midland which remain unsurveyed
- Overall, we find no evidence for a decline in the Skokholm population since 1995, as the confidence limits of each population estimate overlap with those of every other (Fig. 2). We conclude that the breeding population of European Storm Petrels on Skokholm Island has been stable in recent decades
- We make two recommendations for future whole-island playback censuses: 1. the use of consistent survey methods, following the 2016 census protocol (Wood et al. 2017); and 2. the use of consistent analytical methods, using our online analytical toolkit (Padget et al. in prep.) for more user-friendly and repeatable calculations of population estimates and their associated confidence limits
- This report builds on the skill and persistence of wardens, fieldworkers and scientists to develop call-playback census methods in a species that remains challenging to study. Our work would not have been possible without their hard-won data, for which we express our sincere thanks

3. Introduction

Skomer, Skokholm and the Seas off Pembrokeshire form an EU Special Protection Area, which since the UK's exit from the EU remains designated for conservation Annex 1 species including the European Storm Petrel *Hydrobates pelagicus* (EU Birds Directive, 2009). Breeding European Storm Petrels are challenging to survey, because they are only active at the colony at night, nest in fragile and often inaccessible habitats such as cliff scree, boulders and stone walls, and are prone to human disturbance at the nest. Skokholm is home to the largest breeding colony in Wales, one of the largest in the UK (Mitchell et al., 2004). The species is currently amber-listed in Wales as a species of conservation concern (Bladwell, 2018), due to apparent declines in the breeding population from previous census attempts (Betts, 1994, Scott, 1970, Thompson, 2005, Vaughan, 2001, Vaughan and Gibbons, 1996).

As part of 'Seabirds Count', a census of breeding seabirds in the UK and Ireland coordinated by JNCC from 2015-2021, a 'call-playback' census was conducted on both Skokholm and Skomer Islands in 2016 (Wood et al., 2017). This contemporary survey highlighted the difficulty in comparing the census results with previous European Storm Petrel population estimates, due to the variation in methods used for surveys and for calculating the probability of a response to call playback by an occupied burrow. Therefore a reliable measurement of the error of population estimates was required from statistically-derived confidence intervals which would then allow a more valid comparison of population change over time and the assessment of conservation status.

Here, we recalculate historical estimates of the European Storm Petrel population on Skokholm Island, using the analytical techniques first used for the NRW-funded 2016 survey and developed subsequently as an online platform for fieldworkers with funding from JNCC (Bolton et al., 2021, Padget et al., in prep). Data for Skomer Island prior to 2016 were sought but found to be unavailable, therefore we focused on Skokholm Island.

Our overall aim is objectively to assess the population trend of breeding European Storm Petrels on Skokholm Island, and by including a recalculated estimate for Skomer Island (the only other known breeding location) to provide a population estimate for the wider SPA.

3.1. Objectives

- Review previous census work, and collate available data for recalculation of population estimates of European Storm Petrels on Skokholm Island
- Include potential variation between different habitats (e.g. rockfall vs wall) in calculation methods
- Recalculate previous population estimates for Skokholm Island and their confidence limits, and recalculate the 2016 population estimate for the Skomer, Skokholm and the Seas off Pembrokeshire Special Protection Area
- Assess the evidence for population change on Skokholm Island
- Make recommendations for future population monitoring

4. Review of previous census work

Here follows a synthesis of reports of primary census efforts, and reviews of previous census data. Our aim is to review this material objectively, noting methodological issues and data availability for reanalysis of census estimates.

4.1. Early pioneers

Ronald Lockley's studies of seabirds on Skokholm included an approximate estimate of 500 breeding pairs of European Storm Petrels (ca. 200 in walls, ca. 300 around the coast) from counts of occupied burrows (Lockley, 1932). Successive fieldworkers used smell or unspecified methods to agree with this first estimate throughout the 1940s (Conder and Keighley, 1950, Lockley and Buxton, 1947) and 1950s (Davis, 1957). With the advent of mist-nets, Mike Harris concluded the population must be much higher as more than 900 individuals were ringed in 1963 (Harris, 1964).

These first estimates set the scene for later work, but the methods and extent of island coverage do not permit comparison with later census work.

4.2. 1966-69 (Scott, 1970)

Derek Scott carried out his doctoral studies over four seasons on Skokholm. Using a combination of burrows found by audible calls and the distinctive smell of storm petrel, he mapped burrow distribution. Using mist-nets placed around the island he also carried out mark-recapture work on the survival rates and population size, estimating a far greater island population than had been suspected: 6,200 breeding European Storm Petrels (range 5000-7000). The use of tape-playback during mist-netting is known to attract non-breeding birds which will have inflated Scott's estimate of population size. Nonetheless, Scott's estimate was way in excess of the 500-600 previously estimated.

Scott's data are not currently available, and the methods were very different to call-playback methods, therefore we cannot include Scott's estimate in our assessment of population change.

Scott's original ringing records are being digitised. Mark-recapture statistical techniques have developed considerably since Scott's work, so the reanalysis of these data might be useful to extend the historical scope of population.

4.3. 1989-94 (Betts, 1990, Betts, 1992, Betts, 1994)

Mike Betts aimed to repeat Scott's census estimate and develop new survey methods: using an image intensifier to observe birds at breeding sites, listening for calls from nest burrows and eliciting a response to call playback later in the season during incubation (churring song). He found a very similar spatial distribution of nest sites, but strong variation in numbers in some areas (Betts, 1990). Permanent marking of AOSs in the wall system began in 1992, finding far fewer than Scott (1970).

Survey methods for The Quarry were developed using a quadrat system to survey a subset of available habitat, estimating 1400-2800 AOS in the largest subcolony on

Skokholm (Betts, 1994), subsequently recalculated to 900-1800 using aerial photographs to extrapolate more accurately to available habitat (Betts pers.comm., in Perrins 2002).

Repeated census of stretches of wall containing the majority of AOSs (North Pond and Little Bay walls) took place until 2001, but with a varying methodologies and numbers of visits per year. Betts' work formed the basis for annual transect monitoring from 2010 (Sutcliffe, 2010, Sutcliffe and Vaughan, 2010).

The whole-island population size was initially estimated as 4000-8000 by scaling up from The Quarry estimate (Scott estimated a third of European Storm Petrels bred in The Quarry), which Betts recalculated to 2700-5400 AOS (Betts pers.comm., in Perrins 2002).

Due to methodological differences with later playback and lack of available primary data, we could not reanalyse Betts' data, although we include his estimates in qualitative comparisons.

4.4. 1995 (Vaughan and Gibbons, 1996)

This census was co-sponsored by RSPB and CCW, aiming to re-examine the spatial distribution of European Storm Petrel AOS found by Betts (1990) and Scott (1970). It was the first study to deploy call playback, the standard method of identifying AOSs, and an attempt at response rate calibration.

With the benefit of hindsight, there methodology was problematic: a small number of playback calibration visits was made (four nocturnal visits to calibrate just two diurnal visits to enable diurnal survey); and response rate was calibrated only at walls, not rockfall habitat (the majority of suitable habitat on Skokholm). Two years after Vaughan & Gibbons published their report, Ratcliffe *et al.* (1998) indicated marked differences in response rate between habitats, which has subsequently been found to be important in other census work (Bolton et al., 2010, Wood et al., 2017). Nocturnal survey work is not feasible in coastal subcolonies, and thus has been abandoned on safety grounds. Although an extenson of Betts' coverage, only a subset of coastal habitat was surveyed and extrapolated to the area of apparently suitable habitat.

Vaughan & Gibbons (1996) indicated what was, at the time, thought to be a much lower population estimate than previous efforts (3500 AOS, range 3000-4000), although this does not conflict with Bett's recalculated estimate the previous year (see 4.2 above). Decline was indicated on the south coast of Skokholm in 'rock-burrow' habitat (burrows in soil/stones under rock boulders).

The 1995 census was an important step in developing call-playback census techniques on Skokholm. Original data available was limited, but we attempted response rate calibration using data from two diurnal visits to a small number of sites.

4.5. 2001 (Vaughan, 2001)

This survey repeated the coverage of 1995 using only diurnal calibration of response rate, not just in walls as in 1995 but also in rockfall habitat to align with JNCC's Seabird 2000 methods at other census sites in the UK. Also, a greater number of visits were made to calibration plots (Wall 6 visits, Rockfall 9) thus calculation of response rate can be expected to be more reliable.

Vaughan estimated the Skokholm population to be 1966-2048 AOS. He found a similar number of AOSs in wall, but far fewer in rockfall, the most widespread habitat type on Skokholm (The Quarry consist of rockfall and boulders): analytically, the relatively high response rate of AOSs in the rockfall site (North Haven) translated into a lower population estimate than in 1995 using a Wall response rate.

This indicated that the 1995 census likely over-estimated the number of European Storm Petrels in rockfall habitat (Sutcliffe, 2010).

All response rate calibration and survey data were available for reanalysis, using habitat-specific correction factors.

4.6. 2003 (Thompson, 2005)

Thompson aimed to repeat Vaughan's 2001 survey, but made two changes: (i) he judged the extent of suitable habitat measured by Vaughan to be an over-estimate and (ii) although he deployed habitat-specific response rate calibration, he rejected this approach and pooled response rates as he found no difference in response rate.

These changes brought a much-reduced population estimate of 1009 AOS, questioned by Sutcliffe (2010) who re-evaluated Thompson's data using Vaughan's approach (same suitable habitat areas, habitat-specific response rates) and recalculated a whole-island population estimate of 2500 AOS, similar to that of Vaughan (2001) and Vaughan and Gibbons (1996).

We judge Sutcliffe's reevaluation of area extrapolations to be reasonable, and integrate this into our reanalaysis of Thompson's 2003 data. Response rate calibration and survey data were available for reanalysis, using habitat-specific response rates.

4.7. 2014 (Whittington, 2014)

Will Whittington spent April to September on Skokholm, working on the annual transect surveys and attempting to survey additional sites to compare with Thompson's 2003 census. He also assisted with studies of diet (Rob Thomas & Renata Medeiros, Cardiff University) and thermal imaging (Matt Wood, University of Gloucestershire).

He highlighted the decline in AOS in the wall system, and included designs developed with wardens for a nest-box wall to provide additional habitat and a means of studying storm petrels without undue disturbance. Comparing rockfall habitats surveyed 2003 and 2014 was hampered by the 2014 work being carried out in August when response rates would have been lower in sites containing chicks and/or no parents. A moderate decline in rockfall AOS outwith The Quarry was noted (particularly at Crab Bay, and Frank's Rocks) but this was viewed with caution due to later survey dates.

Importantly, Whittington also documented changes in the mobile rockfall habitat, comparing images of sites around the island that had experienced rock falls to create additional habitat or storm-washed habitat loss (e.g. 18 AOS were lost at North Haven in the winter of 2013-14). This unpredictable and inevitable turnover of available habitat must be borne in mind when considering the longer-term population change: extrinsic factors such as habitat change may be equally important as intrinsic factors such as reproductive success and survival.

4.8. 2016 (Wood et al., 2017)

The aim of this NRW-funded census was to undertake the first SPA-wide census of European Storm Petrels on both Skokholm and Skomer Islands, using consistent methods between islands and in line with census methods used elsewhere in the UK (Bolton et al., 2010), as part of the JNCC-led UK Seabird Count 2015-21.

The primary aim was to use the generally-accepted asymptote-extrapolation approach in response rate calculation (Bolton et al., 2010, Bolton et al., 2017, Shewry and Murray, 2017), in favour of estimating minimum numbers of confirmed AOS in calibration sites (Ratcliffe et al., 1998) which was the method traditionally used on Skokholm (Vaughan and Gibbons, 1996, Vaughan, 2001, Thompson, 2005, Brown and Eagle, 2017). Asymptote extrapolation techniques have been used on Skomer (Brown, 2006) to account for AOS potentially missed over the course of calibration visits, highlighting the need for a standardised method across the SPA.

Suitable habitat was identified by eye in the field, and also by use of infrared imaging equipment to locate likely occupied sites from nocturnal flight activity (nine new sites were located on Skokholm). Imaging was also used to examine inaccessible locations: for example, in June most of one survey transect at The Quarry on Skokholm suffered a rock slide that destroyed most of the available habitat, and likely many AOS with it (Brown and Eagle, 2017).

The census involved a considerable amount of field effort to achieve survey coverage of all likely habitat, and also playback survey to verify the lack of European Storm Petrel AOS in representative areas of shearwater burrows. A lower response rate was detected in rockfall than in walls, confirming the validity of habitat-specific response rate calibration used in 2001 and 2003

New analytical approaches were developed to estimate the asymptote number of AOS in calibration plots, accepting the ‘Maximum Likelihood’ (ML) method as the most robust method (Padget et al., 2019), and recommending its use in future surveys to calculate a more meaningful response rate for use in population estimates, and their confidence intervals.

4.9. Summary of previous census efforts

The wall system on Skokholm is readly accessible compared with coastal rockfall areas, and so the walls have been surveyed more frequently. Sutcliffe (2010) found a clear decline in AOSs in the same stretches of wall subjected to playback in whole-island census efforts (1995: 253, 2001: 92, 2003: 113), suggesting that as walls have degraded over time they have become less suitable nesting habitat, but cautioning that different playback methodologies and response rate calculation methods were used. Some error in the estimates is likely, but this seems to be a consistent trend supported by historical photographs of the wall system (Whittington, 2014).

Population change in rockfall habitat (the majority of storm petrel habitat on Skokholm) is less well understood, because earlier playback census work in coastal rockfall relied on area extrapolations or inconsistent coverage between surveys, and minimum-maximum AOS estimates are reported rather than confidence intervals.

Considerable uncertainty about methods and the coastal rockfall population is acknowledged in previous census reports, yet the conclusion has been drawn that Skokholm's population of European Storm Petrels must be in decline. This may be due to the large initial population estimate made by Scott (1970), and the observed decline in the sub-population in the wall system, but this subjective conclusion of a declining population cannot be supported objectively. The more reliable aspects of historical surveys, particularly at The Quarry, indicate a stable population:

Sutcliffe (2010) noted that the first estimate of population size in The Quarry (900, although Scott inferred that the 'true' population was larger) was in approximate agreement with later census efforts, at this the largest subcolony on Skokholm,.

On reviewing previous census efforts, we conclude that:

- Response rate calibrations must include estimation of the asymptotic number of AOS detected in a calibration plot (Padget et al., 2019, Wood et al., 2017), because even 10 calibration visits are known to under-estimate the number of AOS (Sutcliffe, 2010, Thompson, 2005). The 'minimum estimate' approach should not be used
- Confidence intervals for response rates should be calculated, to enable meaningful and objective comparison of population estimates, rather than subjective judgements
- Assessments of population trends should be focussed on the most robust population estimates, in which habitat-specific response rates were calculated in both walls and rockfall (rockfall including rockburrow used by some previous surveys), and all apparently suitable habitat was surveyed: i.e. 2016

Guided by these conclusions we aimed to reanalyse these census data, to recalculate previous population estimates, and include reliable confidence intervals.

5. Recalculation of previous population estimates

5.1. Approach

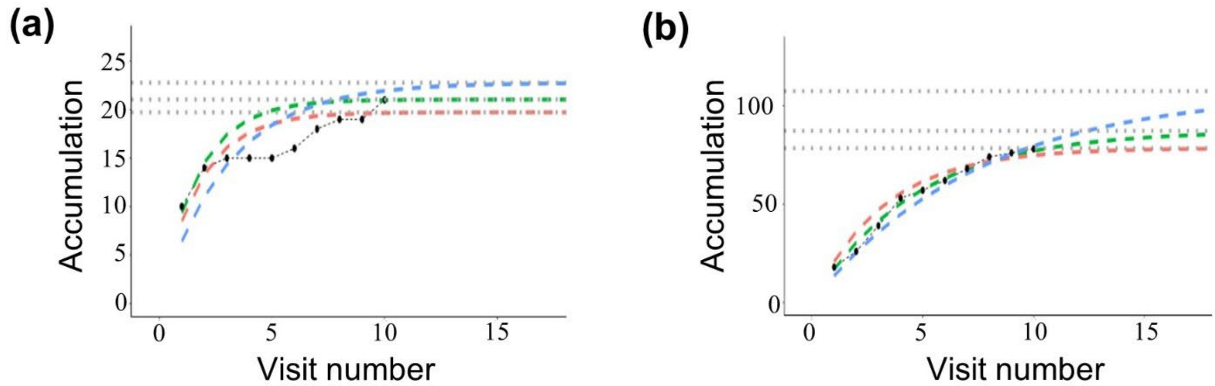
Calculating a population estimate by call-playback involves four steps:

5.1.1. Response rate calibration

European storm petrels nest in inaccessible burrows and are susceptible to disturbance, so it is not possible to open study burrows to confirm occupancy. By using repeated call playback on successive visits one or two days apart, the number of apparently occupied sites will accumulate as more AOS respond (Fig. 1). However, not all birds in AOSs will respond, even after ten visits, so a failure to account these 'missing' AOSs would detect fewer AOS in a calibration plot than are present, resulting in an over-estimated response rate, which would result in an under-estimated population size.

Figure 1. AOS accumulation curves for 2016 response rate calibration in (a) wall and (b) rockfall habitat

As the number of calibration visits increases, the number of AOS detected increases. Graph shows survey data (black line with black points), with the extrapolated asymptote number of AOS as a green dotted line (upper confidence limit in blue, lower confidence limit in red).



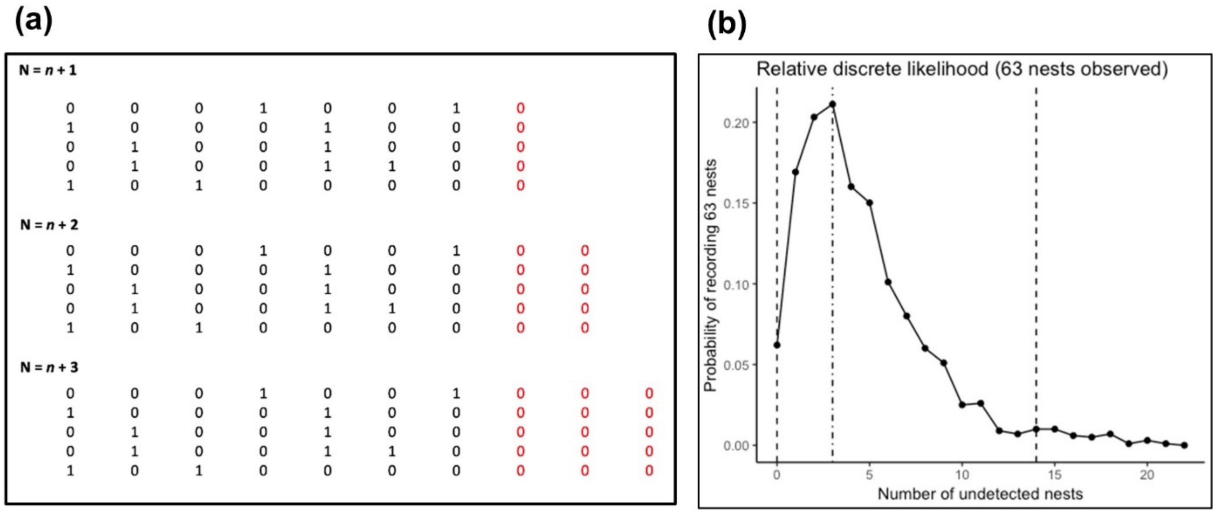
Modelling the shape of the response accumulation curve allows the asymptote (or 'plateau' of the curve) to estimate the 'true' number of AOS present in a given areea, allowing a more accurate response rate to be calculated. This makes a small but important difference compare to the number of AOS detected after ten calibration visits (2003 and 2016 censuses), but a much larger difference with fewer calibration visits (1995 and 2001).

We used a new extrapolation method using a maximum likehood (ML) approach (Padget et al., in prep). Modern computing power allows us to quickly calculate the probability of observing the number of responses recorded, given different parameters for the number of nests at the calibration site. Since the probabilities of the data given the parameters do not sum to 1, this is akin to a 'Likelihood' calculation, where we search parameter space for the values to maximise this likelihood function. The maximum likelihood estimate is the value for N which maximises the expression p(n|N), where n is the number of nests detected in the calibration survey and where N can assume any integer from n to a plausible maximum. For the additional occupied sites assumed in N, these are added as non-responding nests, since, if present, these additional nests remained silent. To estimate the probability p(n|N), a bootstrapping procedure can be used, where responses recorded at the calibration site are re-sampled with replacement to give an estimate of the frequency of detecting n nests given the response rate observed (inferred from the responses) and the number of visits. Hence, we want to know that value for N which maximises the expression:

p(n|N)=L(N|n)

Figure 2. (a) Model response matrices for surveys of ten nests (N), (b) Relative Likelihood of different numbers of undetected nests (N – detected nests)

(a) In this case, seven nests responded to call playback (n, in black), with three additional nests not responding (in red). If there are a greater number of nests than those detected over the calibration visits (N > n), then some nests must have been surveyed and not responded. The probability of n nests being recorded can be estimated by resampling these data with replacement and recording the proportion of the resamples where n nests are recorded (i.e. n columns contain 1 or greater responses). This probability is monotonically related to the Likelihood of N, LN. (b) For the example shown, the most likely number of undetected nests is 3, which when added to the 63 observed, give a most likely value of n of 66. Confidence intervals are estimated where 95% of the estimates are contained within the estimated curve



Where feasible, response rates should be calibrated separately for breeding habitat types, e.g. walls and rockfall, as response rates may vary. Skokholm censuses used different habitat classifications for response rate calibration (e.g. walls only; rockfall & walls; rockfall, rockburrow & walls). Due to the difficulty in defining rockburrow and locating sufficient sites for playback calibration, rockburrow was included as rockfall in 2016, and previous rockburrow data are treated as rockfall in this reanalysis.

Our approach allows, for the first time, a meaningful comparison of Skokholm censuses, by applying a constent method of calculating population estimates, and the first calculation of robust confidence limits to account for sources of error.

5.1.2. Survey

To estimate the number of AOS in wider breeding habitat, single playback visits are made to areas of potentiall suitable habitat and the number of responses is counted. Crucially, the survey methods for this single visit survey must be the same as that for response rate calibration (playback call volume, duration, survey period etc).

The number of responses to playback (n) in single-survey areas is then converted to the number of AOS as follows: AOS = n / RR, where 'RR' is 'response rate'. Habitat-specific response rates are used whereever possible.

Either all potentially suitable habitat is visited (as in 2016) or a known subset area of suitable habitat is surveyed.

5.1.3. Area extrapolation

If a subset of suitable habitat has been surveyed, this must be extrapolated to the total area of available habitat on the island. Areas extrapolation was used in 1995, 2001 and 2003. A small area extrapolation was carried out in 2016 to estimate AOS in an unstable area of rockfall at The Quarry.

5.1.4. Population estimate calculation

The number of playback responses noted in single-survey sites is summed for each habitat type. The number of AOS in a single-survey site is calculated as follows:

AOS = n responses x (1/response rate), where (1/response rate) is referred to as the 'correction factor', calculated separately for different habitat types (rockfall vs walls in the case of Skokholm).

Responses from response rate calibration sites are included in this step: the mean number of reponses detected in the calibration visits is used in the same way as a single visit.

To calculate the error of the population estimate, we have used a new bootstrapping method to calculate upper and lower confidence limits of the population estimate (Padget et al. in prep). This is an improvement on current methods, which simply apply the upper and lower confidence limits of the response rate to the number of playback responses, an approach that will overestimate the error. The new method substantially reduces the error of playback population estimates.

5.2. Recalculation of whole-island censuses

1995 (Vaughan and Gibbons, 1996)

Response rate: 1995 calibration plots were restricted to wall habitat, and only two diurnal visits were made – this is too few visits for our ML method, therefore the Du Feu method (du Feu, 1983) was used, which can be used with as a few as two visits to a calibration plot. A response rate could be calculated, but only with very wide confidence intervals: 0.249 (95% CI 0.14-0.66).

Survey: Single visits were made to 11 of 47 sites considered suitable for breeding, in addition to calibration sites. The area surveyed in 1995 was extrapolated to the total area of “suitable” habitat on Skokholm as laid out by Vaughan & Gibbons (1996), and adopted by Sutcliffe (2010).

Population estimate: Recalculation of the population estimate with confidence intervals is possible 4567 AOS (95% CI 1723-8122), but with such a large error the usefulness of this estimate is limited.

Table 1. 1995 number of Apparently Occupied Sites on Skokholm

Habitat type	Factor	**Estimate** (Du Feu Estimate)	**Lower 95% CI** (Du Feu Estimate)	**Upper 95% CI** (Du Feu Estimate)
Rockfall	Response Rate	0.25	0.14	0.66
Rockfall	Correction Factor	4.02	7.14	1.52
Rockfall	AOS estimate	4143	1563	7368
Walls	Response Rate	0.25	0.14	0.66
Walls	Correction Factor	4.02	7.14	1.52
Walls	AOS estimate	424	160	754
Whole-island total	**AOS estimate**	**4567**	**1723**	**8122**

The limitations are: 1. wall response rate was used for all island habitat, which is mostly rockfall (later studies show playback response rate is much higher in wall than rockfall, which would extrapolate to a lower number of AOS), and 2. only a small amount of calibration data available (just two playback visits to a small number of AOS).

2001 (Vaughan, 2001)

Response rate: In 2001 the calibration method was developed to include habitat variation (rockfall and walls), but unfortunately the Maximum Likelihood method could not carry out response rate calibration for habitats separately. Rockfall and wall calibrations were thus combined (these were the only calibration data available). This response rate, and its associated uncertainty, was used as a correction factor. Sampling error from the extrapolation to un-surveyed sites was combined with sampling error from response rates to provide a global confidence interval for each habitat. The global confidence interval for the island was computed by taking random combinations of the different habitat bootstraps and summing them. A different number of playback visits was made to each habitat (rockfall = 8, walls = 6) therefore the first six visits could be included in response rate analysis.

Survey: Single visits were made to a subset of sites considered suitable for breeding, in addition to calibration sites. The number of responses noted in the area surveyed in 2001 was extrapolated to the total area of “suitable” habitat on Skokholm as laid out by Vaughan & Gibbons (1996) and judged to be reasonable by Sutcliffe 2010).

Population estimate: Our recalculation of the 2001 census data estimates the population at 2391 AOS (95% CL: 1988-3268).

Table 2. 2001 number of Apparently Occupied Sites on Skokholm

Habitat type	Factor	Estimate (ML Estimate)	Lower 95% CI (ML estimate)	Upper 95% CI (ML estimate)
Pooled habitats	Response Rate	0.51	0.14	1
Pooled habitats	Correction Factor	1.98	7.35	1
Rockfall	AOS estimate	1823	1414	2503
Rockburrow	AOS estimate	396	278	573
Walls	AOS estimate	172	108	255
Whole-island total	**AOS estimate**	**2391**	**1988**	**3268**

Note: Due to the low number of calibration sites, response rate calculation was carried out on pooled calibration data from rockburrow and wall habitats

2003 (Thompson 2005)

Thompson made two analytical decisions (reviewed by Sutcliffe, 2010) that produced a low population estimate:

- Firstly, the difference in response rates between habitats identified by Vaughan (2001) was dismissed, applying a mean response rate that weighted the population estimate towards the higher response rate of walls, and thus leading to a lower whole-island population estimate
- Secondly, Vaughan's estimation of suitable habitat areas in the 1995 census (based on advice from a CCW geologist) was dismissed and a replacement area estimation used based on local experience

We have reviewed these two approaches, and accept Sutcliffe's (2010) conclusion that the 2003 population estimate was too low. We have thus reanalysed Thompson's data to produce habitat-specific response rates using the area extrapolations from the 1995 census, and habitat-specific response rates.

Response rate: The 2003 census (Thompson, 2005) followed the same method as in 2001, with more investment in response rate calibration: each calibration site was visited at least 10 times. We used habitat-specific response rates, calculated as described for 2001, for walls and rockfall+rockburrow as two habitat types. Rockburrow was judged too subjective to identify, and response rates not sufficiently different to warrant separate calibration.

Survey: Single visit surveys were conducted in a subset of each habitat type, and the appropriate response rate for each habitat applied. The number of AOS estimates in each area of surveyed habitat was then extrapolated to the total area of that habitat on Skokholm to estimate the population, using the habitat area estimations in Vaughan & Gibbons (1996).

Population estimate: Our recalculation of the 2003 census data estimates a population size of 1308 AOS (95% CL: 936-2003).

Table 3. 2003 number of Apparently Occupied Sites on Skokholm

Habitat Type	Factor	Estimate (ML estimate)	Lower 95% CI (ML estimate)	Upper 95% CI (ML estimate)
Rockfall*	Response Rate	0.37	0.26	0.49
Rockfall*	Correction Factor	2.69	3.82	2.06
Rockfall*	AOS estimate	915	651	1289
Walls	Response Rate	0.37	0.17	0.63
Walls	Correction Factor	2.71	2.77	1.59
Walls	AOS estimate	384	165	896
Whole-island total	**AOS estimate**	**1308**	**936**	**2003**

* Including rockburrow

Despite the greater field effort invested in response rate calibration, this estimate has wider confidence limits than the 2001 estimate, and is markedly lower (although the confidence limits still overlap, indicating no significant difference between the estimates). This contrasts with Sutcliffe's (2010) recalculation of the 2003 data, which estimated the population at 2500 AOS.

Examining the survey data in the 2003 census report reveals no reason that this should be the case, but is not surprising since the densities of storm-petrels detected in the single visit surveys were consistently lower than other years. This is despite a similar response rate being measured at the calibration sites. The number of playbacks at single visit surveys seem to be lower, which might be where the problem arises. Our best guess is that in 2003 a different set of criteria were used to decide whether to carry out playback at a potential nest site. A higher bar to reach before deciding to use playback would miss some birds, hence reduce the apparent density and explain the results. Alternatively, for some reason (i.e. tape used or distance playback was made from) there was a different realised response rate in the single visit survey than in the calibration, although this does not explain the low total number of playbacks recorded for some areas, especially at Windmill Bluff – a very large area with low a low number of responses in 2003. Hence, we removed this from the extrapolation calculations in our analysis, but we should be clear that this does not solve the problem entirely and still leaves us with a relatively uninterpretable result.

2016 (Wood et al., 2017)

Response rate: Habitat-specific response rates were calculated for walls and rockfall separately, sites in each habitat were visited 10 times. Response rates varied quite widely between habitats (Fig 1a & b).

Survey: Almost all apparently suitable habitat was surveyed with a single playback visit, so with no area extrapolation the confidence limits were calculated from bootstrapping applied only to response rate in each habitat type.

Area extrapolation was required in two small cases, using infrared night vision equipment for a handful of small coastal sites, and an area extrapolation for an inaccessible area of the Quarry. We consider this to be minor and did not include this in error bootstrapping, simply adding a total of 141 additional AOS (including 4 occupied nestboxes) to the AOS estimates from playback approach (Table 4).

Table 4. 2016 number of Apparently Occupied Sites on Skokholm

Habitat Type	Factor	Estimate (ML estimate)	Lower 95% CI (ML estimate)	Upper 95% CI (ML estimate)
Rockfall	Response Rate	0.22	0.092	0.38
Rockfall	Correction Factor	4.55	10.9	2.67
Rockfall	AOS estimate	2146	1833	2343
Walls	Response Rate	0.39	0.14	0.68
Walls	Correction Factor	2.71	2.77	1.59
Walls	AOS estimate	100	91	119
Nestboxes & Inaccessible areas*	AOS estimate	141	Blank	Blank
Whole-island total	**AOS estimate**	**2383**	**2080**	**2589**

* Inaccessible areas were surveyed in two ways: (i) coastal areas of rockfall were observed once using an infrared image intensifier and a correction factor applied from infrared observation at a rockfall calibration site (North Haven), and (ii) a dangerous area of The Quarry that suffered a was surveyed using area extrapolation from the rest of The Quarry.

Population estimate: The recalculation of the 2016 census estimates the Skokholm Island population at 2383 AOS (95% CL 2080-2589).

5.3. Population estimate for the Skomer, Skokholm and the Seas off Pembrokeshire SPA

The SPA population of European Storm Petrels is almost entirely found on Skokholm Island, with a much smaller population on neighbouring Skomer Island. There may be small breeding populations on Grassholm Island and Middleholm but these islands have not yet been surveyed systematically. In 2016, both Skokholm and Skomer were surveyed using the same methodology at the same time – the first time this had occurred (Wood et al., 2017) – giving an opportunity to estimate the SPA population.

Using our new analytical method we recalculated the 2016 population estimate for Skomer as 201 (95% CL 155-389) AOS. Unfortunately the data from previous census work on Skomer [ref] was not available so we were unable to carry out a reanalysis of population change on Skomer, but as the population is and has been reported to be relatively much smaller than Skokholm we are content that our reanalysis of population change on Skokholm Island is representative of the wider SPA population.

By adding the 2016 Skokholm population estimate of 2383 AOS (95% CL 2080-2589), the 2016 estimate for the breeding population of European Storm Petrels in the Skomer, Skokholm and the Seas off Pembrokeshire SPA is thus 2584 AOS (95% CL: 2282 - 2885).

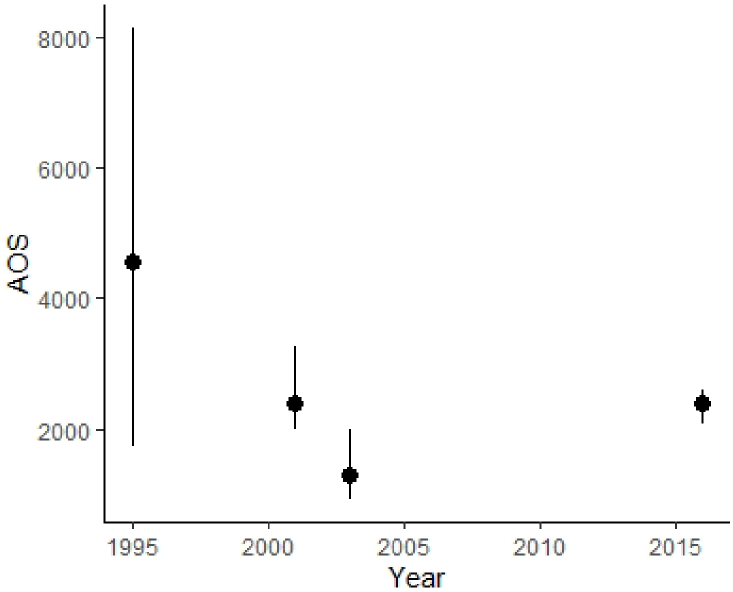
6. Assessment of population change

6.1. A stable population

Our reanalysis of historical census data indicates that the whole-island population of European Storm Petrels on Skokholm Island has not changed significantly between 1995 and 2016 (Fig 2), and therefore no overall decline can be concluded. The current conservation status for European Storm Petrels in Wales as amber-listed (Johnstone and Bladwell, 2016) remains justified for this migratory species breeding on a limited number of island sites with such vulnerability to introduced ground predators, amidst concerns about declines elsewhere in their breeding range.

Figure 2. Population estimates from 1995, 2001, 2003 and 2016 censuses

The apparent decline 1995-2003 is not supported by the data as confidence limits of population estimates overlap. Note the narrow confidence limits of the more reliable 2016 census, reflecting the combination of improved survey methodology and refined analytical techniques.



6.2. Historical perspective

The focus on walls for population estimates may have given a misleading impression of decline in an otherwise stable population. As Sutcliffe (2010) points out, Scott found "…large numbers of birds in all the wall systems, in The Quarry and, by inference, across the whole island." Walls were convenient to study and at the time fieldworkers had no way of knowing they were different to rockfall habitat, but it appears that the suitability of walls has declined since the 1960s (perhaps as stone walls gradually weather, collapse and become filled with soil) and with it the number of storm petrels nesting in them, while the population nesting in The Quarry (and presumably other rockfall sites) has remained relatively stable. Very few birds have been located in soil burrows since Scott's time when such nest sites were frequently used.

The degradation of the wall system has reduced the amount of available breeding habitat for Storm Petrels on Skokholm. While the natural rockfall cannot be managed, provision of artificial wall habitat is feasible. The pioneering spirit of island wardens continues with 'The Petrel Station', an artificial wall of nest-boxes bult in 2017 near The Quarry, in which successful breeding first took place in 2019. This provides the opportunity to increase not only available habitat, but also a valuable opportunity for the monitoring of reproductive success and breeding adult survival, a valuable opportunity to study the ecology of European Storm Petrels.

6.3. Analytical challenges during reanalysis

6.3.1 Area estimates of suitable habitat

Sutcliffe (2010) thoroughly summarises the methods of habitat area estimations and extrapolation of survey data in censuses in 1995, 2001 and 2003. We accept his judgement on the lengths of walls and areas of rockfall habitat that may be suitable for breeding Storm Petrels. In some cases area extrapolation is unavoidable, if the breeding colony is too dangerous to survey or the area to be surveyed is too large to be covered. We recommend that area extrapolation is avoided as far as possible to avoid a loss of accuracy in calculating total population size, instead surveying all suitable habitat as in the 2016 survey (Wood et al. 2017). If extrapolation is necessary it should be carried out as systematically as possible to avoid bias (Bolton et al., 2021).

6.3.2. Survey dates

Calibration data were collected on variable dates in each census – it is valuable to calibrate response rate at a large number of sites, but logistically challenging to complete all sites on the same day. As far as possible, calibration visits should be made on the same or adjacent dates.

All sites should receive the same number of visits, because the calculation methods in the Shiny app "Stormie" (Padget et al., in prep) cannot currently accommodate variable numbers of visits and in some cases additional calibration visit data had to be discarded – it is better for all sites to receive seven visits than for one half to receive five visits and the other half ten.

6.3.3. Data presentation and archiving

Locating original census data and interpreting methods have been the largest challenges in this reanalysis. We have used a consistent framework in presenting previous census data, clarifying the steps in the calculation of population estimates and making the original field data available as print and online appendices.

We strongly recommend this framework approach is followed in future, to enable future reanalysis as analytical techniques continue to evolve.

7. Recommendations for future population monitoring

7.1. Maintain annual transects

The annual transect surveys carried out since 2010 should be continued, although fewer than ten playback visits to each transect may be sufficient to maintain the accuracy of the transect population estimate. This is beyond the scope of this report and requires simulation study.

7.2. Decadal whole-island census

Although demanding of resources, it is essential to validate population change observed from annual transect surveys by the use of a whole-island playback census, on a decadal basis.The frequency of such census work used to be dictated by the legal reporting requirements of the EU Birds Directive; the post-Brexit reporting cycle has yet to be established but our recommendation is that it should not become less frequent. Now that a reliable whole-SPA census has been undertaken for European Storm Petrels, a benchmark exists for future census using comparable methods.

Such census work should include the following considerations:

7.2.1. Survey of all available breeding habitat

Access to some areas of Skokholm has its challenges, but given the relative accessibility of most subcolonies, all apparently available habitat should be surveyed once using call playback. Knowledge of the distribution of rockfall and scree visible from a coastal boat was especially useful in this regard (M.J. Wood pers. obs.), and the use of aerial imagery to define and plan survey of large areas of habitat such as The Quarry (G. Eagle & R. Brown pers.comm.).

When combined with a pre-census check for the occupancy of inaccessible potential new subcolonies using night vision equipment (Wood et al., 2017), it shoud be possible to identify all subcolonies of more than 5-10 AOSs.

7.2.2. Inclusion of inaccessible areas

Infra-red imaging equipment has been used to estimate the numbers of AOS in inaccessible areas by extrapolation of flight activity, by calibrating nocturnal flight activity with known occupancy at accessible sites (Wood et al., 2017). This was carried out using a single observation of flight activity to calibrate repeated playback visits: in future whole-island censuses we recommend that diurnal playback and nocturnal flight activity receive the same number of repeated visits (i.e. to match ,currently ten) to improve accuracy and allow calculation of Confidence Intervals for the flight:AOS calibration. This approach has been explored on a wider scale (Perkins et al., 2018) and can be useful to include areas too dangereous for fieldworkers to access.

7.2.3. Accurate calculation of response rate to call playback

Response to call playback is known to vary between years, habitat types, subcolonies, and with date within a season (Bolton et al., 2017, Ratcliffe et al., 1998, Wood et al., 2017) therefore these potential influences on the precision and accuracy of the response rate must be considered in future census work.

To enhance the accuracy and minimise the error of response rate calibration, we specifically recommend:

- Using the same playback equipment and call for calibration and survey...
- in a sufficient number of playback calibration visits (currently ten)...
- to a sufficient number of AOSs (at least 50)...
- in each appropriately selected habitat (currently rockfall vs walls)...
- with consideration of the effect of advancing date as the survey progresses

This latter consideration is not considered important on Skokholm in 2016, but this should be verified in each whole-island census.

8. Acknowledgements

"…the work, although demanding, was a total pleasure. To sit in the darkness surrounded by a choir of singing Stormies was quite unforgettable." Michael Betts, October 1994

Monitoring European Storm Petrels is demanding but rewarding work, which might explain why so many fieldworkers have persevered over many years to develop methods for this enigmatic species. We thank every sleep-deprived one of them.

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10. Appendices

Data Archive Appendix

If you are interested in analysing the data from this project we welcome contact to share our insights from analyses and familiarity with Skokholm island terrain, which may prove useful to your study. Please contact mjwood@glos.ac.uk

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

Further copies of this report are available from library@cyfoethnaturiolcymru.gov.uk