Conservation Breeding of the Spoon-billed Sandpiper (*Calidris pygmea*) at WWT Slimbridge

WWT Project Report, Review and Recommendations, 2011-2021

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Disclaimer:

This document is a compilation of the knowledge gained by all contributing parties of the conservation breeding project for Spoon-billed sandpipers at WWT Slimbridge. This document should be used in conjunction with continually evolving practices in captive wader care. The recommendations provided reflect experience gained throughout the project and are not exclusive. Recommendations are intended to provide a base of consideration for future conservation breeding activities.

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Cover Image:

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Executive Summary

Conservation breeding programmes aim to create self-sustaining populations of species in a captive setting. These serve as ark populations acting as insurance against wild extinction, with the potential to bolster wild populations, and if necessary, reintroduce species when appropriate.

The Critically Endangered Spoon-billed sandpiper *Calidris pygmaea* (SBS hereafter) is a small migratory wader that inhabits parts of the East Asian-Australasian Flyway. It has a range of approximately 8,000km from far northeastern Russia where it breeds, to Southeast Asia where it resides in winter. Research in the early 2000s suggested the population was precariously small with a rapid rate of decline, and under imminent threat of extinction. Causes of decline were numerous and under investigation. Conservation measures were in development or early stages of deployment with their effect not likely to be in time to prevent extinction. No captive population of SBS existed at the time, though other small waders were being housed and bred successfully in captivity. Action was needed to reduce the risk of global extinction. A captive population offered security for the species, with the added possibility of returning subsequent chicks to the wild population.

A feasibility study, project proposal, and project justification were developed in late 2009 through to late 2010. Collaboration between multiple organisations began soon after, gathering knowledge and gaining experience, trialling methods and protocols needed to ensure success of the programme. In the summer of 2011, planning and preparation came to fruition with the collection of the first cohort of eggs, with the chicks arriving at WWT Slimbridge later that year. Another trip was made in 2012 to bring back additional eggs, completing formation of the first conservation breeding population of SBS.

It was known that keeping and breeding SBS in captivity would come with challenges. Their vast range occupies multiple habitats and climates, and varying photoperiods at different times of year would be difficult to replicate at WWT Slimbridge, in rural Gloucestershire, United Kingdom. Basing techniques on the knowledge and experience of working with other small waders (and other avian species more generally), WWT took an adaptive learning approach, culminating in SBS breeding in captivity for the first time in 2016. In total 19 eggs were laid over four years (2016, 2018, 2019, 2021), producing seven hatchlings, resulting in three fledglings joining the adult flock.

Unforeseen challenges were encountered throughout the project, with unexpected deaths through flight collisions with the aviary, calcium deficiency in eggs and chicks, and a stress-induced infection heavily affecting the remainder of the captive population in later years. Though these challenges were moderated, and some rectified, they prevented this captive population from becoming self-sustaining, with the death of the last female in 2021 and last males in 2024.

It is not currently known when the last opportunity might be to collect eggs for any new conservation breeding population, which should be addressed at a matter of urgency. This needs to be paired with impact assessments on the local and global population. Similarly, research on wild SBS diets would improve captive nutrition through body condition and likely improve breeding success.

From this project we have learnt that consistent and quality year-round care is ultimately the path to achieving a self-sustaining captive population. Maintaining circannual rhythms is key to maintaining good health and welfare. This is best achieved through regular and constant annual photoperiod, coupled with appropriate seasonal temperatures from project initiation. Careful consideration is required for facility and aviary design based on the host's location, balancing trade-offs in terms of climate, biosecurity, and bird welfare. Quality of light and pair compatibility appear to be significant

factors in breeding success. As well as a hands-off approach (using remote assessment methods) for health and welfare monitoring, thorough record-keeping and ongoing review will increase the knowledge base for keeping and breeding SBS in a captive setting. Hosts experienced in wader husbandry and breeding will be in a good position to host a new captive population and more likely to be able to provide the recommendations listed in this document.

Without this conservation breeding project, its *in-situ* sister project would not have been conceived. Spoon-billed sandpiper headstarting was developed after the 2011 egg and chick collections and transportation. The resilience of eggs and chicks showed it was possible to incubate and rear them on-location for direct release back into the wild at point of fledge.

As a high-profile species, these projects have also contributed immeasurably to East Asian-Australasian Flyway species and habitat conservation awareness and initiatives, from the public to governments.

Since the project began, the state of the wild population has become better understood and although the rate of decline appears to have reduced they are still threatened with extinction without further conservation measures. An auxiliary population is as important now as it was when conservation breeding of SBS first began. We hope the following information can be applied not only to projects for other species, but ultimately to the next populations of SBS for conservation breeding.

1. Introduction

1.1 Aims of the document

The primary purpose of this document is to aid in the preparation of feasibility studies and decision making for future SBS conservation breeding attempts. It aims to do so by achieving the following:

- Report/document events during the project from implementation to final viable breeding year (taken largely from the Annual Report summaries 2011-2021, Annex 5);
- Review overall husbandry and practices throughout the project, with comparison to what wild SBS would experience (Chapter 2. Spoon-billed sandpiper Husbandry); and
- Provide recommendations for future hosts based on evidence and experience during the project (Chapter 3. Considerations and Recommendations).

Note that years subsequent to 2021 have been omitted as non-breeding years, though data for these years (and raw data in most cases for all years) is still obtainable from WWT.

Furthermore, the SBS conservation breeding project has generated over a decade's worth of knowledge and experience that has been applied to multiple other conservation breeding and headstarting projects (e.g. see the Project Godwit Headstarting manual; Hiscock & Costa, 2023).

1.2 Spoon-billed sandpiper

1.2.1 Description

Spoon-billed sandpiper have a short characteristic spatulate-tipped bill on a small calidrid body (Figure 1). In winter they have grey head and dorsal plumage, and white ventral plumage (the latter apparent all year-round). In summer the grey is replaced by mottled rust-red feathers covering the head and neck, becoming more sparse down the neck and chest. Rust-red surrounds a dark centre on feathers on the back (fringed with white when freshly moulted). Juveniles are duller showing grey-brown dorsal plumage until their first moult into winter plumage. The bill and legs are silky black all year round. Males and females are the same in appearance but with females on average being slightly larger. According to biometrics recorded by WWT on captive birds (in-house measurements of adult SBS, 2011-2024) adults weigh between 26-35g, depending on sex and time of year. They stand at approximately 100mm in height, with a body length of around 130mm. The wingspan ranges from 170-240mm, with an average left wing measuring between 70-100mm.

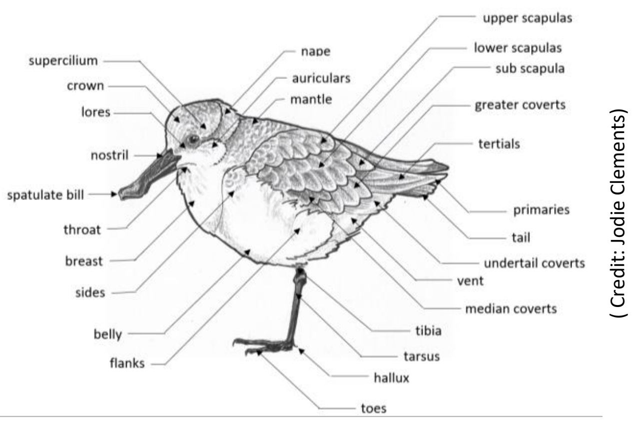


Figure 1 – SBS anatomy

1.2.2 Range

Spoon-billed sandpiper breed on coastal tundra in far northeastern Russia from the easterly reaches of the east Siberian Sea to the Bering Sea of the coast of the Chukotka Peninsula southwards to the Kamchatka Peninsula (Figure 2). They migrate over land and sea making several stopovers for refuelling in Russia, Democratic People's Republic of Korea, Republic of Korea, and China where they will also undergo moult. Spoon-billed sandpiper winter on coastal mudflats in Myanmar, Bangladesh, Thailand, Vietnam, and southern China.

Figure 2 – SBS distribution

1.2.3 Population estimates

The first population estimate for SBS in 1977 suggested there were between 2,000-2,800 pairs (Rose and Scott, 1977). Research published in 2002 suggested only 1,000 pairs remained based on surveys undertaken at visited breeding grounds in 2000 (Tomkovich *et al.*, 2002). Monitoring at the known breeding grounds continued and a new estimate of approximately 402-572 pairs was suggested in 2004 (Syroechkovskiy, 2004). In 2010 a new estimate was made of 120-220 pairs, suggesting a rate of decline of 26% per year between 2002 and 2009 (Zoeckler, Syroechkovskiy and Atkinson, 2010). The effort to mark SBS was increased going forwards to give additional and more accurate estimates of the population. In 2016 it was suggested that there were 420 mature individuals (210-228 pairs) based on data from a stopover site, giving an annual decline rate of 9% between 2009 and 2016 (Clark *et al.*, 2018). In 2021 this estimate was updated with data from additional years to give an estimate of 490 mature individuals (Green *et al*. 2021). This has been updated again in 2024 encompassing additional subsequent years to give an estimate of 443 mature individuals (Green *et al.,* 2024). Over time estimates have become increasingly more accurate and although SBS are not in as steep a decline as once thought, they are still fast approaching extinction.

In 1988 SBS were listed on the IUCN Red List as 'Threatened' then moved to 'Vulnerable' in 1994. A sharp decline warranted a new status in 2004 of 'Endangered' and initiated further monitoring and research in causes of decline. They were first listed as 'Critically Endangered' in 2008 and remain so today.

1.3 Justification for conservation breeding

The small population size and rapid rate of decline during the early 2000s suggested that SBS would become extinct by 2020 (Zoeckler, Syroechkovskiy and Atkinson, 2010). Reasons for decline were still under investigation, and measures to address this decline were still being developed or in early implementation. Effectiveness and population responses to these measures were also uncertain. Other small *Calidris* species similar to SBS had been kept and bred in captivity at the time, and historically (AZA Charadriiformes Taxon Advisory Group, 2014), so it appeared feasible to attempt to hold a conservation breeding population of SBS in captivity. This would reduce the risk of complete global extinction while *in-situ* conservation measures took effect. A self-sustaining population would also potentially supplement the wild population, and in the event of wild extinction have the capacity for reintroducing the species when appropriate. Analysis was conducted to determine the effect of removal of individuals on the wild population: taking eggs (compared to later life stages) was deemed to be least impactful to the donor population and most suitable for the purpose of captive breeding, particularly if implemented immediately given the rate of decline assumed at the time. Additionally, if eggs were collected early in the season, females would also have the opportunity to lay again that year. Producing egg collection and rearing protocols could be (and was) developed through other common small wader species prior to use on SBS. Some funding was already available, and WWT was the institute with the necessary avian conservation breeding experience to take on the project.

1.4 Approximate costs

Approximately £150,000 was spent building the facility on greenfield land. This included all groundworks and construction of indoor (portal, kitchen, Room #1 and #2) and outdoor facilities (Annexes An#1 and An#2, Polytunnels P#1 and P#2), as well as pest/predator proofing. The cost also included materials to cover outdoor structures, plumbing, electrics, and (initial) substrates to furnish aviaries. It did not include egg collection trips, incubation and rearing equipment, licensing and permits, or staff time. Additional significant costs later in the project included CCTV, netting replacement, substrate replacement, light enhancement, additional external breeding aviary, misting system, extractor fan installation (and removal), and roof replacement. Running costs were approximately £20k-25k per year (excluding staff time and utilities costs).

1.4.1 Staffing

Day to day care of the captive SBS needed three full time staff minimum throughout the year for husbandry and maintenance (including record keeping) in a stand-alone biosecure facility, with additional support when these staff took annual leave or had SBS chicks to rear (eggs/chicks remained separate initially where possible to reduce health risks on the eggs/chicks posed by the adults). In addition, there was significant involvement from veterinary staff on a routine and ad hoc basis, as well as support and time from staff in other departments in WWT (administration, research/evidence, finance, etc.) to maintain and progress the project.

1.5 Permissions and licenses

The whole process from initial project conception to the first arrival of SBS at their final destination took approximately two years. Essential administration for the project spanned multiple countries and organisations, including governments and governing bodies. This included proposals, justification, methodology, and permitting processes through Russian government agencies (with support of other relevant authoritative organisations) for handling and transporting eggs/chicks, licencing to take chicks and/or eggs from Anadyr to Moscow and export to the UK (pre-travel health checks/swabs were required). For arrival into the UK, an import licence and Balai approval (animal health conditions determined by the Balai Directive for the movement and import/export of animals) was required from the Animal Plant and Health Agency. International travel was facilitated by an outsourced company (JCS Livestock - James Cargo Services Ltd.).

1.6 Advice sought

In the planning phase of the conservation breeding project, collections and institutions that housed/bred small wading birds were identified and several contacted and/or visited before the project began. Throughout the project some of these were revisited and others came to visit the SBS facility. Additional expert advice was also sought in various aspects of husbandry as knowledge gaps became apparent over time. Table 1 is a full list of experts/advisors contacted.

In addition, meetings were held annually involving staff caring for the SBS, relevant stakeholders, and advisors, to assess the breeding season and husbandry as a whole and discuss and decide modifications to be made short and long-term to further breeding success.

Table 1 – Specialist advice sought

Individual	Organisation	Location	Expertise	Visited SBS facility?	WWT visited the advisor	Timing
Achim Johann	NaturZoo Rhiene, previous Chair of the European Association of Zoos and Aquaria (EAZA) Charadriiformes Taxon Advisory Group (TAG)	Germany	Captive breeding of Ruff	Yes	Yes	2012-13
Amanda Ferguson	Zoological Society of London (ZSL)	UK	Animal nutrition	Yes		2016-17
Andrew Digby & Daryl Eason	Department of Conservation (DOC)	New Zealand	Kakapo science and husbandry, Vitamin D and diet			2017
Andrew Owen	Chester Zoo	UK	Curating birds	Yes		2012
Barbara Helm	University of Glasgow	UK	Chronobiology, photoperiod of migratory birds	Yes		2013-15
Chrissey Kelly	Pensthorpe Conservation Trust	UK	Captive breeding of waders	Yes		2013-17
Evgeny Syroechkovskiy, Elena Lappo & Pavel Tomkovich	BirdsRussia	Russia	SBS breeding in the wild	Yes		2015
Francis Baines	Independent / UV Guide UK	UK	UV lighting in reptile husbandry	Yes		2016-24
John Ewen	IOZ, Zoological Society of London (ZSL)	New Zealand & UK	Plumage colouration (dietary basis for)			2015
Kai Clausen	Private breeder	Germany	Captive breeding of waders		Yes	2012
Kris Carrein & Geer Scheres	Walsrode Bird Park	Germany	Curating birds	Yes		2013
Laura Gardner	Zoological Society of London (ZSL)	UK	Curating birds, nutrition, husbandry			2014-17
Linda Henry	SeaWorld San Diego	US	Provision of UV lighting for birds, in particular penguins			2014-15
Liz Brown	Department of Conservation (DOC)	New Zealand	Captive breeding of Black Stilts			2011-24
Ludger Brehmer	Private breeder	Germany	Captive breeding of waders	Yes	Yes	2011-24
Mark Roberts	WWT Slimbridge	UK	Captive keeping/breeding waders	Yes	Yes	2011-24
Mark Stidworthy	International Zoo Vet Group	UK	Bird pathology and histology			2011-24
Michael Mace	San Diego Safari Park	US	Curating birds	Yes		2016
Nigel Clark	British Trust for Ornithology (BTO) / Independent	UK	Knowledge of waders	Yes		2011-24
Nigel Simpson	Bristol Zoo / Wild Place Project	UK	Curating birds	Yes		2014
Paul Zwetsloot	Private breeder	UK	Captive breeding of waders	Yes	Yes	2011-24
Rhys Green	Royal Society for the Protection of Birds (RSPB) / Independent	UK	Knowledge of waders	Yes		2011-24
Robert Elner	Environment Canada	Canada	Biofilm, wild diet			2017
Simon Matthews	Al Wabra Wildlife Preservation	Qatar	Curating birds	Yes		2013
Tim Birkhead & Nicola Hemmings	Sheffield University	UK	Egg development		Yes	2016-21

1.7 Expeditions to collect eggs/chicks

1.7.1 2011 Expedition

Twenty-five eggs were collected from the breeding grounds in the vicinity of Meinypil'gyno, Chukotka, late June/early July. They were collected already partially incubated by their parents as it was believed this would provide safer (physical) transit of the embryos compared to transporting fresh eggs. Nicol-Harper *et al.* (in prep.) later observed that later egg collections in SBS were associated with higher hatch rate. It has also been suggested that transport type and distance travelled may affect hatch rate (E. Loktionov, 2023, pers. comms.). The eggs continued incubation artificially in a house in the village where eight hatched. Five eggs ceased developing and were left in Meinypil'gyno for post-mortem. On 8 July the chicks and hatching eggs were transferred in portable incubators via boat to Anadyr over several days. Nine eggs hatched on the boat. Of the remaining three eggs, two hatched in Anadyr and one was dead in shell.

The chicks were initially reared indoors in an apartment in the town and transferred to outdoor pens between 10 and 14 days old. Sixteen chicks were transferred to Moscow Zoo on 18 August aged between 35 and 44 days via domestic flight to undergo a 30-day quarantine before being transferred to the UK. However, their departure was delayed approximately two months due to a case of psittacosis in Moscow Federal City.

On 11 November, 13 SBS were flown to Heathrow airport, then driven to WWT Slimbridge quarantine facility to start 30 days of quarantine. All 13 SBS were then transferred to the Spoon-billed sandpiper facility (hereafter called the SBS facility) at WWT Slimbridge.

Project photographs from the 2011 expedition and transportation to Slimbridge (UK) shown in Figure 3.

3a. WWT SBS Team (2011)

3b. Egg collection in Meinypil'gyno (June 2011)

3c. Egg transportation. Loading portable incubator and transported via quad bike (June 2011)

3d. Egg weighing in incubation house in the village (June 2011)

3e. Egg measuring (June 2011)

3f. Incubation (June 2011)

3g. Transporting eggs and chicks to the Heritage Cruise ship for transportation to Anadyr (July 2011)

3h. 'Hatchers' used to separate eggs close to hatching (July 2011)

3i. Incubation and rearing setup on the cruise ship (July 2011)

3j. 2011 cohort indoor rearing at a flat in Anadyr, Russia (July 2011)

3k. Outdoor rearing site, Anadyr (August 2011)

3l. Outdoor rearing units, Anadyr (August 2011)

3m. 2011 cohort holding at Moscow Zoo (August 2011)

3n. 2011 cohort holding at Moscow Zoo (August 2011)

3o. 2011 cohort arrival at Heathrow airport (November 2011)

3p. Set-up at QS (November 2011)

3q. Transferring to SBS facility (December 2011)

3r. Release into indoor room of SBS facility (December 2011)

(All photographs credit: WWT)

Figure 3 – Project photographs: 2011

1.7.2 2012 Expedition

In 2012 another expedition to the breeding grounds near Meinypil'gyno was undertaken to collect more eggs to increase the size of the captive flock at WWT Slimbridge, and to even out the sex ratio for better chances of breeding success (sex ratio at the time estimated based on size and weight only showed a male bias). It was decided to translocate eggs rather than chicks in 2012 due to the losses and health issues seen in the 2011 cohort during transport and quarantine, compared to the minor losses of transporting the eggs/embryos. Egg collections took place in June with the majority of incubation carried out at facilities in Meinypil'gyno. On 26 June the eggs left the village bound for the UK. They arrived at WWT Slimbridge on the 4 July, just a few hours before hatching began.

In conjunction, a new project began in Meinypil'gyno as a direct result of the 2011 translocation, to attempt to increase the population with direct conservation action using a technique called headstarting. Eggs are collected and artificially incubated *in situ*. The chicks are reared with minimal human contact initially in a house in the village before being acclimatised to the surrounding natural habitat in an aviary outside the village prior to being released into the wild during the southward migration of SBS and other waders. Headstarting is more efficient and immediately impactful in comparison to possible captive breeding outputs (see e.g. Canessa *et al.*, 2019, where adaptive management analyses revealed headstarting to be more impactful than captive breeding for an amphibian conservation programme).

Project photographs from the 2012 expedition shown in Figure 4.

4a. Expedition gear (for egg collection, captive breeding and headstarting) (May 2012)

4b. Egg transportation (June 2012)

4c. Transporting eggs for conservation breeding from Meinypil'gyno to Anadyr via helicopter (July 2012)

4d. Assistance from the flight captain in transporting the eggs (July 2012)

4e. Arrival to WWT QS (July 2012)

4f. Egg check upon arrival to QS in time for hatching (July 2012)

4g. QS setup

(All photographs credit: WWT)

Figure 4 – Project photographs: 2012

2. Spoon-billed sandpiper Husbandry

2.1 Facilities and Utilities

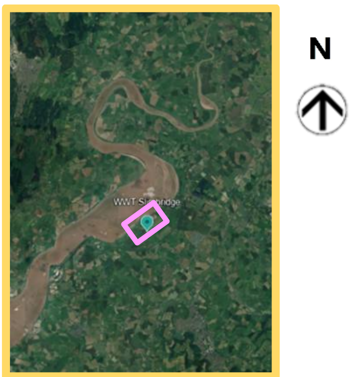
This section describes ever-present aspects of the project (location, facilities, water systems, and substrates). Any major changes made to these aspects over time are mentioned here but can be found in more detail in the Annual Report summaries, Annex 5.

2.1.1 Location

The SBS facility is located on the grounds of WWT Slimbridge Wetland Centre in the southwest of England on the eastern side of the River Severn (Figures 5a and 5b). The area immediately surrounding the facility is a managed nature reserve utilised by thousands of birds (mostly waterbirds) throughout the year, for passage, breeding, and wintering. A captive zoological collection consisting of birds from taxa across the globe are also held on site. Surrounding this is farmland of both arable and pastoral type (Figure 5c).

WWT Slimbridge was chosen/volunteered to host captive SBS largely due to the amount of experience already present through conservation breeding of avian species since the charity was developed in the 1940s. Funding and space was also available through WWT as well as established connections to other zoos and conservation organisations. The location of the facility (Figure 5d) was chosen as it was off public display to limit disturbance, and on a rested/greenfield piece of land that had not previously held captive birds. This area was already designated to the Conservation Breeding Unit for conservation action purposes (e.g. experimental rearing for release trials and release projects).

5a. Location in the United Kingdom (Google Earth)



5b. WWT Slimbridge location (Google Earth)

5c. WWT Slimbridge (Google Earth 2005 imagery)

5d. Conservation Breeding Unit – SBS facility inside white dashed line (Google Earth 2013 imagery)

Figure 5 – Location of the breeding facilities and surrounding area

2.1.2 Housing

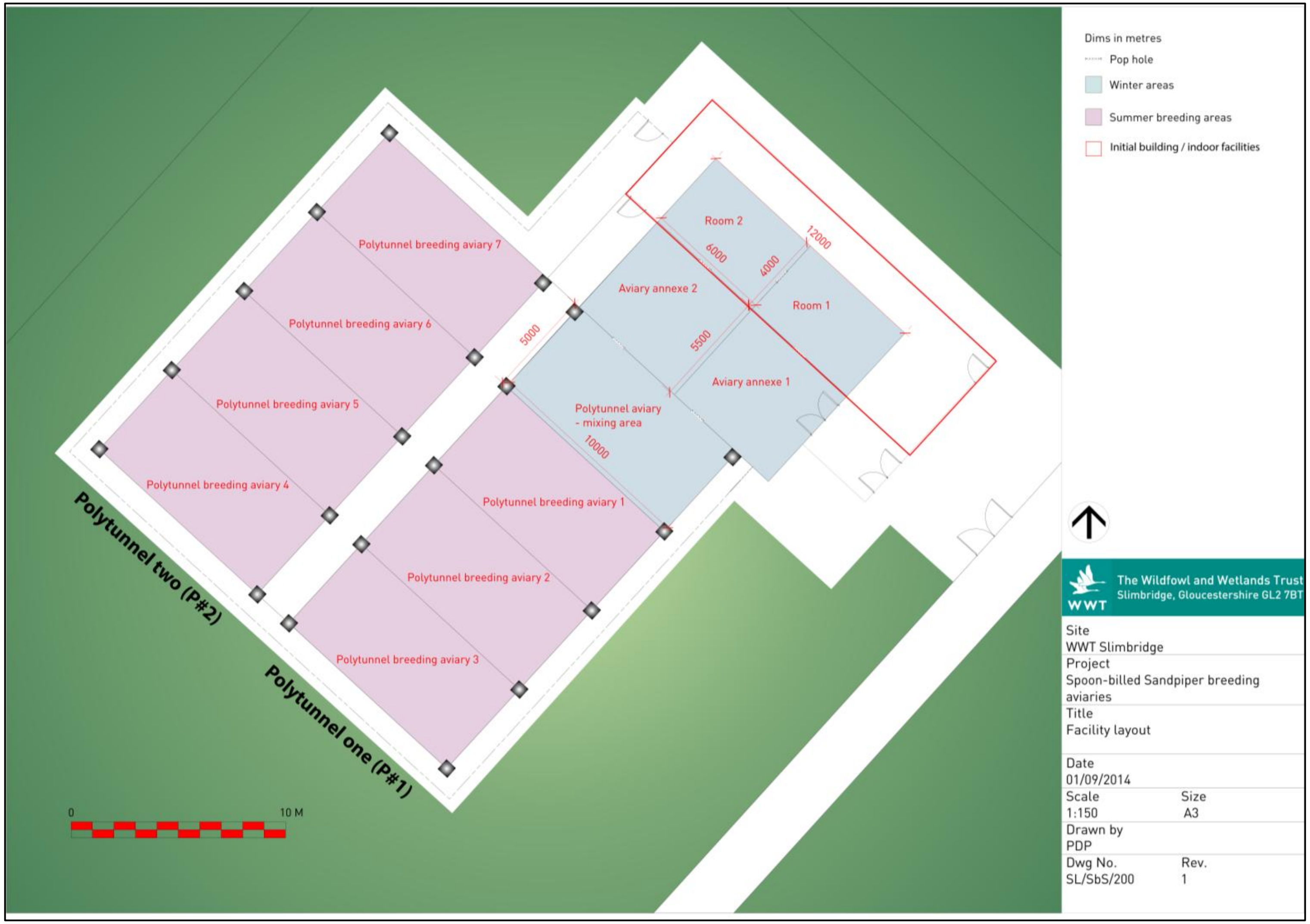


Figure 6 – Facility layout with dimensions and orientation

2.1.2.1 Construction

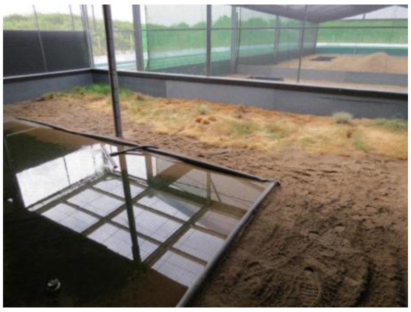
The facility (Figure 6) was purpose-built for the project to be all-encompassing; able to cater for the entire SBS lifecycle in a biosecure environment. Construction began in early 2011 starting with the indoor facilities to house the SBS through the first few months after arrival and to maintain them within the same building. One-way glass was fitted to view the SBS from the personnel corridor (Figure 7a). The rooms were equipped with infrared heat lamps, UV bulbs, fan heaters, and air filters (Figure 7b). The walls and ceiling were wipe-clean white plastic. In 2014 a tailor-made tent was installed as a soft inner lining of Room #1 giving a safer space for the SBS to occupy, as the installed equipment was noted to be a flight hazard. Collisions and blood on the walls of the rooms were seen frequently prior to this. Light fittings and flying hazards that were required to remain in SBS occupied areas were netted or covered with pipe lagging.

In March 2012 two aviaries were built annexed to the main building with temporary aviaries within them giving the SBS (2011 cohort) access to a small outdoor area until the main permanent annexes were complete. Later the permanent aviary annexes (An#1 and An#2) were made habitable by covering the inside with soft nylon netting to reduce risk of collision injury, the temporary aviaries within them were taken down giving the SBS a slightly larger outdoor area. The annexes had a clear corrugated impermeable plastic roofing, allowing sunlight in, keeping the worst weather out, and reducing biosecurity risks. Figure 7c-f show typical setup of the areas up until 2014, including An#1 set up for breeding purposes. Figure 7g shows typical setup that was used for most of the remainder of the project.

7a. One-way glass onto the rooms (2011)

7b. Initial room setup using gravel substrate (2012)

7c. Initial temporary annexe setup (2012)

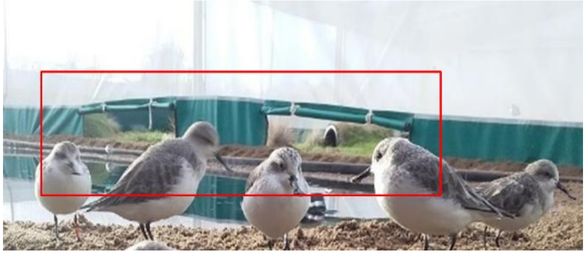


7d. Tundra type habitat added to An#1 wintering area for breeding season (2013)

7e. Tundra type habitat added to An#1 wintering area for breeding season (2013)

7f. Final room setup (2019)

7g. Final annexe setup (2019)



7g. An example of the pop-holes (within red box) used between breeding aviaries. The pop-holes between the MA, annexes, and rooms were solid doors, still about the same size, that needed to be entirely removed.

(All photographs credit: WWT)

Figure 7 – Photographs showing indoor and annexe facility layout

In 2012, two approximately 20m x 10m polytunnels (P#1 and P#2) started to be constructed (photographs in Annex 2), joined, along the long edge, by a personnel corridor. Guttering was added to collect and direct rainwater outside of the facility and pest/predator proof fencing. The short side of P#1 joined to the annexes, forming the SBS facility (Figures 8b and 8c). The polytunnels were predominantly for use in the breeding season, split into 10m x 5m aviaries with apexed ceiling (can be seen in Figure 8e) approx. 3.5m high in the centre and 2.3m on the short sides (Figure 8d) P#2 was initially used to house three pairs (2014) giving them a larger space of 15m x 10m (also apexed) (Figure 8e). This was split to trial much smaller aviaries the following year (Figure 8f), then reverted back to 10m x 5m. The section/aviary of P#1 joining the annexes was used in addition to the rooms and annexes to form the wintering area. This aviary (Figure 8g) was called the Mixing Aviary (hereafter abbreviated to MA) also 10m x 5m with an apexed ceiling being where the 2011 and 2012 cohorts were first mixed as a flock. The rooms and annexes combined were too small to house the flock in winter without this additional aviary. Birds could be moved between all aviaries in P#1, the MA, and the annexes and rooms via pop-holes that could be opened and closed, and example of which can be seen in Figure 7g.

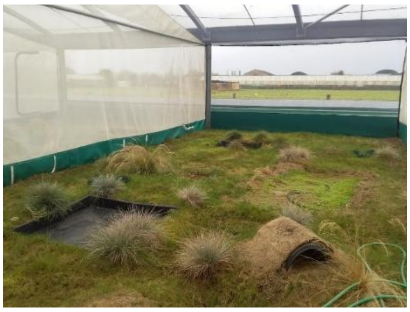
The entire facility was built to be pest and predator proof. The polytunnels were surrounded by a pest/predator proof fence buried approximately 0.5m deep backfilled with type 1 limestone. The fence was approximately 1.1m high (above ground) with an overhang at 45 degrees from the facility (Figure 8a). The fence was attached to the indoor facilities building. The building, annexes and polytunnels were built on a hardcore platform. Pest/predator traps were also added on the outside of the fence for added protection. Traps were used indoor within staff only areas on the occasion there was a breach.

The orientation of the facility was dictated by space availability, prevailing winds and need to provide adequate sunlight for the birds. During the planning phase, the orientation of the facility i.e. positioning of the summer and winter aviaries, was not considered as a factor in housing design.

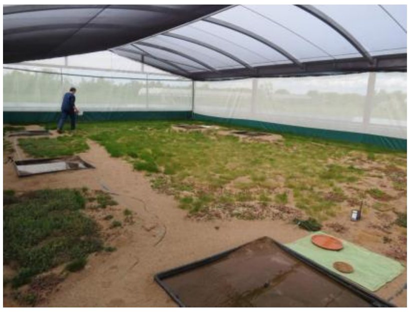
8a. Predator proof fence overhang

8b. Polytunnels under construction (2013)

8c. Finished SBS facility (2014)



8d. Breeding aviary setup - out of season, UV light units behind the camera (2019)



8e. P#2 prior to moving birds in (2014)

8f. One of two smaller breeding aviaries trialled (2015)

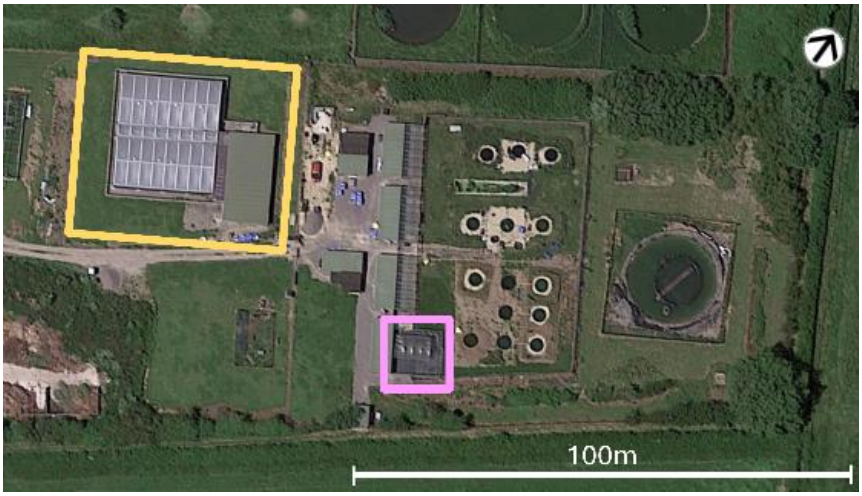
8f. MA setup, UV light units behind the camera (2019)

(All photographs credit: WWT)

Figure 8 – Photographs showing polytunnel construction and aviaries

In addition to the SBS facility, a separate external breeding aviary was built in the winter of 2015/16 to house a pair out of close proximity to other pairs. This was part of a trial testing whether distance/proximity to other pairs contributes to better breeding activity. It was known as the 'Craneland Aviary' being situated in a facility once used for cranes (Figures 9 and 10). It was situated approximately 45m from the closest breeding aviary in the SBS facility with several buildings and fences between them. It consisted of an inner aviary lined with 19mm knotted nylon mesh and a curved roof of polythene above it, the same as the SBS facility (2.1.3 Materials). It was landscaped similarly to the other breeding aviaries with two ponds on a closed filtration system. The bottom 30cm of the aviary was boarded and an electric fence attached to it. Surrounding this was another larger aviary made of metal panelling buried in the ground, also boarded at the base with an electric fence attached. Pest/predator traps were also added around the perimeter for added protection.

The Craneland Aviary was decommissioned after the 2018 breeding season as SBS pairs placed here did not settle as well as hoped, showing very limited breeding activity, and temperatures in summer getting extremely high there. As the Craneland Aviary was also within a Balai area at the time the SBS pairs placed here were not permitted to leave for a period of at least 30 days, possibly up to 90 days as per the Directive for Balai Approval.



(Basemap: Google Earth)

Figure 9 – Craneland Aviary proximity to SBS facility

(Credit: WWT)

Figure 10 – Craneland Aviary setup (2016)

2.1.2.2 Space use

Within the SBS facility the indoor and outdoor areas were used for multiple purposes depending on the time of year. The rooms, annexes, and the MA were predominantly used for 'wintering' the SBS, and the breeding aviaries used predominantly for the breeding season. There was no intermittent area used to simulate stopovers or staging between summer/winter or winter/summer. Instead, the SBS (as a flock) were given access to one or two breeding aviaries in spring and autumn in addition to the wintering areas. For exact aviary moves shown in Annual Report summaries, Annex 5.

When unoccupied during summer the rooms were stripped of substrates, tents, additional lighting, etc. and thoroughly cleaned and disinfected to be used as incubation and rearing facilities in the event the SBS laid. There were no dedicated incubation and rearing rooms in the facility.

There was also no dedicated quarantine area/sick bay when the facility was built. In the latter years of the project when there were fewer SBS some previously occupied areas were used for storage, display/tour purposes, and quarantine areas for sick individuals.

2.1.2.3 Catching/moving SBS

The layout of the facility meant that SBS had to be caught if needing to be put in P#2 or the Craneland Aviary. A variety of catching techniques were used including: mist netting, hand nets, fishing nets, and directly picking up distracted individuals.

2.1.3 Materials

Materials were chosen for different qualities they possess and purposes of use. Listed below are the materials chosen/changed through the project and purposes of use. For 'outside' areas all walls/ceilings had a double barrier to reduce the risk of aerial predators reaching the SBS. Structural materials and planning drawings are shown in Annex 1.

2.1.3.1 Outer material of polytunnels (including corridor between P#1 and P#2)

Roof

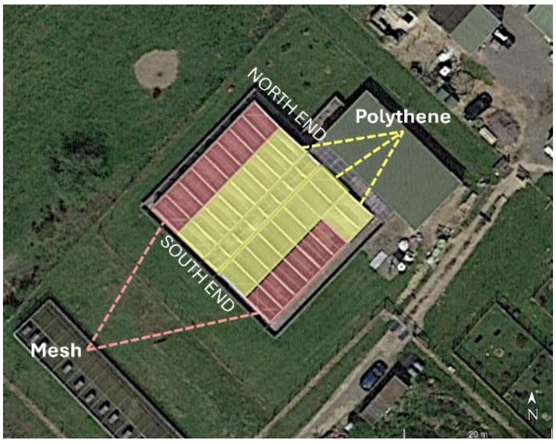
This was initially entirely covered in polythene sheeting with 89% light transmissibility (though opaque in appearance) allowing in some natural light whist keeping the worst of the weather out, and most importantly, reducing biosecurity risks (external pathogens i.e. wild bird faeces entering the facility). Heat proof tape was used between the steel polytunnel structure and the polythene. It is worth noting this degraded over time with microplastics entering the aviaries. The polythene itself was long lasting, however, it was easily damaged by gulls and corvids pecking it and needed to be cleaned at least annually to remove moss and algae as these reduced the light permeability.

Industrial extractor fans were installed in the roof in March 2015, one above each of the breeding aviaries, to remove the heat trapped by the curved polytunnel rooves in hot weather (these were removed in 2020 when the plastic roofing was replaced).

The end sections of the polytunnel roof, or 'D' shaped sections, were initially covered in polythene. This was replaced with 19mm knotted nylon mesh in March 2018 to allow for better airflow to further cool the aviaries and remove trapped heat in summer; with the exception of the section on the MA given this area is used during winter when disease risk is higher.

In January 2020 the polythene was replaced. Almost half was replaced with black 19mm knotted nylon mesh (Figure 11). This allowed more natural light into the aviaries whist maintaining some areas covered from the worst of the weather (this included areas with light fittings and sockets). The

MA was covered completely with polythene again as this area was used mainly in winter when external disease risks are higher. At this point, biosecurity became less of a priority (after assessing current risks posed) and increasing chances for successful breeding took president. Light quality is known to have impacted the captive breeding of the SBS with evidence seen over multiple years (2.5 Reproduction).



(Basemap: Google Earth)

Figure 11 – Polytunnel roof replacement (2020)

Walls

Initially the outer walls (including the walls along the corridor between the polytunnels) were covered in green shade cloth (semi-opaque) with a 500mm green base border of PVC coated fabric (opaque). This was to allow some light and air movement whilst offering some weather protection, particularly at the base where splash back from heavy rain could enter the facility bringing external pathogens with it; and also to reduce disturbance from staff outside of aviaries. In January 2015 the shade cloth was replaced with black 19mm knotted nylon mesh (Figure 12a) for better light permeability and air flow. The base border remained in place.

2.1.3.2 Inner material of polytunnel

Ceiling

The material used for the ceilings of all the polytunnel (and annexe) aviaries was always black polyester hexagonal knotless micromesh (semi-opaque) (Figure 12c). This provided a soft cushion in case of flight collisions, however, it was noted to act like a trampoline in places it was taught, pushing them back with force, if flown into, in an uncontrolled manor sometimes towards the floor. Three deaths associated with trauma were potentially due in part to this effect (CCTV footage did not show exact impact areas). The micromesh was replaced regularly due to weather damage, mostly from the sun rendering it brittle and prone to tearing. This was exacerbated when the polythene roof was replaced in part with knotted nylon mesh. Replacing micromesh was time consuming and costly, needing to be stitched in place. Previously one large panel was used for each of the polytunnels to cover four breeding aviaries, but later one panel per aviary was used so they could be replaced as and when needed without replacing the entire ceiling, also meaning SBS didn't have to be shut in for extended periods.

Walls

The inner breeding aviary walls were made from white PVC coated polyester mesh (semi-opaque) (Figure 12d) with a 200mm green base border of PVC coated fabric (opaque) (Figure 12b). The base border was to stop visual contact between the SBS pairs whist in breeding aviaries. However, this was not adequate once the tunnels were introduced into the aviaries but did not appear to deter breeding efforts by the SBS. The gauge of the PVC mesh was very fine meaning visibility through it was already restricted. It allowed some airflow but quite limited. On days of strong winds, it acted as a sail and occasionally pulled straining wire fastenings that it was hung to, loose or was pulled from the substrates it was buried in. This material was robust and did not need replacing at all during the project, it was also easy to clean.

2.1.3.3 Lining for annexes

Hexagonal knotless micromesh was used to line the walls of the annexes over the metal mesh panels to create a double barrier, but not on the wall where they joined the building/rooms, the wooden exterior remained exposed to the birds. In March 2013 windows were added here to give more light to the SBS when shut inside the rooms. In January 2014 window glass was covered with opaque sticky-back plastic in response to an SBS death due to collision with one of the windows. The windows remained in place with no additional covering.

2.1.3.4 Lining of rooms

Initially the rooms had no lining as the SBS were feather-cut (to reduce flight capabilities) so the walls posed no threat. However, over time as they gained and maintained flight (stopped feather-cutting), so light fittings, taps, and the walls themselves became a hazard. In 2014 a made-to-measure tent built from PVC coated polyester fabric was commissioned with a slightly smaller volume than the room for them to occupy.

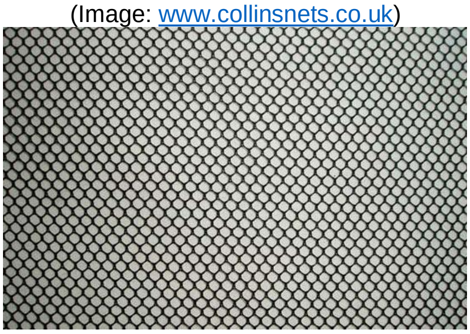
2.1.3.5 Small breeding aviaries

In some years, the smaller breeding aviary cages located within P#2 were covered with hexagonal knotless micromesh with shelterflex for a base border (Figure 12e).

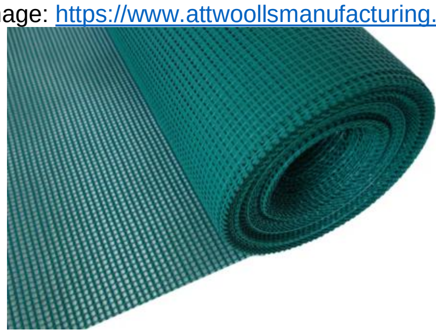
To get through partitions/materials into or between aviaries/tents, zips (plastic and metal) were sewn in to act as doors. These lasted a number of years but gradually all corroded or were damaged beyond use due to sand and disinfectant, particularly in locations where foot dips were located. Metal mesh panel doors on hinges lasted longest without the need for replacement. Where possible, these were covered with mesh on the side facing into aviaries, to reduce collision trauma risks.

12a. Knotted nylon mesh
(Image: www.collinsnets.co.uk)

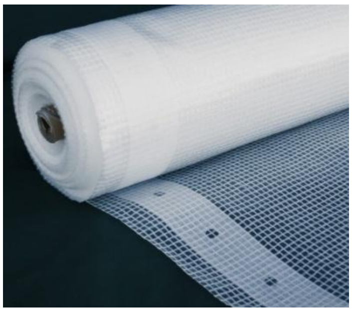
12b. PVC coated fabric
(Image: https://www.attwoollsmanufacturing.co.uk/)



12c. Hexagonal knotless micromesh
(Image: https://norfinenets.co.uk/)



12d. PVC coated polyester mesh (shown in green but bought in white
(Image: https://www.attwoollsmanufacturing.co.uk/)



12e. Shelterflex
(Image: www.collinsnets.co.uk)

Figure 12 – Materials used for the interior of the polytunnels

2.1.4 Substrates

In the wintering areas (rooms, annexes, and MA), an 80mm thick layer of holm sand was used to cover the floor, on top of weed matting. River sand was used initially but found to be too coarse with all replaced with holm sand in early 2012. Holm sand was also used in the butyl lined ponds in these areas, with some butyl left exposed in the centre for maximum depth. Sand throughout the facility was replaced as and when needed. In selected area, this was done daily in the early years, and sand was replaced in its entirely at least once per year. In the wintering areas the SBS had access to both saturated/damp and dry substrates. When the SBS arrived in the UK in 2011 varying sizes of gravel were used for substrate, but these were found to stick to the SBS's feet with faeces leading to foot issues. In later years fine gravel was used in large water trays to overcome foot issues, as being submerged in water eliminated the sticking effect. This needed rinsing through at least every other day.

The breeding aviaries comprised a combination of holm sand and turf (low maintenance LT2) used to create an undulating landscape. Some larger hills and butyl lined scrapes (filled with sand and water periodically) were present. Sedums, grasses, and heathers were also used sporadically (Figure 13). In later years other larger/taller shrubs and grasses were added. Any dead turf was replaced before each breeding season (didn't survive due to heat/lack of water) and sand was replaced in areas of high use/traffic. Initially the breeding aviary substrate was predominantly dry due to the intense heat in the polytunnels. Though some aviaries were equipped with a soaker hose, the turf and vegetation largely died unless regularly watered, which in turn disturbs the SBS during the breeding season. From 2019 with the installation of a misting system the SBS had access to both wet and dry substrates whilst in the breeding aviaries and less vegetation needed replacing.

All substrates and foliage were disinfected before the SBS were given access to it. Holm sand was often mixed with clay/sediment which was rinsed clear before being disinfected. Vegetation was managed in the breeding aviaries throughout the year, with management only undertaken when necessary, when breeding aviaries were occupied by pairs. Any turf coming into the facility was inspected thoroughly for foreign materials that may cause harm (from ingestion or exposure).

Figure 13 – SBS foraging amongst heather (2018)

(Credit: WWT)

2.1.4.1 Furnishings

Artificial Christmas trees (Figure 14a), including branches and wreaths were placed sporadically throughout the aviaries to break up the eye line, create visual barriers, and provide additional foraging opportunities. However, these would shed plastic 'needles' if not replaced frequently.

(Credit: WWT)

14a. SBS use of an artificial Christmas tree (2018)

(Credit: WWT)

14b. First of several tunnels added to breeding aviaries (2018)
)

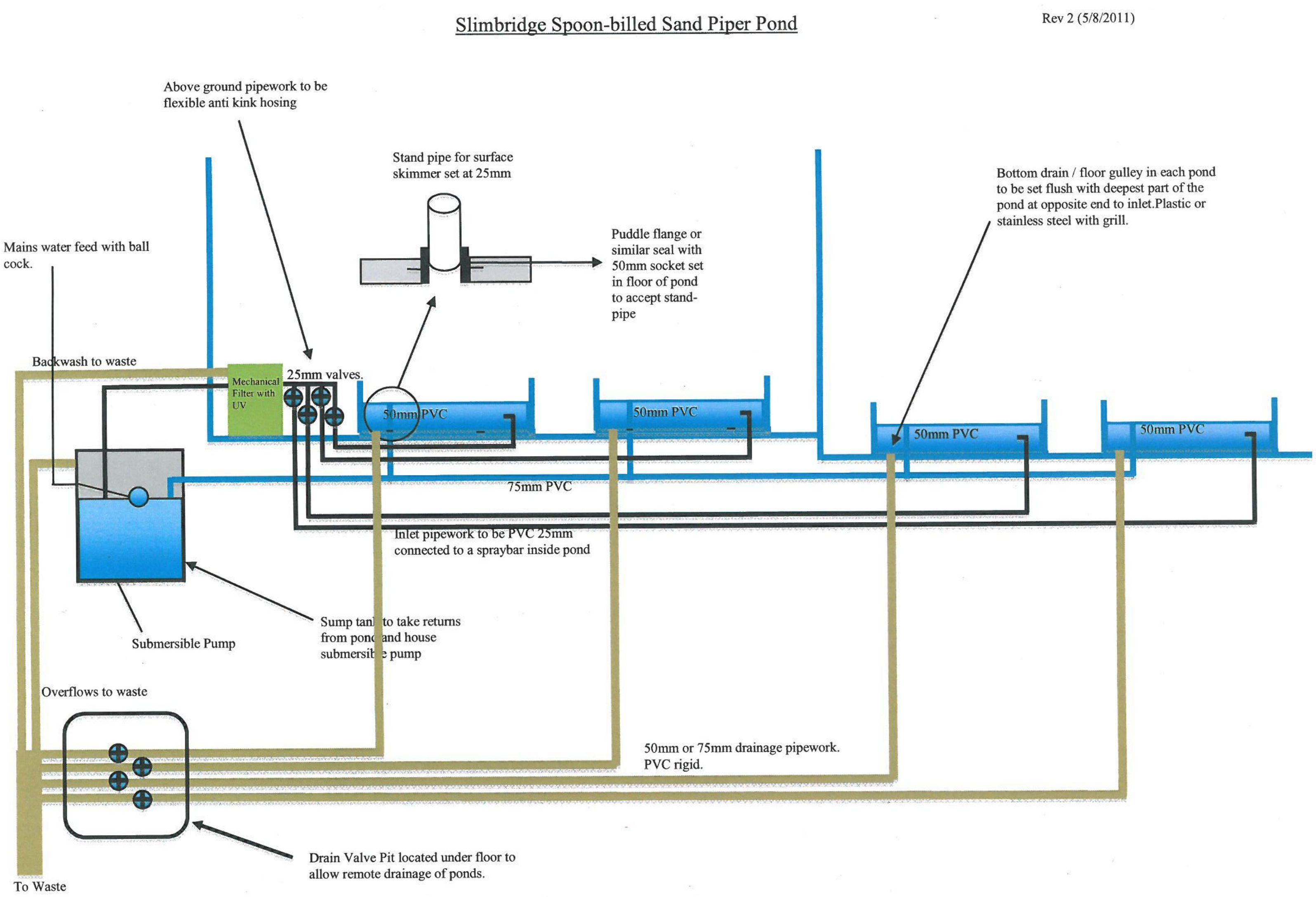
Figure 14 – Examples of furnishings inside the aviaries (2018)

In 2018 a 30cm diameter corrugated drainage pipe was part buried then covered with sand and turf in a breeding aviary to act as shelter, break up the landscape, and serve as a display stage (Figure 14b). In winter 2018/19 additional straight and angled pipes were added to all breeding aviaries to be occupied as they appeared to be well utilised.

The substrates used throughout the facility were prone to absorbing spilt food or being difficult to remove food from without removing lots of substrate. This can cause issues particularly in warm humid areas leading to the build-up of pathogens over time. To mitigate this, towels were used under all food dishes, large enough to catch spilt food or food walked out of dishes stuck to feet. They were also soaked in antiseptic solution (F10 Antiseptic Solution) before being placed in aviaries to reduce pathogen build-up in these areas and as a preventive measure against foot issues.

2.1.5 Fresh water systems

Room #1 and Room #2 both had one concrete lined shallow pond measuring approximately 3.1m x 1.1m. These were on a closed filtration system with a UV steriliser added. Each annexe also had one concrete lined pond of the same size; these were later expanded to approximately 4.5m x 2.2m and butyl lined. These ponds were on the same closed water system as the rooms (Figure 15). Initially salt was added to this system (approximately 2ppt, far below sea-level salinity to avoid salt build-up in the substrates) via the sump though was eventually stopped as salinity could not be maintained.



(Source: WWT Maintenance Department)

Figure 15 – Annexe/room water system

The MA had a shallow standalone pond with a drainage outlet, approximately 7m x 3m. This was filled with water and salt again far below sea-level salinity, drained and refreshed regularly (once a week initially to once/twice a day for most of the project).

All BAs had a least one 115cm² pond (two ponds if in a 10m x 5m aviary) with the top flush with the level of the substrate. These ponds in both polytunnels were on another closed filtration water system separate from the room/annexe water system. Water was pumped into the first pond of each polytunnel and gravity fed to the next pond (through pipes buried within the substrate), and so on, until it drained into a central sump for recirculation (Figure 16). This system was also fitted with a UV steriliser. One of these small ponds was also fitted in the MA although not used (covered with butyl). The small ponds in P#2BA#1 were not present initially as it was used as a storage area but were added to the system before use as a breeding aviary.

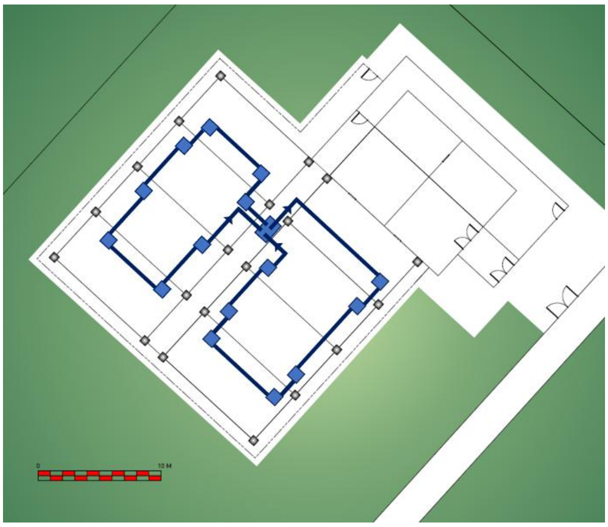


Figure 16 – Breeding aviary pond configuration

2.1.6 Salt water provision

Between 2011 and 2014 it was standard practice to have 'wet' food dishes (food items presented in water) placed within larger dishes of salt water. Shallow trays or dishes of salt water were provided in addition whenever foot issues were prevalent. Salt water was also thought to maintain salt excretion glands, keeping nares clear through salt excretion. From summer 2014 (when the breeding aviaries were first used) salt water was only provided to SBS occupying the breeding aviaries if foot condition was poor.

2.1.7 Other utilities

2.1.7.1 Electrics

Electricity usage increased throughout the project as new husbandry advances were made, particularly to lighting. Generally, electricity usage was high due to the almost 24-hour periods of light provided during the breeding season, as well as multiple incubators and brooders, heating or cooling appliances during winter and summer respectively, constant use of pumps, filters, and sterilisers for water systems, and various ambient lighting in the facility being generally dark due to the layers of netting and polythene. Electricity usage was not recorded for the SBS facility specifically (a calculation may be made upon request).

Many alterations were made to the facility electrics which came with disturbance to the SBS throughout the project, often involving loud tools and unfamiliar staff. Disturbance between 2012-14 was highest due to the need for electricians and other contractors to complete relevant works such as installations and rewiring (4-8 months per year had at least one visit).

The facility was not completely weather-proof causing issues to fittings and appliances in the outside areas of the facility exposed to rain. Despite best efforts to water-proof sockets, the appliances and connecting cables themselves would short-out and corrode leaving some unusable, thus requiring further disturbance to remove old and install alternative installations (for specific cases refer to Annual Report summaries, Annex 5).

2.1.7.2 Waste

One of the biggest waste products of the project was old or contaminated substrates; sand and turf. As the wintering areas were never rested (or only rested for short periods), substrates were replaced entirely here at least once a year. The breeding aviaries (bar P#1BA#1) were in use for up to three months a year only, and so only heavily used, soiled, damaged/dead substrates were replaced. Additionally, areas with environmental screening results with high loads of undesirable pathogens were usually replaced with fresh substrate. Although sometimes this was disinfected rather than replaced depending on location/substrate (for details see Annual Report summaries, Annex 5).

Hexagonal knotless micromesh was also a significant waste product. This covered much of the inner surfaces of the aviaries within the polytunnels and the annexes to protect the SBS from the hard surfaces of the facility and create a double barrier from aerial predators. This had to be replaced almost annually due to weather damage.

Additionally, wastewater was extensive given the need for flowing/fresh water. It was not possible to measure water usage for the SBS facility specifically, but based on rough estimates it was in excess of 300m^3 annually for an average year. Waste water was sent to a treatment wetland and was diluted with other waste mains water used for cleaning.

2.2 Ambient Environment

Wild SBS experience broad seasonal changes in environmental conditions over each calendar year, due to the nature of migrating long distances with multiple stopovers. Recreating the ambient environment exactly was not possible in the SBS facility in part due to the almost reversed climate in the UK as opposed to that experienced by wild SBS. Replication was attempted to the best of abilities and situational circumstances.

2.2.1 Temperature

Wild SBS wintering in southeast Asia from mid-October to mid-April experience average monthly highs exceeding 30°C, with lows during this period being warmer than highs on the breeding grounds during the breeding periods (18°C average low in January in Myanmar versus 15°C average high in July in Russia). Migration stopovers are quite cool on the journey north, with temperatures ranging 2-19°C. On the breeding grounds from late-May to mid-August, SBS are exposed to average lows down to -2°C, with average highs ranging 3-15°C. Southbound migration is warmer, with temperatures ranging 14-29°C (Figure 17).

At Slimbridge, natural temperature variation is more muted, and the pattern is reversed, with coolest temperatures experienced in February (with an average local low of 2°C) and warmest in July and August (local high 23°C Figure 17). Hence, in the absence of any mitigation, the captive SBS would have experienced a temperature pattern in opposition to other circannual cues such as photoperiod (i.e. colder temperatures associated with short days and warmer with long, as opposed to cool summers and hot winters in the wild). It is worth mentioning that even with temperature mitigation, circannual cues (some we could control and some we could not) are at times in conflict; although we can provide warmer or cooler temperatures this is naturally associated with sun exposure, which for the captive SBS was not the case.

Actual temperatures within the facility in summer were often much higher than natural locational measurements; in the extreme, ground level temperatures within the facility reached a maximum of >50°C (in Craneland Aviary in July 2018; ≥40°C in at least one area in at least one month April-August 2015-2021). Further details in Annual Report summaries, Annex 5. This was due to the structure of the facility itself, and the materials used to cover it and separate areas/aviaries. The curved rooves of the polytunnels covered in polythene trapped heat, and the layers of small gauge black mesh absorbed heat and restricted air flow, and the white partitions restricted airflow considerably. The heat of the summer appeared to negatively impact the SBS, causing them to become inactive when breeding activity was desired. To mitigate against the heat, various measures were implemented and trialled. The cold and damp winters also appears to affect the SBS, potentially causing prolonged moult in harsh conditions.

2.2.1.1 Temperature mitigation

Starting in chronological order, in 2011 and 2012, the SBS were confined to, or always had access to, a heated indoor space, with ambient warmth from fan heaters plus heat lamps for basking. From 2012 when the SBS had outdoor access, they were shut in during severe winter weather (i.e. low temperature and precipitation). Heat lamps were turned off during hot weather in 2013.

From April 2014, ice and fresh water were regularly added to the sump in the polytunnel corridor to try and cool breeding aviary ponds during hot weather – to have a significant effect, ice needed adding regularly with frequent water changes to remain cool. Following the 2014 breeding season, the recombined flock was confined to the MA and annexes during heatwaves.

In winter 2014/2015, the indoor areas no longer had heat lamps, with fan or oil heaters used in place, eliminating the chances of flight collisions and provided a safer heat source. Heated soil cables were also added under the sand to provide further warmth - this worked provided SBS stood directly on the sand covering the cables. The cables also dried out the sand surrounding them. Additionally, ceiling fans on a thermostat were installed in P#1 in March to remove the heat trapped in the polytunnels – this had some effect, but the aviaries were constantly being heated and the fans were more or less constantly on.

In November 2017, heated soil cables were added in substrate under UV light units in a desire to encourage the SBS to roost here over winter - there was no evidence this increased the SBS tendency to roost here. Winter 2017/2018 was also the beginning of a photoperiod time-shift to bring the breeding season forward to the cooler months of spring (2.2.2.3 Photoperiod) – essentially successful in terms of breeding earlier in the year (though possible knock-on effects to health). Heat lamps were also added to each side of the UV light units in January 2018, to encourage the SBS to stand nearby - there was no evidence this increased their tendency to roost here, though did increase the visible spectrum here.

Approximate locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Breeding grounds (Beringorvskiy, Russia)					3	10	15	14				
					-2	3	9	8				
Stopover (Pogibi, Sakhalin)					11			22				
					2			14				
Stopover (Rudong, China)				19				29	26	23		
				11				23	20	16		
Wintering grounds (Gulf of Martaban, Myanmar)	32	35	36	37						32	32	31
	18	25	22	24						24	23	19

WWT captive population Slimbridge, UK	7	8	11	15	18	21	23	23	20	15	10	8
	3	2	4	7	9	12	15	14	12	9	5	3

(data from accuweather.com)

Shade	Temperature (°C)
	<2
	2-5
	6-9
	10-13
	14-17
	18-21
	22-25
	26-29
	30-33
	≥33

Figure 17 – Average monthly high and low temperature at monthly associated location for wild adult SBS

In March 2018, three of the plastic 'D' ends of each polytunnel were replaced with 19mm knotted nylon mesh to aid in cooling – successful in increasing airflow but limited effect when air outside is also hot. In May a paddling pool with a water fountain was added to the corridor between polytunnels in an attempt to reduce air temperature through evaporation – limited effect on the facility but considerable in the immediate area.

In March 2019, an 'underfloor' (under sand substate) cooling system was set up in P#2BA#2 and P#2BA#3 to trial during the SBS's time in the breeding aviaries – this had limited effect, there were multiple reasons and not worth correcting for the output. In the same month, to provide further cooling, an overhead misting system was set up in both of the polytunnels extending along all of the breeding aviaries (with the exception of the MA and annexes) – this was fairly effective at cooling the aviaries, it had to be used constantly to have an effect, so the ground underneath became saturated quickly. In May and June an industrial air conditioning unit was also placed in the corridor between polytunnels in an attempt to cool aviaries on hot days – this had limited effect and only on the aviaries it was directed into. Ice was added (additionally to ice in the sump) to the empty aviary P#1BA#3 pond for the meltwater to be circulated through the system to occupied aviaries (ensuring the SBS had no direct contact with ice avoiding collision risks and sticky effect) – this had limited effect, only really being felt in the pond immediately adjacent for a short time. The Phillips LED bulbs from the light fitting in P#1BA#2 were replaced with dull emitter heat lamp bulbs from October 2019, to provide a source of heat for the newly bred 2019 cohort (separated from the main flock) – there was no evidence this increased the SBS' tendency to roost here.

During extremely hot weather in the summers of 2020 and 2021, emergency measures included:

- Direct chilling of the polytunnel pond systems sump using a large water chiller – this proved not very effective as the pump was too strong not allowing water to be chilled before being dispersed again, also limited in effect with such a large volume to cool;
- Ice packs under sand or towels – SBS were occasionally seen to stand on them; and
- Ice blocks in the ponds of occupied breeding aviaries (put into occupied aviaries as meltwater didn't reach all aviaries when placed in pond of unoccupied aviaries) – this was only really effective on the pond its placed in for a short time.

In the winter of 2020/2021, the 2019 cohort (still separated from the main flock) were given an ark shelter over the pop-hole to their adjoining aviary with heat lamp and heated soil cable – there was some evidence of use; and infrared heaters were provided outside – again some evidence of use. In summer 2021, all SBS were shut out of the MA and confined to An#1 during extremely hot weather.

Throughout the project temperatures of each aviary/area were monitored. Aviaries to the north of the facility were typically cooler with the hottest to the south. Individuals/pairs were ranked on a series of factors (2.5 Reproduction) and those ranking higher i.e. with a better chance of breeding, were put in cooler aviaries (unless they had already bred/paired well in an aviary previously, in which case they were placed there again given the precedent).

For details on all temperature mitigation see Annual Report summaries, Annex 5.

2.2.2 Light

Sunlight i.e. solar spectrum, is required by all birds at species-appropriate intensity in seasonally appropriate doses. This provides warmth (2.2.1 Temperature), vision, circadian/circannual rhythm cues, and vitamin D. Birds are able to see more colours of the visible spectrum (in natural daylight) than humans can, being tetrachromatic (Vorobyev *et al*., 1998). In captivity the various aspects of sunlight must usually be provided as separate components, rarely comparable to direct sunlight. For the SBS it has been difficult to replicate the light conditions, particularly in winter months when they would naturally be exposed to high intensity sunlight for longer periods. It was not fully understood that the SBS had such specific requirements, namely of sunlight/ultraviolet light in terms of breeding success (in terms of producing healthy chicks and maintaining healthy females), until the direct consequences were observed. The first eggs laid at the facility in 2016 showed there were calcium-related issues in the females that laid them. One clutch was thin-shelled and missing the final cuticle deposited before laying. One of the eggs from this clutch was soft with multiple layers missing, collapsing soon after collection (from a pond in which it was 'dumped'). Another egg of this clutch did hatch after artificial incubation but died three days later with post-mortem revealing osteopenia as the cause. Another clutch laid that year by another female had eggs which appeared normal, but the one chick that hatched died a day later also with osteopenia (and a yolk sack infection). Some eggs in subsequent years were also noted as thin shelled and/or missing the cuticle layer but chicks did survive post-fledging. It was also noted on occasion that laying females would lose condition over the breeding season (females of other *Calidris* species are known to use their own calcium reserves to aid in egg formation; Reynolds & Perrins, 2010).

2.2.2.1 Light intensity (artificial)

Solar radiation is the electromagnetic energy reaching Earth's surface from the sun. It can be used as a guide for light intensity in captivity.

Wild SBS experience a variable light intensity schedule as they migrate across latitudes (Figure 19). They encounter average daily solar radiation in excess of 12 Mj/m^2 at all times, with peaks over 20 Mj/m^2 in wintering grounds February-April, and again on the breeding grounds in June. Wild SBS, particularly in winter but also in summer, have very limited opportunity to regulate their exposure to light given the lack of cover in their environment, so would experience these readings with only minor deviation. By contrast, the natural conditions at the location of the SBS facility comprise average daily solar radiation exceeding 12 Mj/m^2 from April to August only, with levels dropping as low as 2.1 Mj/m^2 in December, not taking into account the layers of polythene and netting between direct exposure and the SBS themselves. The amount of direct sunlight without any barriers (polythene, netting, etc.) was zero. Though the light did penetrate, its intensity and duration were reduced by materials used to construct the facility creating full shade or dappled light. The number of hours the SBS had the opportunity for this sunlight was limited through winter. It is worth noting that on cool/cold days if sunlight was available to bask in, the SBS would actively choose to roost in it (Figure 18).

Figure 18 – UV light with heat lamps vs. sun spot

(Credit: WWT)

It is important to take into account sunshine hours when considering light intensity, as this differs to photoperiod insofar as they do not need, and it may in fact be detrimental, to have the maximum intensity for the length of the photoperiod. A range of different lighting in differing locations and heights was provided in the SBS facility to give varying intensities which were also staggered in switching on and off to simulate natural sunlight/cloud cover and sunrise/sunset. Detail of the specific artificial lighting provided in 2.2.2.2. Light quality.

Although artificial light at night can be detrimental to wild animals (particularly migratory species; see Gauthreaux & Belser, 2006), there are no known detrimental effects of multiple light sources on captive animals, nor of switching lights on/off instantaneously rather than gradually fading (mimicking sunrise/set) or failing to mimic east-west progression where multiple light units are in use.

Approximate locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Breeding grounds (Anadyr, Russia)					18.9	20.8	18.8	12.9				
					7.9	9.3	8.3	6				
Stopover (Pogibi, Sakhalin)					18.9			14.4				
					8.2			7.5				
Stopover (Yancheng, China)				17.6				16.8	14.7	12.3		
				9.5				8.9	8.1	6.5		
Wintering grounds (Sittwe, Myanmar)	18.4	20.3	22.1	22.4						16.6	16.2	16.8
	9	9	9	8						6	8	8

WWT captive population (Weston-Super-Mare, UK)	2.7	4.9	8	12.7	16.4	17	16.9	14.4	9.9	5.7	3.3	2.1
	4.1	3.9	5.7	7.2	7.4	7.3	7.7	7.2	6.8	4.3	3.9	4.1

(data from weatherbase.com)

Shade	Solar radiation (Mj/m^2)
	<5.0
	5.0-9.9
	10.0-14.9
	15.0-19.9
	≥20.0

Shade	Sunshine hours*
	<5.5
	5.5-6.4
	6.5-7.4
	7.5-8.4
	>8.5

Note: * Sunshine hours are underlined

Figure 19 – Average daily solar radiation and sunshine hours at monthly associated location for wild adult SBS

2.2.2.2 Light quality (artificial)

Artificial lighting provided to the captive SBS varied over the course of the project. Light quality was adjusted as knowledge of both captive and wild birds increased, coupled with additional expert advice sought over time. Sunlight was always available, though reduced in quality/intensity due a combination of layers of polythene, mesh, netting, and/or glass.

Artificial lighting provided

- 2011: Overhead florescent strip lights and compact ultraviolet (UV) bulbs (in QS).
- 2012: Overhead florescent strip lights and compact UV bulbs, additional compact UV bulbs added in May. All of the low frequency ballast and fluorescent tubes were replaced with high frequency ones so ensure there was/very little no flicker. This decision was based on advice received from an experienced private breeder and evidence in published literature for other bird species.
- 2013: Luminaires added to rooms and annexes in March. Additional fixtures used soon after with 20W bulbs as luminaires not adequate. Some fixtures moved from rooms to annexes as a night light in May. Windows added to annexe/room walls in March to allow more natural light inside.
- 2014: Flood lights added to each end of the polytunnel corridor for use overnight during the breeding season. UV bulbs in rooms switched off in November as thought to be flickering, no UV light provision from here.
- 2015: Luminaires containing Truelight bulbs fitted above all breeding aviaries, and LED floodlights fitted in the MA in April after consultation with Philips lighting teams.
- 2016: A scaffolding tower fitted with luminaries was used for ambient lighting during the breeding season between the small aviaries in P#2.
- 2017: UV tube light units (Growth Technology Lightwave T5) with Arcadia bulbs were installed over the pop-hole of the MA and An#1, and between An#1 and Room #1, these being areas the SBS reliably walk under (food dishes also placed underneath) at a height to expose them to 2.2 UVI after consultation with an external zoo lighting advisor. UV tube light units were also installed in Room #1 and most of the breeding aviaries by March. An additional UV tube light unit was added to the MA in November and all units were lowered to give an exposure reading of at least 4.0 UVI year-round.
- 2018: A larger UV tube light unit was installed in P#1BA#1 with heat lamps either side of it to encourage the SBS to roost there. Luminaires were placed on a scaffolding tower in polytunnel corridor during the breeding season.
- 2019: The heat lamps next to the UV tube light unit in P#1BA#1 was replaced with LED bulbs to increase the spectrum in February (as not used to roost as intended). Luminaires were placed on a scaffolding tower in polytunnel corridor during the breeding season.
- 2020: Luminaires were placed on a scaffolding tower in polytunnel corridor during the breeding season.
- 2021: Luminaires were placed on a scaffolding tower in polytunnel corridor during the breeding season.

Light bulbs were replaced outside of the breeding season when they had blown or if they were flickering

Ultraviolet light

Ultraviolet light is a portion of the solar spectrum not visible to humans but partially visible to most avian species. UV is important for birds both physiologically (with effects on hormones and vitamins;

Rana & Campbell, 2021) and in terms of allowing them to experience their surroundings in as natural a manner as possible (F. Baines, 2017, pers. comms.). UV light contributes to skin health, immune health, and vitamin D synthesis which is important for gene transcription and calcium metabolism.

Wild SBS experience average monthly UV indices in excess of 7 UVI on the wintering grounds from October to April (peaking at 12 UVI before spring migration) (Figure 22). Lower levels experienced during breeding are equivalent to those experienced at the location of the captive breeding facility during summer (3-4 UVI) but the actual amount the captive SBS receive from sunlight is much lower due to the layers of materials covering the facility and within it, although to some level this is mitigated with artificial UV light provision.

The SBS were provided with UV lighting from hatch and showed no adverse effects prior to attempting to breed, however, the quality/intensity did not appear adequate for adults to successfully breed. Improvements to UV light provision are outlined above. It was decided to provide the SBS with a more or less constant level of UV light throughout the year largely due to the nature of the units used; it was difficult to give anything more than a reading of 5 UVI without lowering the units to almost unusable heights (they needed to be covered with netting to make them 'bird-safe'). The idea was that by providing higher UVI at times when SBS would naturally receive lower UVI (during the breeding season) would compensate for not receiving levels seen by wild SBS during the winter months. Figures 20a and 20b shows how UV light units within the aviaries were made 'bird-safe', sewing netting around padded units and structures to reduce impact of collisions. The netting, foam, and pipe lagging needed to be replaced regularly as it degraded rapidly being exposed to the UV light at high levels. In some cases during the breeding season males would stand on the netting where possible to sing from (Figure 21). Possibly a reason to consider providing much higher display points, if able to provide without introducing collision risks.

(Credit: WWT)

20a. Netting and pipe lagging around large UV unit suspended in the MA to reduce collision risks

(Credit: WWT)

20b. Small UV light and additional light units hanging on a stand within the MA with pipe lagging and netting to reduce collision risks

Figure 20 – Photograph showing 'bird-proofing' UV light units

Figure 21 – Photograph of a male SBS stood on the netting using as a display point

(Credit: WWT)

Approximate locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Breeding grounds (Anadyr, Russia)					3	4	4	3				
					7.9	9.3	8.3	6				
Stopover (Pogibi, Sakhalin)					3			4				
					8.2			7.5				
Stopover (Yancheng, China)				5				6	5	4		
				9.5				8.9	8.1	6.5		
Wintering grounds (Sittwe, Myanmar)	8	10	12	12						10	8	7
	9	9	9	8						6	8	8

WWT captive population (Weston-Super-Mare, UK)	2	2	3	3	4	4	4	4	4	3	2	2
	4.1	3.9	5.7	7.2	7.4	7.3	7.7	7.2	6.8	4.3	3.9	4.1
Artificial UVI provision 2020 average (from one to five units depending on time of year, rounded to nearest integer for comparison)	4	4	5	6	6	6	5	4	4	4	4	4

(data from weather-atlas.com)

Shade	UV index
	<3
	3, 4
	5, 6
	7, 8
	9, 10
	11, 12

Shade	Sunshine hours
	<5.5
	5.5-6.4
	6.5-7.4
	7.5-8.4
	>8.5

Note: * Sunshine hours are underlined

Figure 22 – Average monthly UV index and sunshine hours at monthly associated location for wild adult SBS

2.2.2.3 Photoperiod

In Figure 23, the line labelled ‘As experienced by wild SBS’ illustrates the best estimate of photoperiod encountered by wild SBS (including astronomical twilight for all locations). It should be noted that the artificial light that the SBS were provided included civil twilight only, and so the daylengths are shown shorter than ‘as experienced by wild SBS’ (as using astronomical twilight makes daylength longer than if using civil twilight). One study suggest that twilight generally is not considered a photoperiodic signal (Dawson, 2015). More likely it is overall changes in day length that signal and trigger seasonal responses in birds (Quispe, Protazio, & Gahr, 2017). Note that this approximation has SBS migrating instantaneously, whereas actual movement durations would slightly dampen the 'jumps’.

From January until late March, the wild SBS are modelled to be in Martaban, Myanmar (c.17°N); during this time the photoperiod increases gradually from 12.85 to 13.75 hours of daylight. They are then modelled to migrate to a stopover at Rudong, China (c.32°N), jumping to 14.1 hours of daylight, which gradually increases to 15.57 hours by early May. A larger 'jump’ occurs when they migrate to the next stopover at c.52°N, to 18.43 hours, increasing more steeply to 20.43 hours by early June. The final stage of northward migration brings them to 24-hour daylight at the breeding site of Meinypil'gyno, Russia (c.63°N), where they remain for almost two months. This process is largely mirrored for the return migration, with photoperiod decrease rates becoming shallower at each ‘jump’.

It was important to replicate the photoperiod of wild SBS to ensure any eggs laid at the facility could be transported to Russia within the correct time frame for releasing chicks with other migratory waders including SBS. Photoperiod plays a key role in maintaining circannual rhythms including timing of breeding. The SBS experienced a slightly different photoperiod each year of the project (Figure 24). Changes were made annually for the betterment of the SBS as knowledge and experience increased. The SBS appeared to respond most positively in terms of breeding in years they experienced 24 hours of light during the breeding season. In 2018 the photoperiod was altered most drastically to shift the breeding season earlier in the year, allowing the SBS to breed in the cooler months of spring (breeding took precedence over timing of breeding by this point). This had a desirable effect though it potentially contributed to higher stress levels and poor health of the SBS long term. Altering the lengths of the seasons with photoperiod may have also caused detriment long term.

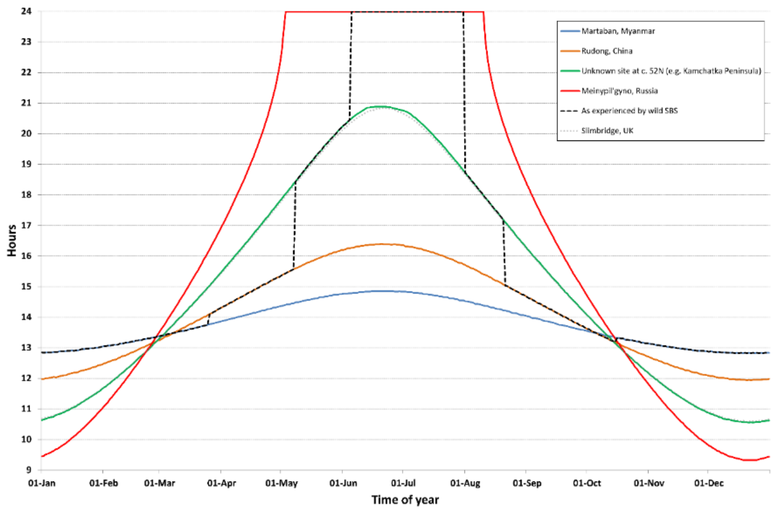


Figure 23 – Average annual photoperiod for wild adult SBS

Considerations

Average annual photoperiod for wild adult SBS (Figure 23) was used as a guide for artificial light provision within the SBS facility. However, this annual experienced wild photoperiod conflicts with the actual photoperiod at Slimbridge, UK (except during the periods of stopover at c.52°N).

Calendar year conflictions

From January until the end of February, the Slimbridge photoperiod is shorter than that which would be experienced by wild SBS; this was remedied where needed with artificial light provision before sunrise and after sunset. During March and April, the Slimbridge photoperiod is longer than that which would be experienced by wild SBS; this could not be altered effectively without radical changes to husbandry at detriment to the SBS. Whilst wild SBS stopover at c.52°N during May and most of August, the Slimbridge photoperiod matches that experienced by wild SBS; however, it is shorter during the breeding period of June and July (at c.63°N), when wild SBS would experience 24-hour daylight (requiring artificial supplementation). From late August until mid-October, the Slimbridge photoperiod is longer than that which would be experienced by wild SBS; this could not be altered effectively without detriment to the SBS. Then for the remainder of the year, the Slimbridge photoperiod is shorter than that which would be experienced by wild SBS, again requiring artificial supplementation. However natural photoperiod for Slimbridge was utilised during the winter to provide a natural sunrise and sunset. Rather than being plunged into sudden darkness with artificial light being turned off in a dark setting.

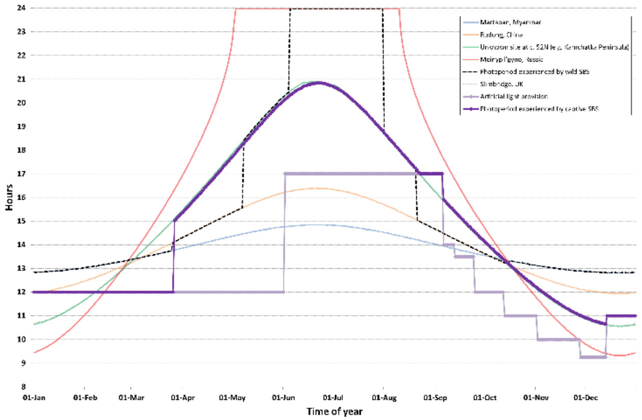
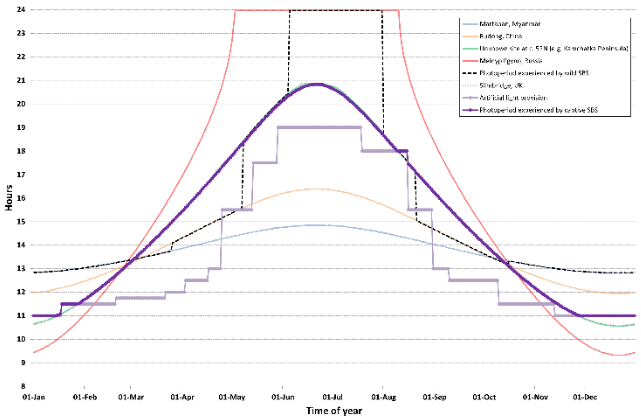
Jumps in photoperiod are likely important in triggering biological processes related with breeding (or wintering depending on the time of year), coupled with other factors such as food abundance and type, and temperature. Other factors may include influence of others (intra - and inter - species), and habitat type/change. The captive SBS were separated into pairs in breeding aviaries at least by the time the 24-hour daylight period is reached (further detail provided in 2.5 Reproduction). In the early years exact photoperiod was determined in part by the equipment in place to provide it (details in Annual Report summaries, Annex 5).

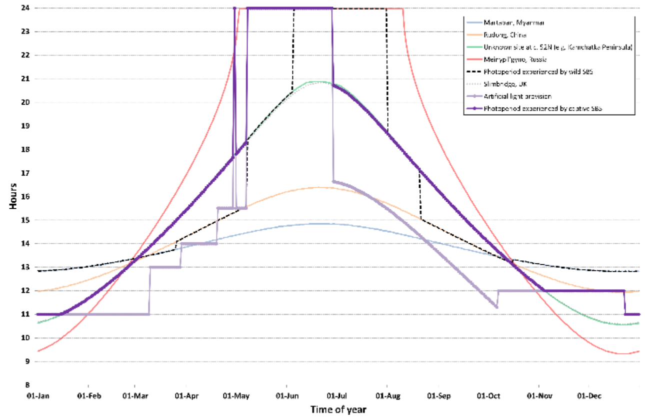
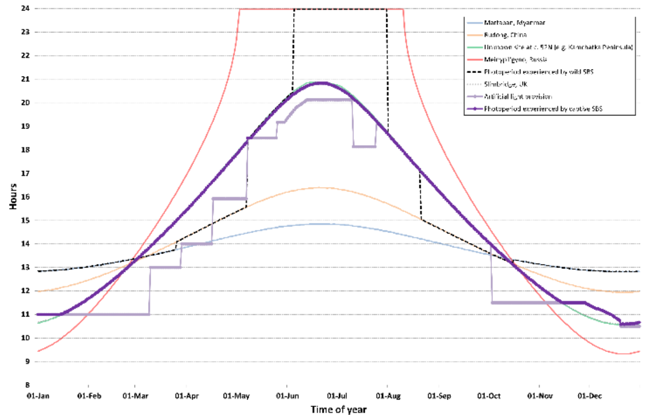
Power cuts happened infrequently and for short periods not usually affecting the SBS in terms of photoperiod provision. However, the SBS did often become nervous immediately following a power cut and avoided dark indoor areas until power returned.

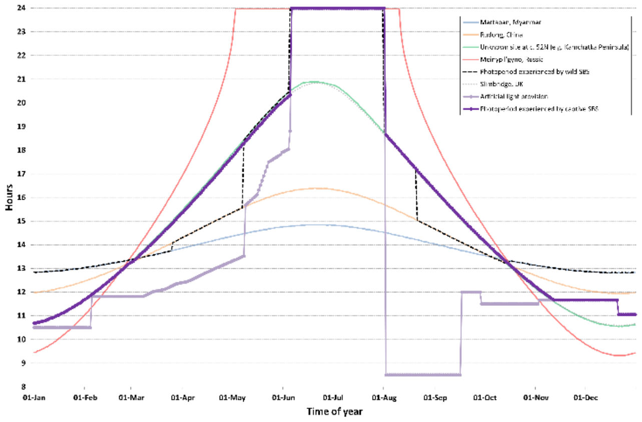
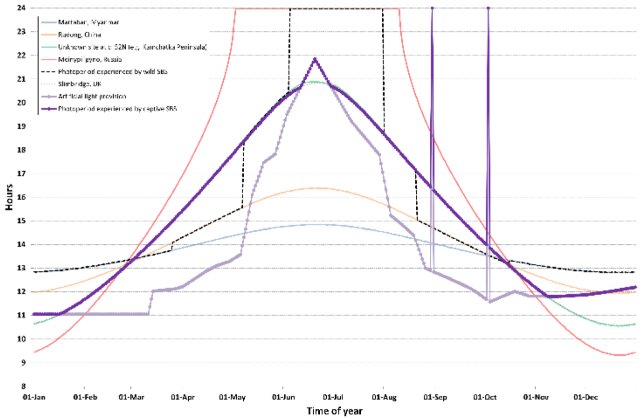
Annual variations in the photoperiods experienced by the SBS are shown in Figure 24. The graphs were created based on all written data/evidence available from records kept throughout the project. Graphs can be viewed in more detail in Annual Report summaries, Annex 5.

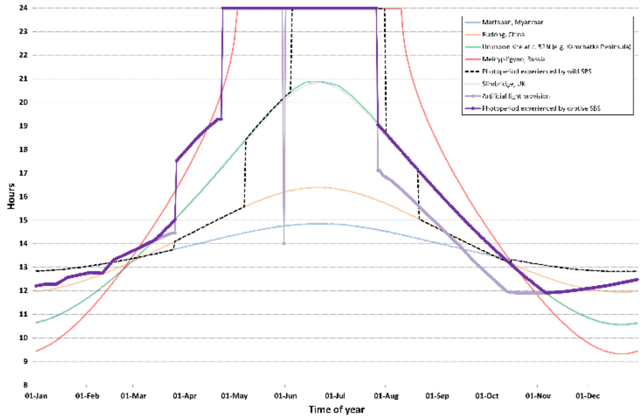
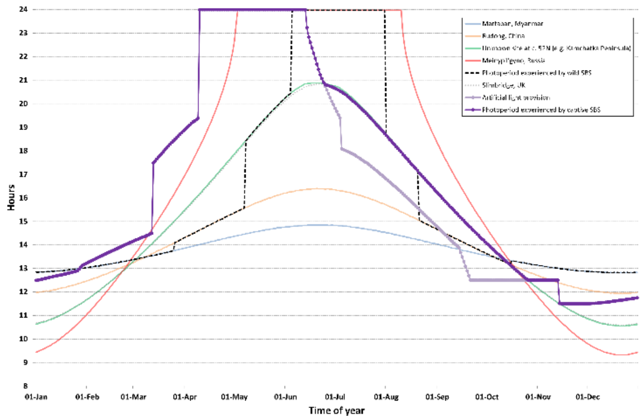
Figure 24 – Photoperiods for each year

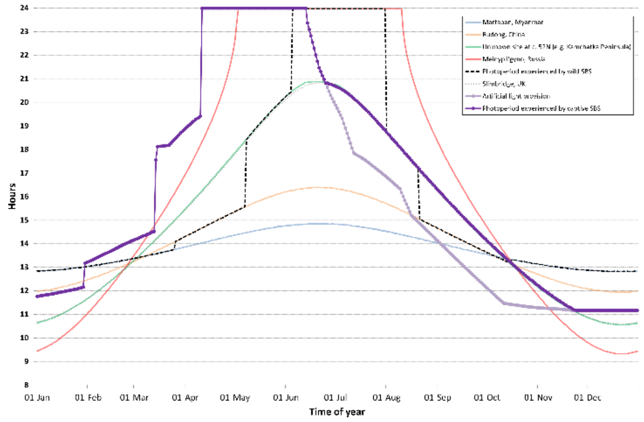
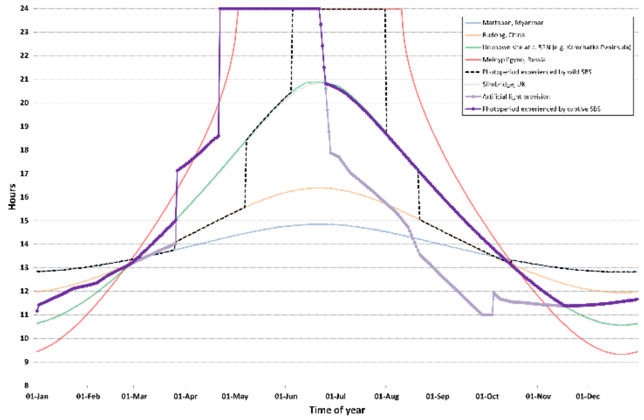
Notes:
Graphs are as above (Figure 23) with the addition of two purple lines; light purple = artificial lighting photoperiod as provided to the captive SBS; dark purple = photoperiod experienced by the captive SBS (i.e. artificial period superseded by natural photoperiod where relevant)
#1 - The sudden changes in artificial photoperiod occur in part to simulate the 'jumps' experienced by migrating wild SBS, but also due to the rudimentary light timers initially installed
#2 - To avoid being plunged into sudden darkness, the on/off times for the various lights in use were staggered by about one minute between each

Year/photoperiod	Explanation	Effects/observations
2012 [= leap year]  	Until March the SBS were kept indoors with no natural light sources. From April the SBS had access to outdoor aviaries and therefore experienced natural photoperiod from this point. See Note #1.	There weren't any recorded effects specifically related to this photoperiod. No breeding activity occurred this year, in part due to age but also due to aviary moves/types.
2013  	Windows were added to Room #1 and #2 in March allowing more natural light to enter. Faulty timers and power cuts caused some issues in August and November. See Note #1.	No breeding attempts were made this year; some heightened aggression during breeding season only.

Year/photoperiod	Explanation	Effects/observations
2014 	This was the first year with a 24-hour photoperiod during the breeding season. This was also the first year the cohorts were introduced, the first year both cohorts were of breeding age, and the first year the breeding aviaries were accessible. See Note #1. Note the spike when lights were accidentally left on overnight.	Breeding activity was observed from early April to late May/early June, though no eggs were laid. Activity appeared to begin early, most likely triggered by the (UV) lights being left on overnight mistakenly in late April (see visible spike).
2015 	Unfortunately, no evidence could be found to confirm that the 24-hour light was turned on for this breeding season. Hence, the above figure represents photoperiod provided by other lights in the facility; if the 24-hour light was indeed turned on, the pale and dark purple lines would follow the black dashed line for June and July (photoperiod experienced by wild SBS). See Note #1. New computer-controlled light timers and information cables were installed in October 2015, allowing transitions of light hours to be much smoother where appropriate. Lights could also now be faded on and off, rather than suddenly switched.	Breeding activity seen from late April to early/mid-June, though no eggs laid.

Year/photoperiod	Explanation	Effects/observations
2016 [= leap year]  	Returned to 24-hour photoperiod during breeding season (confirmed by records). The light timer system installed in October 2015 failed in autumn 2016; prior to replacement in mid-September, staff manually turned lights on/off in line with their working day (approx. 08:00-16:30 equalling 8.5 hours). The replacement timers could provide gradual increases and decreases in daily light provision but were unable to fade on and off. See Note #2.	Breeding activity seen from early April to mid/late June; eggs laid early June; two hatched although died shortly after.
2017  	Unfortunately, no evidence could be found to confirm that the 24-hour light was turned on for this breeding season. Hence, the above figure represents photoperiod provided by other lights in the facility; if the 24-hour light was indeed turned on, the pale and dark purple lines would follow the black dashed line for June and July (photoperiod experienced by wild SBS). There were two occurrences in late summer/early autumn where artificial lights were mistakenly left on overnight (see spikes). Rather than holding the SBS on a set number of light hours for winter the photoperiod began to gradually increase. This was done as the first step towards ‘time-shifting’ (see 2018) and made their winter period shorter. It was noticed in December that the lights were going on/off in the incorrect order; this was not thought to have affected the SBS and was corrected going forward. See Note #2.	Breeding activity from mid-May to late June. Note that the lack of eggs may be due to two 2016 breeding females losing their partners prior to the 2017 breeding season. Accidental spikes in autumn appeared to influence the SBS, with multiple individuals heard singing over the next few days after each occurrence.

Year/photoperiod	Explanation	Effects/observations
2018 	Following a shorter winter, with introduction of six-week time-shift – this brought the breeding season forward to spring to avoid intense summer heat. As the season was brought forward the Slimbridge photoperiod no longer affected the artificial photoperiod, so the SBS experienced the migratory jumps in location/photoperiod that wild SBS experience. They received 24-hours of light exactly six weeks earlier than wild SBS typically experience, with duration of this period extended beyond the usual eight-week breeding season by another five weeks and five days. The winter photoperiod incorporated an additional two-week time-shift, bringing the following breeding season forward by a total of eight weeks. This meant another short winter, shorter that in 2017/18. A power cut occurred in May resulting in the artificial light provided dipping to 14 hours for one day. As this occurred during daylight hours this did not affect the photoperiod experienced by the SBS. See Note #2.	Breeding activity seen from early March to mid/late May; eggs laid late April/early May; two hatched and one fledged but died shortly after. Early signs indicated the time-shift had the desirable effect, including moulting into breeding plumage six weeks earlier than in previous years. However, extending the breeding season yielded no additional clutches.
2019 	Following a shorter winter the time-shift increased to eight-weeks. 24-hour photoperiod was introduced eight weeks earlier than wild SBS typically experience, and extended by one week and two days. See Note #2.	Breeding activity from early March to late May; eggs laid late April; three hatched and two fledged (survived to adulthood).

Year/photoperiod	Explanation	Effects/observations
2020 [= leap year]  	A more typical winter length followed by another eight-week time-shift, with minor extension to breeding season. See Note #2.	Breeding activity seen from March to late May. No eggs were laid.
2021  	The SBS were given a longer winter (due to health issues/deaths from 2019), followed by a time-shift decreased to six weeks. See Note #2. A jump in artificial lighting occurs in winter to make up some time taken away the previous year.	Breeding activity seen from early April to late June; eggs laid mid-May, but none hatched. Winter 'jump' did not affect the SBS because the Slimbridge, UK photoperiod was longer.

2.2.3 Water

On the breeding grounds wild SBS would encounter melt water streams meeting brackish lakes, fed by the Bering Sea. They can also be seen pecking the snow for food prior to melting in June. During migration and throughout the winter they use coastal mudflats from the Kamchatka peninsula and Sakhalin in Russia, Democratic People's Republic of Korea, Republic of Korea, China, though to Bangladesh. Water quality varies with some concern historically and in recent years regarding pollution, both industrial and agricultural (Zöckler, Syroechkovski and Bunting, 2008; Zöckler, Beresford and Bunting, 2016).

2.2.3.1 Water quality

Chlorinated tap water was used throughout the facility in the stand-alone ponds and filtered systems with no additional chemicals or treatments used before the SBS had access, though the two filtered systems (2.1.5 Fresh water systems) each had a UV steriliser. There was no obvious detrimental effect of using tap water. Salt was added to some stand-alone ponds for the purpose of having access to brackish/salt water outside of the breeding season (no obvious detrimental effects of not having saltwater year-round). The filtered system in the polytunnels also had watercress added whilst in use for added filtration. No water was left standing before use (method sometimes used in captive collections to de-chlorinate the water). Naturally occurring invertebrates occasionally colonised the ponds in the polytunnel system which the SBS fed upon. Additional aquatic invertebrates (bloodworms) forming part of the SBS diet were also added to these ponds when SBS occupied those areas. Some aquatic invertebrates (defrosted brine shrimp and plankton) were fed in bowls of water rather than ponds as they created a visibly oily surface to the water and caused concern it may affect plumage condition if bathed in. All water bodies were refreshed regularly, with sumps, filters and pumps cleaned approximately once a week. Deep cleans of ponds were carried out as and when needed or at times minimal disturbance would occur, at least twice annually but more if algae build up was rapid. All water bodies contained a sand or gravel substrate banked up to the edges of the ponds and trays to allow the SBS access in and out. These substrates were cleaned or replaced as and when needed or at least annually for larger ponds/systems.

Occasionally ground water and wastewater would backflow into the filtered systems of the SBS facility when drainage systems of the whole site were generally under stress from high volumes of water e.g. after high rainfall. In these events the system was emptied and cleaned thoroughly and only used again once drainage was no longer an issue. This did appear to cause gut upset occasionally from the additional bacteria (seen by unusual coloured faeces).

In-house water quality testing was done in June and July of 2014 (Table 2). Water quality was found to be good. High levels of phosphorus seen in the June sample were likely because of food and excrement potentially entering the closed water system.

Table 2 – Water quality test results

Parameter / Sample code	Date sampled 23 Jun 2014	Date sampled 29 Jul 2014
Ammonia expressed as N - mg/L		
SBS1	0.12	0.08
SBS3	0.15	0.12
SBS4	0.05	0.26
Biochemical Oxygen Demand (ATU) - mg/L		
SBS1	4	8
SBS3	2	3
SBS4	3	5
Nitrate - mg/L		
SBS1	9.6	4.8
SBS3	9.3	23
SBS4	23	4.9
Phosphorus (Total) – mg/L		
SBS1	12*	0.12
SBS3	13*	0.78
SBS4	24*	0.16
Suspended Solids (Total) - NTU		
SBS1	10	10
SBS3	10	10
SBS4	10	11

Note: * High levels

2.2.3.2 Precipitation

Spoon-billed sandpiper in the wild experience significant seasonal changes in precipitation with minimal rain in winter/early spring (3-9mm), an increased amount during the breeding season (23-40mm) and most during migration with the highest at the end of autumn migration as they reach the wintering grounds (131-288mm) (Figure 25). In contrast, Slimbridge has a more consistent rainfall (54-78mm) increasing in autumn and winter (91-112mm) (Figure 25). However, the SBS were undercover in the facility for the first 8 years approx. as biosecurity was paramount to husbandry and so only a very minimal amount of rain entered through the mesh sides of the facility which they could been seen to actively stand in. The SBS were occasionally sprayed with a spray bottle of tap water during summer in extremely high temperatures which some also seemed to actively stand in. In March 2019 a misting system was installed above all breeding aviaries in an attempt to cool these aviaries by mist evaporation during the breeding season. This also saturated the middle third of these aviaries (underneath the misting nozzles) as it required use for prolonged periods for be effective, sometimes exceeding six hours a day. Having large areas of saturated/wet substrate that was continuously 'rained on' potentially impacted breeding (substrate suitability and locations for nesting). The misting system was not used to simulate precipitation that wild SBS would encounter; the misting system was not installed in any wintering areas to be able to do so. In January 2020 the polythene roof was replaced in part with mesh primarily to allow more natural sunlight in (detailed in 2.1.3.1) but also allowing natural precipitation into the facility. Biosecurity became less of a priority in order to give the SBS a greater chance to breed successfully.

Approximate locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Breeding grounds (Beringorvskiy, Russia)[1]					23	24	40	63				
Stopover (Pogibi, Sakhalin)[1]					46			79				
Stopover (Juegang, China)[1]				86				131	123	55		
Wintering grounds (Gulf of Martaban, Myanmar)[1]	3	5	9	39						288	94	15
WWT captive population Slimbridge, UK *[2]	93	63	54	60	54	66	73	78	91	96	112	98

Notes:

* Slimbridge UK precipitation not what captive SBS experienced and varied annually due to facility and husbandry changes

[1] Data from weatherbase.com

[2] Data from metoffice.gov.uk

Shade	Precipitation (mm)
	<50
	50-99
	100-149
	150-199
	≥200

Figure 25 – Average monthly precipitation at monthly associated location for wild adult SBS and captive SBS at Slimbridge

2.2.4 Air quality

Air quality was only formally monitored once during the project, in December 2019. This was done following increased coughing from staff upon entering the facility and when in other certain areas of the facility. The results were unremarkable. It was thought that the coughing may be due to synthetic fibres from the microfibre towels used under food dishes and in roosting areas shedding from daily washing in the washer/dryer. The microfibre towels were then replaced with linen and cotton towels in November 2021 which appeared to resolve the staff's coughing. It is unknown how or if the same fibres affected the SBS.

The SBS facility was built in close proximity to a large composting site approximately 40 metres away. In the early years of the project bonfires were held here regularly and on days this coincided with a north-easterly wind smoke and ash would blow into the facility and linger for several days after. It is not known how or if this affected the SBS. It was agreed in 2017 that bonfires would only be lit when a south-westerly wind prevailed to reduce the risk.

2.2.5 Sound and vibration

Where possible major sound and vibration disturbance was avoided or limited in the proximity of the SBS. However, not all could be eliminated. The SBS appeared more habituated to maintenance sounds (drilling, hammering, etc.) over time, though were never incapacitated by panic or stress when such noises did occur even as young chicks. The SBS where more reactive to loud or sudden noises generally during the breeding season, including aeroplanes flying overhead, triggering singing/displaying in males.

The SBS appeared most wary of other birds calls. They would react to alarm calls from wild and other captive birds, as well as calls from predatory birds. Depending on the threat (though not always identifiable to staff) they would either become alert and alarm call, crouch flat to the floor, run and hide, or fly. They would usually revert to normal behaviour after a few minutes or when the threat had passed.

The SBS have rarely been reactive to the sound of people, be it talking or going about routines. This may be in part due to a radio being played as ambience in the WWT facilities they were housed (QS and SBS facility) in the early years of the project.

2.3 Behavioural and Social Management

This section covers the social and behavioural dynamics of the captive SBS with explanation of significant events and decisions, and evaluation of the methods and outcomes.

2.3.1 Group structure

Generally, the SBS were housed as pairs during the breeding season and put together as one flock for the rest of the year. This appeared to be adequate to house the SBS in terms of social needs and welfare. The SBS typically acted as a flock when housed with multiple others with some indication of a hierarchical structure. It is difficult to say whether they are less or more settled the smaller or larger the group size. The SBS appeared more active when housed as a large flock compared to a small group, likely with more individuals creating/acting on more stimuli. When there were just two remaining males they appeared just as settled as the flock were when numbering 20+, possibly more settled with fewer triggering alert responses. They also appeared less active generally. Over time they may have become accustomed to the facility, with reduced sensitivity to potential threats due to the predator free nature of captivity or even age.

There were only a small number of cases of aggression severe enough to warrant intervention during the project. This was seen as aggression between males leading up to the breeding season, and some cases of bullying towards visibly weak individuals. They were either separated (into breeding aviaries if associated with breeding aggression, or isolated due to sickness/weakness) or visual barriers within the aviaries installed to reduce interactions.

Several housing strategies were trialled to facilitate successful breeding including allowing a small group to form their own pairs, moving males to breeding aviaries before females, and swapping females between breeding aviaries (details in 2.5 Reproduction). Testing/trials were usually done for one season only, unless they showed very positive responses.

The SBS, males particularly, would react to other SBS songs during the breeding season; both from others within the facility and from recordings taken from wild SBS they have never encountered with equal response.

2.3.2 Migratory needs

It was noted that the 2011 cohort, while housed in the rooms (before given access outdoors), would roost in the most south-westerly corner during that winter period regardless of where heat lamps/sources were located. Roosting positions/locations were not generally noted during the project, but this occasion was thought to be associated with migratory instincts. The orientation of the facility, and thereby location of the wintering and breeding aviaries, were built in mind of the prevailing winds, the space available and provision of sunlight rather than with direction of natural migration in mind.

The furthest breeding aviaries were positioned south-westerly of the wintering aviaries, meaning the spring and autumn 'migration' was reversed for the captive SBS (moving SW in spring and NE in autumn). It is not clear if or to what extent this effected the SBS in terms of welfare and breeding.

The captive SBS appeared to show signs of migratory restlessness in spring and autumn, seen as hyperactivity, darting about the aviary and making flight circuits around the aviary, though direction was not noted/able to be noted.

Prior to 'migration' the SBS usually only had access to one habitat type, summer or winter. During migration they have access to both types. Coupled with other sudden and gradually changes in husbandry (diet and photoperiod), this made up the captive equivalent of migration.

The importance of migration is possibly significant in preparation to breed, both physically and mentally, but the specific requirements for captive birds are not well known. There have been limited ways to simulate migration in this facility and therefore difficult to determine its importance and what aspects of true migration are needed for successful breeding of SBS in captivity.

2.3.3 Influence of other species

The SBS were only ever housed as a single species flock at WWT Slimbridge. They were in proximity of a captive Black-tailed godwit *Limosa limosa* flock housed approximately 15m away from 2016 to 2021 (closer on occasion during the breeding season). It was thought that the breeding pairs of Black-tailed godwit may have contributed to breeding activity seen in the SBS during the breeding season, either stimulation by their breeding calls and/or making the general area appear suitable for breeding with their presence. There was limited testing done (by having breeding pairs closer/surrounding the SBS facility for one year) to suggest how influential the godwit presence may have been. It didn't appear to have a significant effect, however the godwit pair that were housed closer to the SBS at the rear of the facility didn't settle well and did not breed.

Visible predators external to the facility impacted the SBS negatively with detrimental consequences, triggering evasion behaviours which lead to flight collision injuries. There have been multiple deaths associated with collision trauma however none were witnessed (all occurred outside of staff working hours) so the causes of these flights remain unknown. We do know that when calm the SBS are able to navigate the aviaries well during flight. We also know that Sparrowhawk *Accipiter Nisus*, Buzzard *Buteo buteo* and gulls triggered alert responses in the SBS. It is probable that owls cause the same reaction.

On several occasions a Wren *Troglodytes troglodytes* was seen in the areas the SBS occupied. They actively avoided it and appeared stressed until it was removed. Small birds within the facility but not in the areas occupied by the SBS did not seem to affect their behaviour. The SBS encountered large flocks of waders, ducks and geese seasonally as they migrated through/arrived to Slimbridge reserve but didn't appear to react on them.

2.3.4 Human interaction

Generally, human interaction throughout the project was kept to a minimum where possible but maintained at a level where human presence would not cause stress. Any interactions served a purpose to maintain the health and welfare of the SBS. This included, daily feed/clean routines, daily observations, remote weighing, moult scoring/photography, health checks, treatment administration, facility/equipment maintenance, moving pairs to breeding aviaries, nest location, egg collection, and nest scrapping. In the early years commented feeds were livestreamed to WWT Slimbridge centre.

Every breeding season it was noted that human presence stimulated adults to sing and display. It is not clear why they did this or if it was detrimental to breeding outcomes. Possible hypotheses are 1) they were partially imprinted and therefore stimulated to react on humans as a conspecific, either as a potential partner or as competition, and/or 2) SBS associated humans with high value (rationed) food and were generally stimulated to react, which during the breeding season is shown as breeding behaviours.

Where possible, chick rearing was done in groups of similarly aged chicks to reduce possibilities of imprinting but human interaction during rearing of the 2011 cohorts was more intense given the circumstances of translocation. Recordings of adult calls were played back during indoor rearing for all SBS chicks. One chick in 2018 was reared alone (its only nest mate died very young) but did not appear imprinted to humans and integrated into the adult flock without issue. However, long-term effects were not known as the chick died soon after fledgling (from flight collision).

Visitors (including contractors) were limited where possible to advisors and VIPs, though much unforeseeable maintenance was required throughout the project. Strictly no visitors were permitted during the breeding seasons. After the death of the last female, restrictions to visitors were less stringent. No longer able to produce chicks, the captive SBS and facility then served educational and awareness purposes with plans to open the facility for public tours.

Overall, the SBS were very relaxed in the presence of humans. It had been observed that they appeared nervous of staff that perform routines irregularly, though not to a concerning degree.

2.3.5 Training

Generally, any training and habituation was done for the health and welfare of the SBS e.g. remote weighing, and to minimise stress during interactions. When the SBS were fed live crickets, a high value food item, during daily observations the person feeding them would whistle. This acted like a recall enabling staff to move the flock between aviaries, when necessary, without herding/pressuring them to move. Habituation to new objects was done gradually also with the use of high value foods near objects until desensitised.

After the death of the last female, it was decided the remaining SBS could tolerate more interaction given their primary purpose was no longer to breed. The captive SBS generally appeared adaptable in terms of introduction of unusual items and unusual staff behaviour when gradual desensitisation was done. An example of which was for National Geographic's Photo Ark (https://www.nationalgeographic.org/society/our-programs/photo-ark/) in June 2022 (Figures 26a and 26b). Large boards were initially introduced covered with sand and gradually reduced of sand until clear boards remained. They also needed to become accustomed to staff laying in front of the boards with a large camera and portable lights and be comfortable to feed and stand on the boards. They also needed to be desensitised to the equipment being moved in and out of the aviary. This desensitisation began one month prior to the event two to four times a week.

The SBS also seemed adaptable to larger numbers of people present within their aviary with little prior desensitisation (up to 7 within a 10mx10m aviary, though this in part was possible due to fewer SBS present). In spring 2022 the SBS facility was adapted to host public tours with an in-aviary experience with the SBS (Figure 26c).

26a. First day of desensitisation to limited amount of equipment (May 2022)

26b. End result, photographing the SBS for National Geographic Photo Ark (June 2022)

26c. Leading a tour group (of internal staff initially) with an in-aviary experience (June 2022)

(All photographs credit: WWT)

Figure 26 – Photographs showing training and habituation

2.3.6 Enrichment

The SBS were provided enrichment that improved their health and welfare via means that were appropriate for a conservation breeding programme. Some of these were deliberate, though many were a biproduct of another feature or function. For example, various water bodies were provided throughout the facility and when cleaned the sand banked at the edges was also rinsed. The SBS appeared naturally drawn to the 'tide' of water revealing food items under the sand. Raking the substrate also revealed food items; some individuals would follow staff as they raked the aviaries. In the early years of the project sprinklers and hand misters were used around the SBS which they would choose to stand in, they have also been seen standing in the rain. In later years a misting system was installed (for the purpose of reducing temperatures) which they would choose to stand and forage in. Spoon-billed sandpiper appeared to be attracted to rain or water dripping down netting, pecking the drops when they were within reach. Natural snow events were always utilised by the SBS (Figure 27), seemly very interested in foraging within it. In January 2019 artificial snow was purchased and placed in the wintering areas for the SBS. This was a trial prior to the breeding season to further mimic naturalistic conditions, which they were very interested in foraging upon/within (wild SBS arrive to the breeding grounds with much snow still present in the area). It was not purchased again closer to the 2019 breeding season due to a natural snowstorm in the area in which snow was deposited in the aviaries, this occurred in March. Extra to their diet the facility would give rise to natural live food at different times of the year. Cranefly and cranefly larvae, moths, caterpillars, spiders, spiderlings, water fleas, worms, to name a few. The SBS would pursue the fast-flying insects readily. Occasionally new dietary food items were offered though these were most often dietary decisions rather than for enrichment. Artificial Christmas trees were provided to break up the eyeline, these were used by the SBS as roosting spots and foraging opportunities. In later years of the project more shrubs and grasses were added to breeding aviaries to break up the landscape and diversify the habitat. Large drainage pipes were added to aviaries covered in sand and turf to provide vantage and display points, also shelter.

The SBS were never given any enrichment to exercise physically or mentally unless it was to provide opportunity for naturalistic behaviour i.e. no toys or puzzles for example.

2.3.7 Management of aggression

Leading up to the breeding season the SBS did show increased aggression towards each other, almost always triggered by high value food resources. These encounters were usually resolved by the individuals involved quickly, with one backing down and running away. There appears to be a hierarchy enforced during these encounters. Individuals that are evenly matched will have prolonged encounters that usually start with posturing and calling or singing, progressing to pecking/stabbing, pulling feathers, and ending with one being pinned to the floor under foot and bill until it escapes. There was only one case during the project where individuals were separated due to aggression (early May 2014 two 2011 cohort males showed no signs of stopping their fight and subsequently all SBS were placed in breeding aviaries).

Some seemly aggressive behaviour between pairs during the breeding season appears normal. Both males and females will chase their partner, sometimes over food and at other times over what appears to be out of excitement. The pursuer doesn’t chase for long. If the pursuer chases for long periods or repeatedly with the pursued becoming tired or showing signs of stress then likely the pair are not well matched, and females were usually swapped to make better pairings.

[Credit: WWT]

Figure 27 – SBS foraging after snowstorm (March 2018)

2.3.8 Introductions/reintroductions

Generally, introducing or reintroducing single or groups of SBS was relatively event-free. With all introductions the groups/individuals were able to hear each other for some time (usually several weeks) before being introduced to the same space. Major introductions, such as between the 2011 and 2012 cohorts, was done in a mutual area (the MA). On this occasion there was some minor aggression between some individuals the same day as the introduction, but they acted as a flock almost immediately with the majority of individuals seemingly indifferent to the event.

Introducing juveniles to the adult flock in the adult space saw the same indifference by the adults. The chicks appeared nervous at first, but this appeared to be more likely from being in an unfamiliar area. They mingled with the flock immediately without hesitation, likely instinctually since nervous/stressed.

Reintroducing individuals after being separated into pairs and breeding aviaries was also never an issue. Reintroducing sick individuals after being separated for quarantine or treatment, especially if still visibly unwell, was done with caution and extra monitoring as it has been known for sick SBS to get picked on by others.

2.3.8.1 Deaths/removal of individuals

It is not well observed if or how deaths/sudden removal of individuals affects the rest of the flock. There have been some instances of heightened aggression after a death, perhaps to reestablish a hierarchy, but records suggest this isn't consistent.

When only two (male) SBS remained, including a five-year-old individual, discussions arose regarding welfare considerations should one die, leaving the other isolated. The two remaining SBS died within a day of each other (both were of ill-health) with the longer surviving individual showing noticeable behavioural changes, including increased vocalisation and seeking proximity to the aviary door, seemingly to actively search for a companion. This suggests that SBS accustomed to social environments may experience distress and behavioural abnormalities when housed alone after belonging to a flock.

2.4 Health

Health of the captive SBS was monitored and maintained in a number of ways throughout the project; through direct observation, nutrition and diet, biosecurity and hygiene protocols, phenological monitoring (body weight and moult), diagnosis and treatment, and stress management. This section explains the practices that were in place to monitor and maintain health, how they developed over time, and why changes were made.

2.4.1 Biosecurity

To contribute to the high level of biosecurity of the SBS facility there was only one entrance/exit for personnel (Figure 28) (though there was an additional door at the end of the polytunnels to move large or heavy objects in/out, cleaned and disinfected upon entry). Upon entering the building there was a portal to remove and store outer/dirty clothing and shoes. There was a sink to wash hands with soap and hot water. And finally, there was a barrier to step over into clean footwear that was for sole use in the facility. This footwear was stored in a disinfectant foot dip. It was not permitted to enter the facility if you had been in contact with other birds (wild or captive) in the preceding 24 hours or up to 72 hours during avian influenza season. Any new equipment or resource entering the facility was cleaned and disinfected at the entry portal.

(Credit: WWT)

Figure 28 – Entrance portal to the SBS facility (2012)

Additional foot dips were located at the entrance of every occupied aviary. Staff who entered aviaries (whether occupied by the SBS at the time or not) wore additional clean scrub uniform over their clothes (this also acted as a catch for any threads or debris that might be on personnel clothing). Hair nets were also worn to reduce the risk of stray hairs that could (and have been known to) entangle SBS feet and cause significant damage.

Attempts were made at several points in the project to try to quarantine a number of individuals from the rest of the flock within the SBS facility (for various reasons). As there are separate closed water systems within the facility and confined areas this appeared possible. However, although all possible measures were taken, it appeared that cross contamination still occurred to some degree.

The facility was designed to be pest and predator proof, although there were multiple instances of small birds and rodents entering through small holes or gaps. It is worth noting that, despite the SBS facility being located in an area of high wild bird traffic, biosecurity measures appeared effective in protecting the SBS from diseases found in wild and captive birds on-site, including Highly Pathogenic Avian Influenza Virus (HPAIV) between October 2020 and November 2023.

2.4.2 Hygiene

Hygiene was maintained by a series of protocols ranging from daily to annual, the use of high-quality cleaning and disinfection agents, and staff awareness and training.

The following disinfectant products and chemicals were used according to manufacturer dilution rates:

- F10 Antiseptic Solution products: Cleaning all incubation and rearing equipment, disinfecting substrates before SBS had access, fogging indoor areas before/after quarantine or incubation and rearing purposes, disinfecting breeding aviary water system, dipping towels before use under food dishes.
- Safe4 Disinfectant Cleaner products: Foot dips, cleaning ‘feed and clean’ routine equipment, cleaning aviary panels/nets.
- Brinsea Disinfectant: Occasionally used with distilled water for humidity in incubators and hatchers. Also used to ‘dip’ eggs for disinfecting when required.
- Bleach: Formerly for disinfecting breeding aviary water system until alternative de-greaser sourced.
- Virkon Disinfectant: Formally used for foot dips.
- Jeyes disinfectant fluid.
- F10 degreaser (disinfectant).
- Potassium permanganate: Formalin used to fumigate incubators.
- Washing detergent (non-bio).
- Hand soap.

Products used around the birds were selected from Department of Environment, Food and Rural Affairs (DEFRA) approved brands and recommended dilutions for notifiable diseases (e.g. HPAIV). Changes were made in compliance with national guidance from DEFRA, as well as in response to environmental and sustainability assessments conducted in-house. For example, following revision of the benefits and environmental risks associated with the use of Virkon disinfectant against those associated with Safe4.

2.4.3 Routines

Daily

The SBS aviaries were serviced twice a day, at approximately 08:30 and 15:30 (but whether it was a full or partial service was dependant on breeding activity). Faeces were swept up and disposed of and any dropped feathers collected, recorded, and stored. The substrate was raked for aeration and to provide a softer substrate; this additionally gave the opportunity to assess aviary use and pacing behaviours incurred after the last service. Dry food dishes were replaced in the morning and topped up where necessary in the afternoon. Wet food dishes were replaced both morning and afternoon to prevent bacterial build up. Towels dipped in antiseptic solution were placed under food dishes, in roosting areas, and in areas of high SBS traffic. The towels were machine washed every morning and any that were soiled during the day were replaced in the afternoon. Stand-alone water bodies (salt and fresh water) were refreshed at least once a day, and the ponds or trays were also cleaned/scrubbed. Water bodies on a filtration system were refreshed and cleaned/scrubbed every few days. Spoon-billed sandpiper observations were made every morning, with each individual monitored for a few minutes and any notable health or behavioural observations recorded (daily record sheet example provided in Annex 3).

Foot dips were refreshed every few days and indoor staff areas cleaned every day (all surfaces wiped/swept and mopped where appropriate). The facility was regularly checked (internally and externally) for any maintenance needs, with the netting and mesh housing of the SBS checked daily. Live food was fed and watered at least every other day (further information on live food provided in Section 2.4.7 Diet and nutrition).

Weekly

The SBS were remotely weighed once a week; but not every individual was successfully weighed at each attempt and routine weighing was ceased during the breeding season. During times of moult (twice annually) they were moult scored once a week and record photos taken of each individual.

UV readings were taken once a week and bulbs replaced as and when needed. Filtration systems were thoroughly cleaned once a week with water completely refreshed. When the rooms were occupied by the SBS the walls of the tent were wiped down with disinfectant at least once a week. Any live food was cleaned out once a week. In the later years of the project, timers for the lights were manually input once a week.

Monthly

Temperature loggers (ibuttons) for each aviary were downloaded and data formatted once a month. Vegetation management occurred as and when needed but was limited during the breeding season to avoid disturbance. Monthly reports were written collating the health and husbandry data for that monthly period.

Seasonally

In spring, once temperatures and weather became more stable, the indoor winter area (room/tent) was shut down, all sand and heating and lighting equipment removed, and the tent taken down before being thoroughly cleaned, disinfected, and fumigated, all for potential use as a rearing area in case the SBS laid during the summer. The additional unused room was also cleaned and disinfected for use as an incubation room. All incubation and chick rearing equipment was cleaned and disinfected before use and appropriate heating/cooling equipment and lighting added. Foot dips, footwear change barriers, and personal protective equipment were also added to the entrance of the rooms to facilitate a certain level of biosecurity separate from the adult SBS.

Aviary preparation for the breeding season included vegetation management, cleaning the partitions between aviaries, adding sand to ponds, disinfecting then rinsing the whole breeding aviary water system, descaling and cleaning the misting system, and replacing worn or damaged micromesh including around the UV units. Some areas were re-landscaped, turf replaced, shrubs and grasses added/replaced, sand topped up in sparse areas or replaced in heavily used or soiled areas.

Watercress was also added to the ponds once the water system was running just prior to the breeding season to help with water filtration. All substrates were disinfected prior to the SBS having access.

During the breeding season vegetation management within the facility was only conducted when absolutely necessary, such as when it hindered movement of the SBS around the aviary. Turf and plants beyond the range of the misting system were watered when needed in the occupied breeding aviaries, provided this did not disrupt the SBS.

After the breeding season the ponds in the breeding aviaries were emptied of water, sand, watercress, and disinfected. Vegetation management continued where necessary.

Indoor aviary preparation for winter use included cleaning and disinfection of rooms to be occupied, erecting the indoor tent plus cleaning and disinfecting it, adding sand and disinfecting it, adding/maintenance of lighting including UV units surrounded with micromesh, addition of oil heaters and heated soil cables, and adding pipe lagging to exposed corners/edges of the pop-holes.

2.4.4 Monitoring

2.4.4.1 Body weights

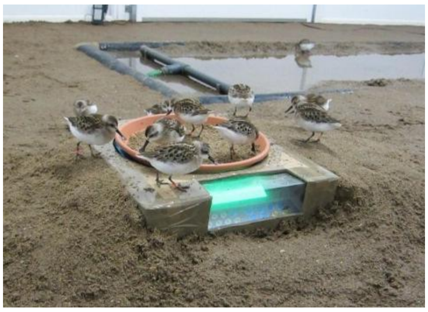
Tracking body weights provided an indication of seasonal fluctuations and normal weights. Changes in weight could be used to monitor the health of individual SBS and provide an early indication of potential health concerns.

There is limited data for wild SBS body weights, the majority during June and July (from two breeding populations) and some from September (stopover site). Sparse body weight data exists for April and October. Therefore, it is difficult to determine what an average annual weight cycle for SBS might be and at this stage it’s not easy to suggest what strategy might be used. From available wild SBS data we can see that body weight on average decreases slightly over the breeding season, and into autumn migration. From June to September approximately 33.8g to 31.8g, around 6% (bearing in mind it’s not possible to know whether all data are from SBS that have migrated and bred). We know that during both autumn and spring migration SBS will make multiple stopovers (four plus) for periods between 3-9+ days per stop to refuel which may be sufficient to roughly maintain body weight as is suggested here. More body weight data may be key to decision making regarding diet and nutrition provision going forward.

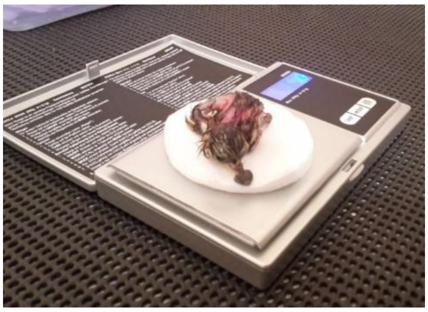
Weighing methods

To remotely weigh the SBS, their strong drive for live food was used as positive reinforcement. They were lured on to a regularly used (familiar) dish atop weighing scales, which were partially buried in the substrate to allow access to the dish/food (Figure 29a). Several weights were recorded for each individual and a mean weight calculated. If an SBS required handling for examination or treatment it was weighed inside a small cardboard box with a flattened tissue on the bottom.

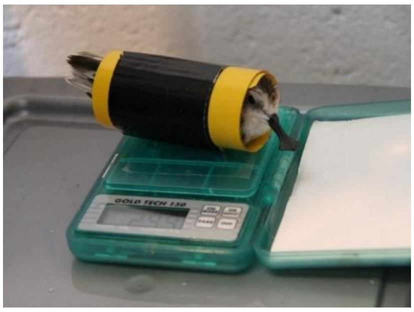
Spoon-billed sandpiper hatchlings were typically weighed on cotton pads (Figure 29b) and, once mobile, they were also weighed in small boxes. Between 2011 and the end of 2012 the SBS were regularly caught for weighing as part of frequent health assessments and placed in an immobilising plastic tube (Figure 29c).



29a. Setup for remote weighing (2013)



29b. Setup for hatchling weight (2018)



29c. Setup for early years weighing (2011)

(All photographs credit: WWT)

Figure 29 – Photographs showing weighing methods

Early rearing weights for the 2011 cohort are missing from the data set. The chicks that bred in 2018 were also excluded unless otherwise stated. Death weights are not included. Birds with ill health are included unless otherwise stated.

Body weight: sexual dimorphism
As shown in Figures 30 and 31, females are typically heavier than males, this is also true for wild SBS (van Gils *et al*., 2020).

Body weight: seasonal changes and cohort comparison
As anticipated, the SBS began to show seasonal variation in body weight at the appropriate times of year, increasing through autumn to a peak in winter and decreasing early spring to a trough in early summer. This rapid weight gain and weight loss is typical for migratory birds, requiring energy (i.e. fat reserves) to migrate in spring, then refuelling at stopover and wintering sites (where SBS will then undergo wing moult requiring further energy) on their return south (Scott, Mitchell and Evans, 1994). The captive SBS went through these seasonal periods of peaks and troughs in body weight in their first three years from hatch (Figure 30) for all cohorts, though reduced in extremity each year. In their fourth year this annual weight cycle appeared to level out maintaining a rough average all year round for the remainder of life.

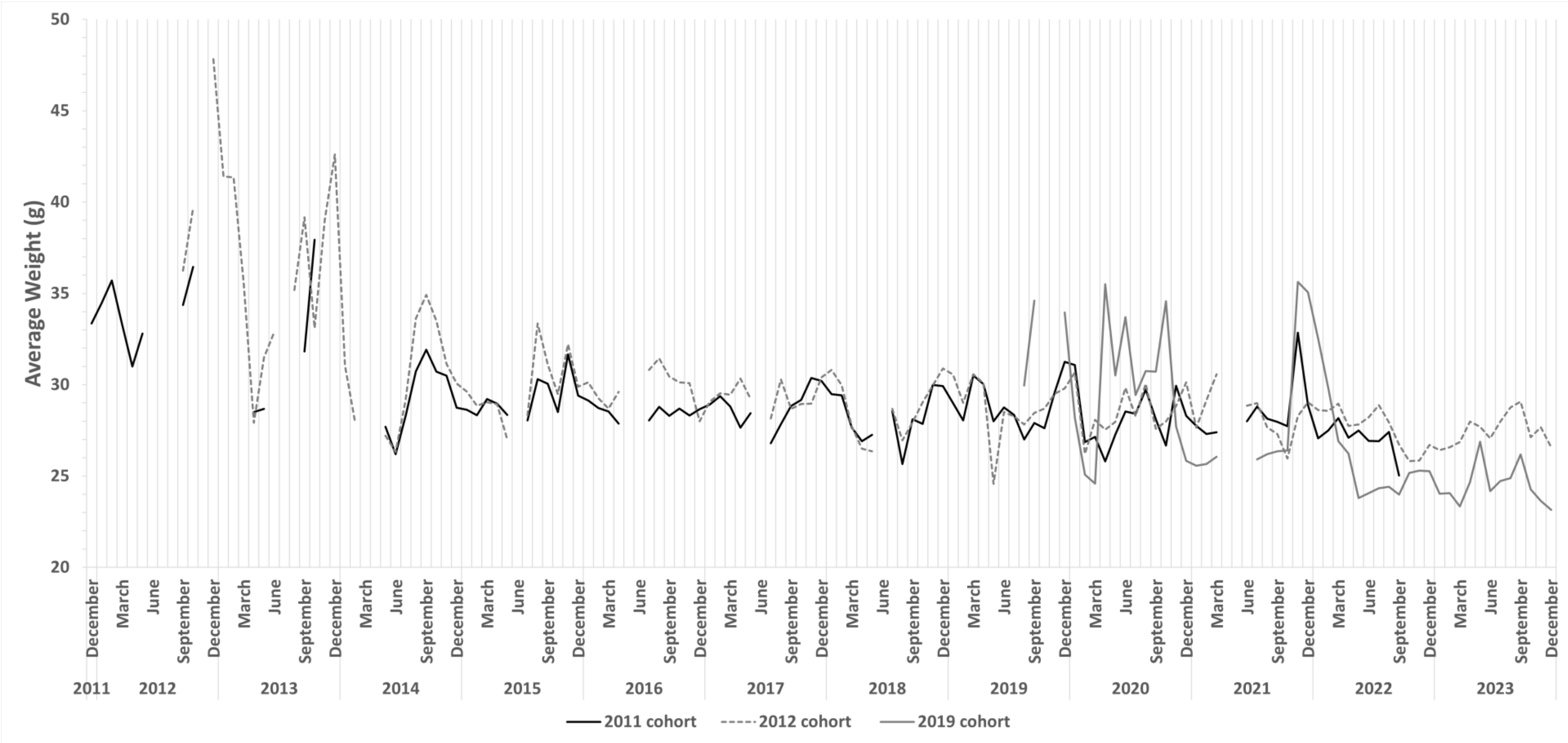


Figure 30 – Average monthly cohorts body weights, all birds, 2011-2023

The levelling out of average body weight for both the 2011 and 2012 cohorts coincided in part with a major diet change in terms of protein content; a typically used seasonal diet change for breeding birds in captivity. Once fledged and weaned onto an adult diet (all by late 2012), the protein content remained fairly consistent (until spring 2014), allowing them to self-regulate their protein intake which may have allowed them to intake what's required resulting in seasonal variants in weight. Note there was an increase in protein in 2011 cohort (not 2012 cohort) from January to April in 2012 which also potentially altered average weight.

All SBS were given a diet higher in protein in 2014 from spring and through summer (breeding season) and a lower protein diet during the winter of 2014/2015, the lowest protein content offered thus far (they continued this seasonal pattern of high/low dietary protein level thereafter). The observable peak and trough in average body weight appeared to be affected again; they peaked earlier and to a much lower average regardless of cohort. By late 2015 there was virtually no seasonal gain/peak or loss/trough seen in the captive SBS (Figure 31). Possibly, they were given a higher protein diet during the breeding season when wild SBS would have a diet possibly at its lowest, also potentially reducing the captive SBSs' ability to self-regulate. However, the effect of captivity is likely to play a significant role as well, given the captive SBS do not undergo any periods of migratory exertion, they do not need such high fat reserves. This weight trend over their lifetime is possibly the result of the body's response to adapt after repeated years without migration.

It is worth noting that the total amount of food offered (where protein content remained the same) was decreased for the 2012 cohort (not 2011 cohort) for January, February, and December in 2013 in response to high weights due to poor foot condition associated with high weight (and feather cutting). Despite the change in quantity, the SBS still showed a peak and trough of a typical annual weight cycle (Figure 30). The 2011 cohort didn't receive any diet changes and also exhibited the same seasonal weight changes during this period (from 2011 to spring 2014, the 2011 and 2012 cohorts were housed separately). Note the protein content of the diet was reduced overall in 2017 (after an occurrence of gout) but continued with a higher protein proportion during the breeding season only.

Maintaining a circannual cycle is known to be important to health and welfare of captive animals including birds (Berger, 2011; Gandia, 2023), making it plausible that it would also affect breeding potential. Preliminary investigation suggests captive SBS are on average 3-4g lighter than wild SBS on arrival to the breeding grounds. It also appears that in years which the captive SBS bred, their average body weights were more comparable to wild SBS body weights. This suggests that the captive SBS with lighter body weights going into the breeding season were likely not in a condition suitable for breeding. It also appears that wild male SBS keep a relatively average weight (possibly even gain weight) through June and July while females lose weight slightly (approximately 3% of body weight) likely a result of egg production. Captive SBS appear to lose weight rapidly during the breeding season possibly making second clutches much less likely (no second clutches ever produced at Slimbridge). The rapid weight gain seen in the male birds in November 2021 (the first without females) (Figure 31) could be due to reduced competition for food (female captive SBS are notably more dominant than males). It may be possible that the separation of sexes is meaningful to SBS circannual cycle, or at least in reducing competition, and therefore possibly breeding success, allowing males (and females) to gain mass/condition before the breeding season.

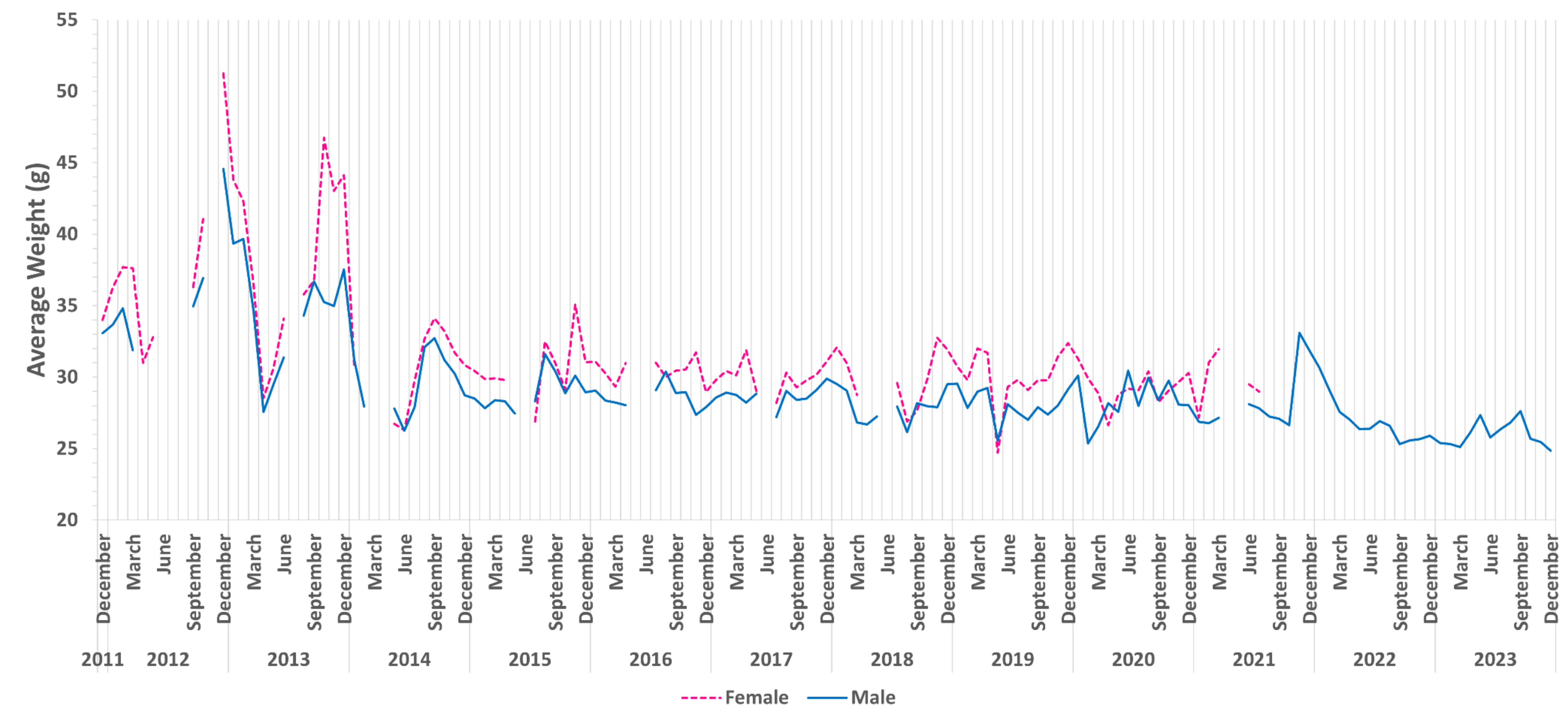
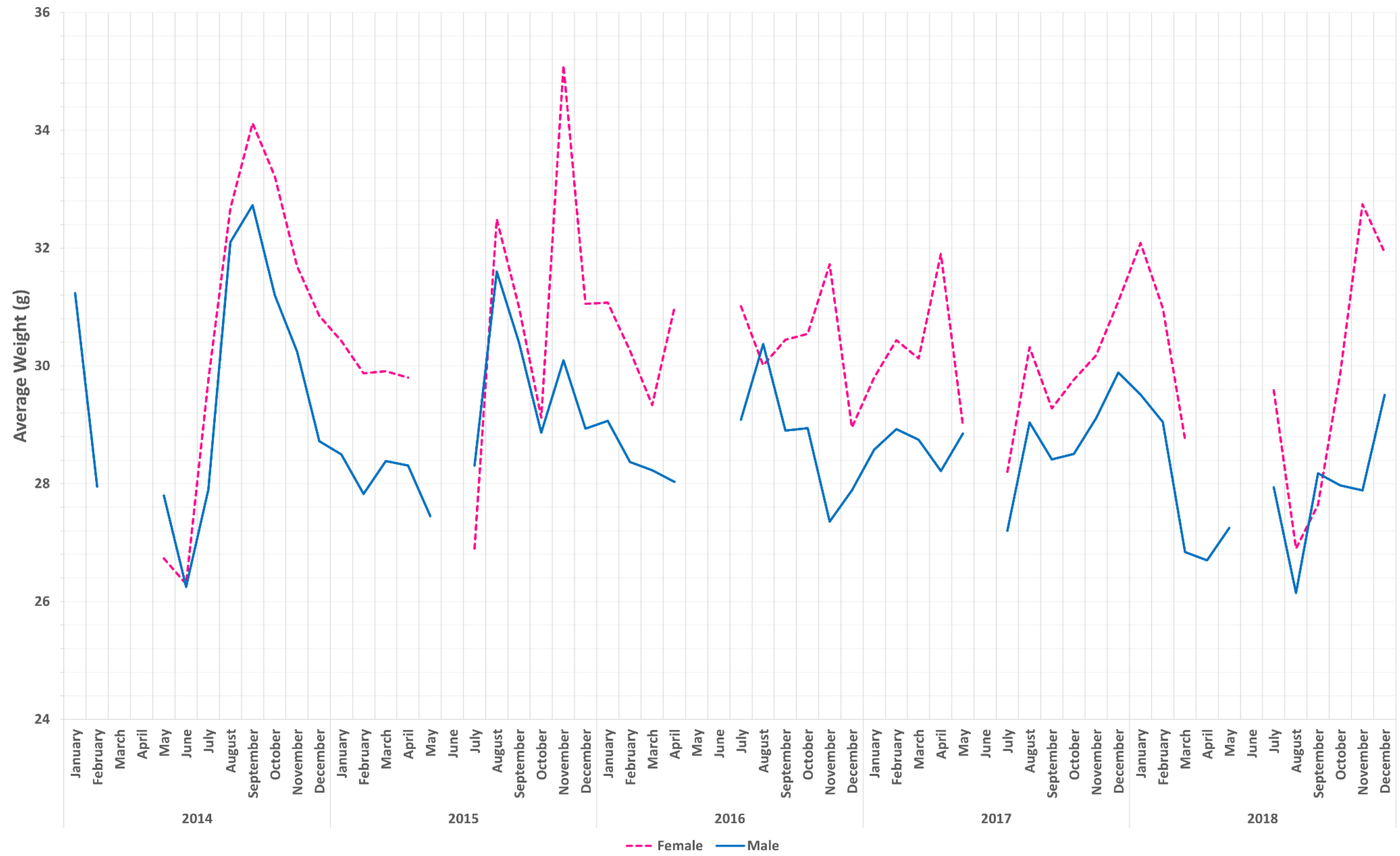


Figure 31 – Average body weights for male:female, all birds, 2011-2023



Note: Juvenile data excluded, and Candidiasis infection period excluded

Figure 32 – Average body weights for adult male:female, 2014-2018

The 2019 cohort seemed to fluctuate in body weight more inconsistently in the first 2-3 years (Figure 30). This was likely due to stress of moving aviaries fairly regularly by comparison which appears to correlate with weight losses. These birds were reared in a breeding aviary from June to December 2019 where they gained and maintained weight. They were then moved to a room/annexe combination for winter shelter, which could explain the first rapid weight drop. In March they were moved to a breeding aviary where they began gaining weight. This fluctuated until November when weight rapidly decreased again. This coincided with another change in living space (2020 Annual Report, Annex 5). In December 2020 they were moved again to the main adult flock with the 2011 and 2012 cohorts. Here they maintained an average body weight until winter 2021/22 where they showed a typical seasonal weight change, increasing over winter, and decreasing again in spring. From this point they appeared to show the same year-round average weight as the 2011 and 2012 cohorts did as adult birds.

The extreme weight highs seen in early years in the 2011 and 2012 cohorts can be, in part, attributed to a rich diet and a small warm area to occupy with reduced mobility; this would correlate given the 2019 cohort started on a lower protein diet from hatch and reared in more suitable temperatures (developed with experience in both conservation breeding and headstarting of SBS). It is worth noting the 2019 cohort birds appear visibly smaller and on average weighed less than the other male SBS. The eggs from which they hatched were lighter on average than the eggs which the 2011 and 2012 cohort came from (using estimated fresh weight) by 0.57g, approx. 7%. They were also slightly smaller in terms of length and breath. The 2012 cohort appeared particularly high in body weight in the early years which, coupled with other factors, lead to chronic foot issues that lingered with many birds throughout life. High weight may also be attributed to a relatively stress-free life in captivity, and small warm spaces to occupy (relative to wild SBS). As wild SBS juveniles remain in the southerly part of the range for the first two years of life it is not unreasonable to believe that they too follow a similar weight pattern, though it is not clear if it is to the same extent we have seen in the captive SBS.

Captive SBS appear to be heaviest in their first year of life, gradually reducing until around four years of age where they reach a fairly constant yearly average (Figure 33). This may not be typical of wild SBS; data for comparison is insufficient.

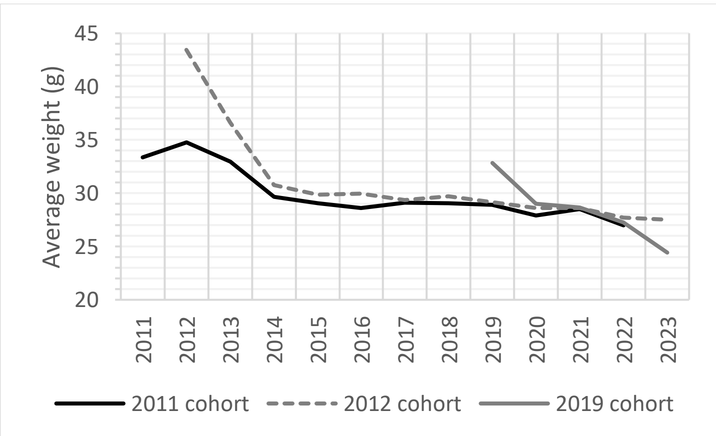


Figure 33 – Average annual weights for each cohort

Body weight: captive bred chicks

All eggs laid at the SBS facility were, on average, smaller than those laid by wild SBS. The SBS bred in 2018 (second egg of second clutch i.e. 2:2) appeared to follow a typical weight gain pattern (based on Gompertz model) seen in wild SBS (Figure 34) despite being a slightly smaller chick than average wild SBS, approx. 6% smaller. The chicks bred in 2019 (1:1 and 1:2) also started as slightly smaller chicks, also 6% smaller, but did not follow the expected weight gain trajectory in those early days (Figures 35 and 36). As adults the 2019 bred SBS were 2.5g lighter on average than other adult males in the captive flock, 9% smaller. The diet provided to the chicks reared in 2018 and 2019 was largely the same. Some variances occurred which may have altered the weight gain outcomes somewhat, though it is not conclusive. Quantities of each food item may have also been different. The main food source was offered ad-lib, but quantities of live food offered may have been different (not weighed).

Chicks that did not live longer than three days have not been included here.

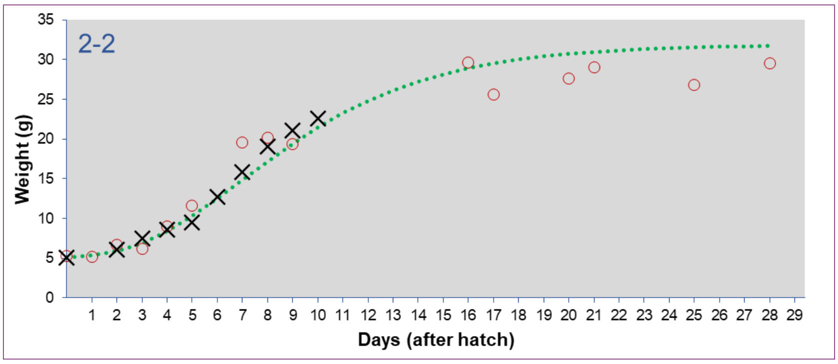


Figure 34 – 2018 bred chick (2/2) rearing weights

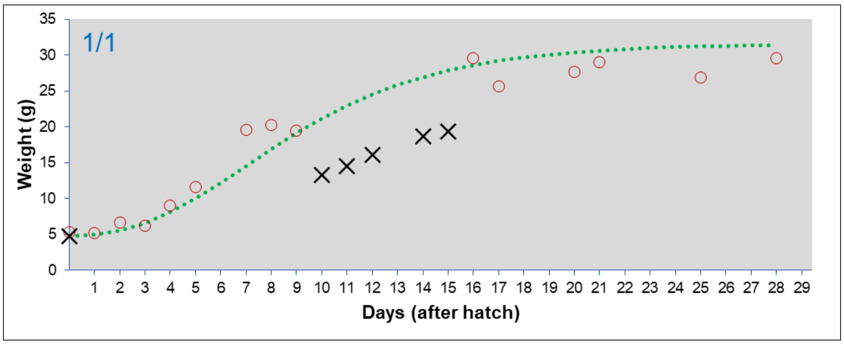


Figure 35 – LBRL (1/1) rearing weights

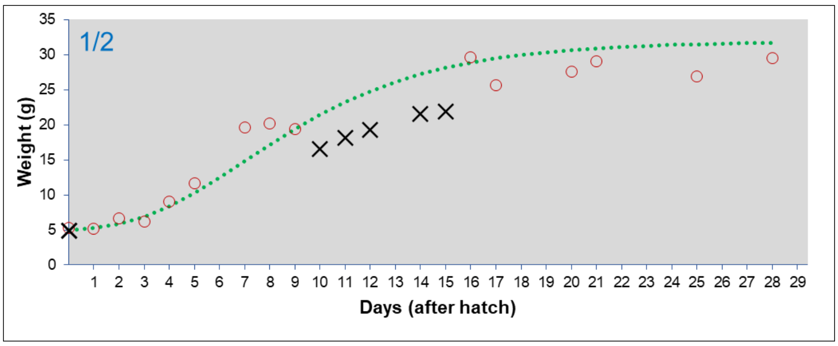


Figure 36 – LBDGL (1/2) rearing weights

Gompertz curve O Wild chick data X Captive chick data

2.4.4.2 Plumage

Moult scoring and plumage quality assessment was another indicator used to determine the health status of the captive SBS (when the SBS in question were all subject to the same environmental conditions/cues e.g. photoperiod, temperature etc.).

Tracking moult patterns gave an indication of seasonal norms. A slow, incomplete, or intermittent moult could often be a sign of ill health, whereas progressive and complete moult was an indicator of good fitness. Unwell SBS generally preened less frequently, causing their plumage to appear unkempt or greasy. Superficial wounds could be identified by blood-stained, parted, or missing feathers. Eye issues often resulted in damp feathers around the eyes and back from rubbing. Damp feathers around the nares or marks of dried discharge could indicate respiratory issues, while wet feathers around the mouth could suggest regurgitation and potential gastrointestinal concerns (SBS bring up pellet naturally but this does not usually affect the birds appearance). Spoon-billed sandpiper that consistently appeared wet and struggled to dry out after bathing or rainfall, with feathers in poor condition, could also be a sign of ill health. Sick/weak birds may find it difficult to maintain feather condition through preening, though it can be a direct issue with the preen gland itself.

Plumage appearance

The winter plumage for the captive SBS (Figure 37a) appeared much the same as wild SBS, though they did not always reach full winter plumage whereas wild SBS are not often seen with retained summer plumage (Table 3). First winter plumage for the SBS bred at WWT Slimbridge appeared more brown than grey (Figure 37b). Though this could be due to wear/captive conditions.

(Credit: WWT)

37a. Adult captive SBS in full winter plumage

(Credit: WWT)

37b. Chick bred at WWT Slimbridge part way through moult from 'first-winter' plumage (brown feathers) into 'adult-winter plumage' (silver grey feathers) (Dec 2020)

(Credit: WWT)

37c. Photograph showing two full summer plumage captive SBS (PRR and PDGR 2018) (Credit: WWT)

(Credit: Wyatt Egelhoff 2019)

37d. Photograph showing a full summer plumage wild SBS (Lime 07), later in the breeding season (21 July 2019)

Figure 37 – Photographs showing plumage appearance

Table 3 – Proportion of adult captive SBS that reached full winter plumage

	2015/16	2016/17	2017/18	2018/19	2019/20
No. of birds reaching 1-1.5 moult score*	17	17	14	17	12
No. of adult birds present (max/Nov)	23	22	19	19	13
% reaching full winter plumage	74%	77%	74%	89%	92%

Notes:
Winter months span two years
Refer to Table 6 for moult score system

The summer plumage of the captive SBS appears to differ slightly to that of wild SBS, on 'arrival' to the breeding grounds due to captive conditions. Newly moulted summer scapula feathers are edged in white and remain this way throughout summer for captive SBS (Figure 37c). For wild SBS, these white tips degrade during migration and general weathering, leaving the rusty-red and black appearing more vibrant by the time they reach the breeding grounds (Figure 37d). The captive birds mostly retain this white edging giving them a slightly duller appearance even in full summer plumage. It is also worth noting that not all captive SBS reach full summer plumage every year (Table 4) whereas it is highly unusual to see a wild SBS on the breeding grounds with any retained winter plumage.

Table 4 – Proportion of adult captive SBS that reached full summer plumage

	2015	2016	2017	2018	2019	2020	2021
No. of birds reaching 6.5-7.0 moult score	10	10	13	13	12	3	2
No. of adult birds present (max)	24	23	19	19	14	5	7
% reaching full summer plumage	42%	43%	68%	68%	86%	60%	29%

Notes:
Refer to Table 6 for moult score system

In appearance the juvenile plumage again seemed the same as wild counterparts but the timing and speed at which they moulted into adult plumage varied wildly across all cohorts and individuals. This is in part due to environmental factors in captivity but not solely. For example, the two fledglings from 2018 both had the same environmental conditions but had very different moults into adult plumage.

Chick 1:1 (later known at Light Blue Red Left) began moulting into winter plumage (from juvenile plumage) in December 2019, completing moult by April 2020. In August new winter feathers began to moult in gradually replacing the old until December, though never completing it, and retaining many old winter feathers. In March 2021 winter feathers began to drop, being replaced with summer, though some were grey with dark centres rather than red with dark centres. He peaked at about 50% summer plumage and began dropping feathers again (summer and winter) late June replacing them with winter plumage. Autumn moult was complete by September with a few retained summer feathers. Moult largely followed the other healthy adults on the same (time-shifted) photoperiod going forward.

Chick 1:2 (later known as Light Blue Dark Green Left) also began transitioning into winter plumage from December 2019 but was also simultaneously moulting in a handful of summer feathers, though many were actually lacking red colouration (grey with a dark centre) same as chick 1:1. In March 2020 some winter scapulas were dropped and replaced with more winter feathers. It retained some summer feathers until June. In August 2020 some more winter scapulas were dropped replaced again with winter. In mid-December 2020 summer plumage began to moult in on the head and scapulas. By April 2021 he was in almost full summer plumage, though many of the feathers again were grey with dark centres. In May 2021 he began dropping feathers and moulting in winter plumage, reaching full winter plumage in August. In February 2022 he began dropping winter feathers and moulting in summer plumage in March, following the majority of the healthy adults on the same (time-shifted) photoperiod.

Throughout the project any dropped feathers were collected, labelled and stored as another means to monitor moult through the seasons and years.

Plumage appearance

Figure 38 shows the primary and secondary feather pattern of SBS with examples of each included.

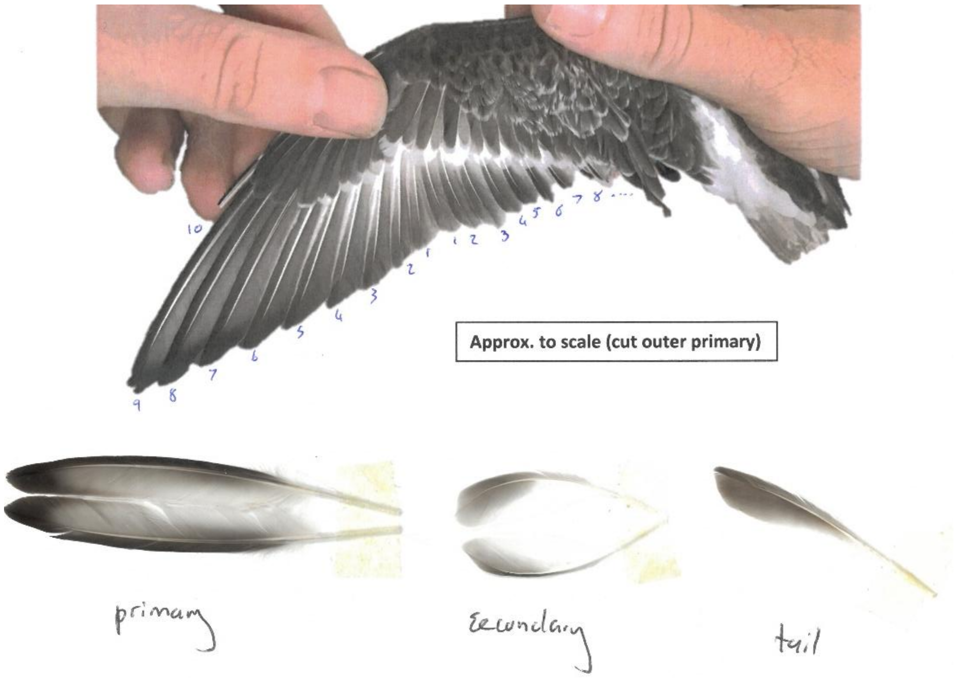


Figure 38 – Examples of primary and secondary feather pattern of SBS

2.4.4.3 Moult

Table 5 is reproduced from 'Recording information on Spoon-billed Sandpipers to aid their conservation' (available upon request to the Spoon-billed Sandpiper Task Force) demonstrates the moult pattern you can expect from wild SBS.

Table 5 – The plumages of SBS throughout their life

Plumage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Juvenile							Red	Red	Red	Yellow		
First winter	Red	Red	Red	Yellow						Yellow	Red	Red
First summer				Yellow	Red	Red	Red					
Adult winter	Red	Red	Red	Yellow					Yellow	Red	Red	Red
Adult summer				Yellow	Red	Red	Red	Red	Yellow	Yellow		

Notes:
Red = A month when a bird is likely to be in plumage
Yellow = A month when a bird is likely to be transitioning between plumages

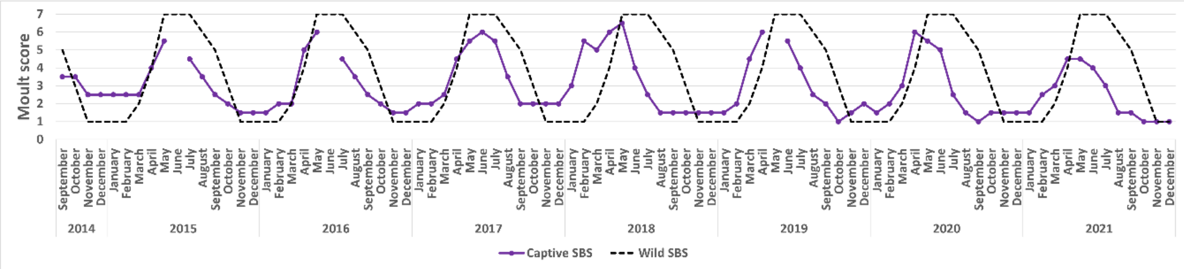
A moult scoring system was developed in September 2014 (Table 6) although notes regarding plumage were recorded since arrival of the first cohort to the UK in 2011 (Annual Report summaries, Annex 5). Generally, annual moult cycle in the captive SBS appeared to correlate well to the moult cycle that is seen in wild SBS (once in adult plumage and before time-shifts) (see Annex 4). For the captive SBS, moult into summer plumage appeared more rapid than moult into winter plumage, and on average they didn't reach full winter or full summer plumage (Figure 39).

Table 6 – Moult scoring system

Score	Juvenile plumage		First summer plumage		Breeding plumage
7	100% juvenile plumage		-		100% breeding plumage
6	A few (<10) winter plumage feathers		-		A few (< 10) winter plumage feathers
5	25% of winter plumage		25% of winter plumage, 75% grey breeding plumage		25% of winter plumage, 75% grey breeding plumage
4	50% of winter plumage		50% of winter plumage, 50% grey breeding plumage		50% of winter plumage, 50% grey breeding plumage
3	75% of winter plumage		75% of winter plumage, 25% grey breeding plumage		75% of winter plumage, 25% grey breeding plumage
2	A few (<10) juvenile feathers		A few (<10) grey breeding plumage feathers		A few (<10) grey breeding plumage feathers
1	Full winter plumage		Full winter plumage		Full winter plumage

Up until autumn 2017 (pre time-shift) the captive SBS typically started moult into summer plumage in April and moult into winter plumage in July, similarly to wild SBS (Figure 40). Moult timing is strongly correlated to the photoperiod birds are exposed to (e.g. in passerines: Coppack, Pulido and Berthold, 2001, but see also Lindström, Daan and Visser, 1994). This is demonstrated well in 2018 for the captive SBS during which the first 'time-shift' in photoperiod occurred (Figure 41). The breeding season was brought forward six weeks (42 days) by altering the daylength through artificial lighting, lengthening the day more rapidly thereby bringing them to the breeding grounds (24-hour daylength) sooner than usual. So, in essence, (photoperiod for) the 1 May (approximate arrival to the breeding grounds) was now experienced on 20 April. This was done to stimulate breeding in the cooler months of the UK spring, more comparable to weather on the breeding grounds, rather than the extreme temperatures seen in the breeding aviaries in summer.

It is worth noting that from 2018, the breeding season was extended (they were held at a 24-hour photoperiod for longer) to allow more time for possible second clutches - in effect, shortening their winter period. This, coupled with a time-shift of eight weeks in 2019, made the winter season significantly shorter; despite 'migrating' them more rapidly. This appears to have affected their moult cycle. It forced the SBS to moult into winter plumage in the heat of the UK summer (and temperatures exacerbated by the polythene roof) rather than autumn, and moult into summer plumage in the cold and damp of the UK winter. Moult into summer plumage in 2019 also began later than anticipated, despite the time-shift being earlier. However, they did catch up, moulting more rapidly with some reaching full summer plumage by the estimated time in line with the time-shifted photoperiod. This occurred again in 2020 after another shortened winter; spring moult was even later than 2019 on the same eight-week time-shift, but again they moulted more rapidly making up the difference. Though the summer period was extended again, the winter period was slightly longer; shifting them by only six weeks in 2021 in light of the poor health of many of the birds. Autumn moult appeared effected too. Duration of moult appeared to extend and transition more staggered with stops and starts.



Note: Missing moult scores of the captive SBS were purposeful to avoid disturbance during the breeding season

Figure 39 – Average captive moult score and typical wild moult score

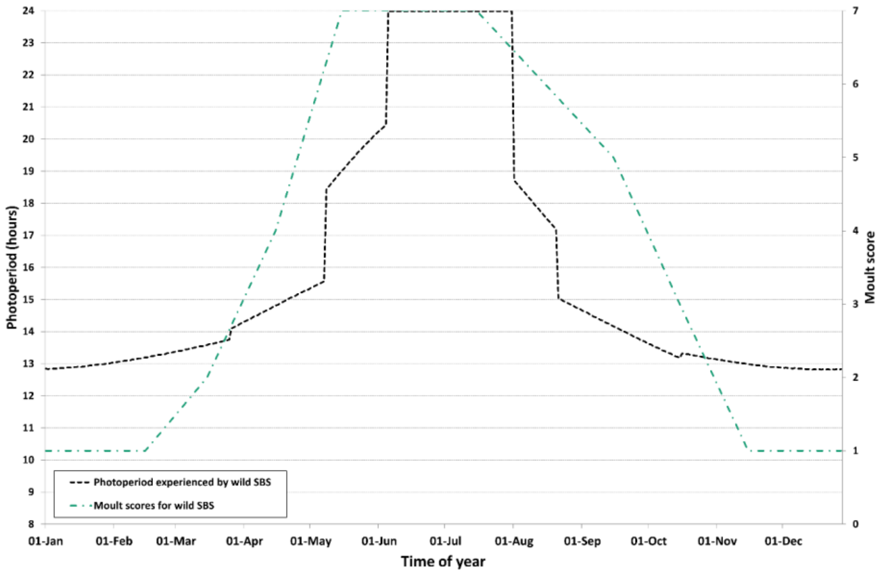


Figure 40 – Average wild moult score and photoperiod

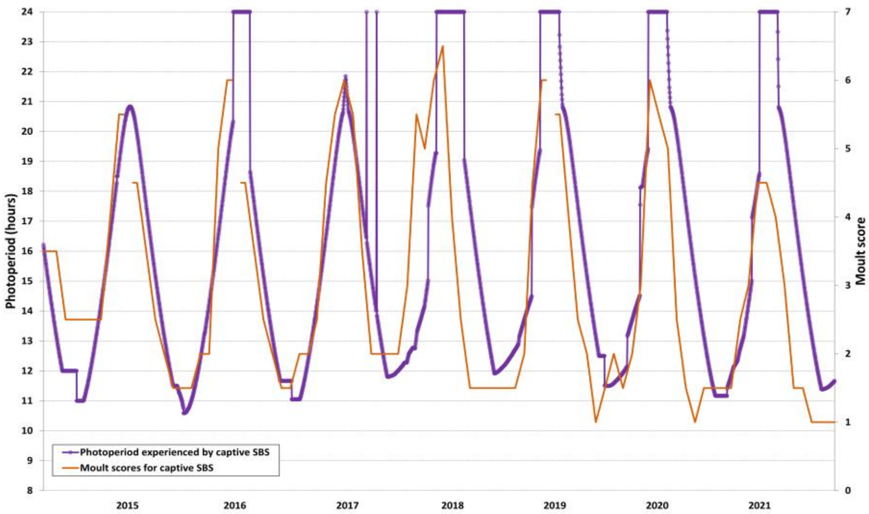
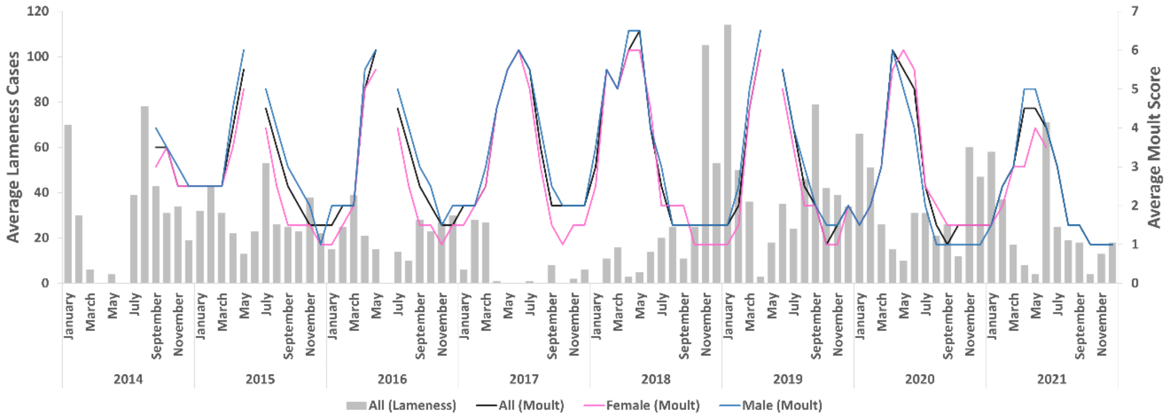


Figure 41 – Average captive moult score and photoperiod

2.4.4.4 Moult and lameness

Moult may also be correlated with lameness in the captive SBS (Figure 42). Lameness appeared to occur during moult throughout the project but was particularly obvious from 2018 when the birds began to show signs related to a *Candida sp.* infection, further compromising their health. Moult can act as a stressor that may contribute to the development of lameness, particularly in birds already burdened by underlying conditions such as amyloidosis. While lameness observed during moult may be linked to discomfort within the leg or cutaneous irritation, other factors, including environmental conditions can also play a role. Additionally, occasional instances of dry, cracked skin on the base of the feet and toes were noted, which may have further contributed to the discomfort.



Note: Juvenile data excluded, and Candidiasis infection period excluded

Figure 42 – Average moult scores, 2014-2021

2.4.5 Diagnosis and treatment

Effective diagnosis and treatment during the project relied on a comprehensive and adaptive approach, involving an internal multidisciplinary team and, when required, external consultants and laboratory services. Clear communication within the healthcare team, daily record-keeping of husbandry activities, facility management and setup changes, and close monitoring of both individual and flock behaviour were important aspects to determine aetiologies of disease. Clinical history (anamnesis), targeted sampling, and in-hand health checks - performed as necessary - further informed the decision-making. Each case was assessed individually, with treatment plans adapted to the specific condition and the bird's response to current or previous interventions, balancing the need for hands-on management with minimising stress; learnt over time.

The choice of drug and route of administration depended on factors such as symptom presentation, drug formulation, and the most effective absorption route (bioavailability). Flock treatment typically involved oral medication administered remotely via live food, mainly Black cricket *Gryllus bimaculatus* and Yellow mealworm beetle *Tenebrio molitor* larvae. For minor cases in certain individuals requiring short-term treatment (e.g. intermittent lameness) or long-term prophylactic treatment, oral formulation was also chosen to avoid daily handling. In more severe cases or when oral medication in crickets or mealworms was unsuccessful, injectable formulations were preferred to ensure full-dose delivery and a faster therapeutic effect. Symptoms considered severe and requiring immediate veterinary intervention included prolonged anorexia and inappetence, lethargy, respiratory distress, increased respiratory effort (especially after eating), crouching, signs of discomfort (antalgic postures), separation from the group, and poor feather condition (e.g. a scruffy appearance). In these cases, intervention could include not only drug administration but also subcutaneous fluids or gavage feeding nutritional support. In 2011 and 2012, in-hand treatment methods were standard; however, from then onwards, due to the direct negative impact of stress, a hands-off approach was prioritised.

Physiological stress (e.g. social dynamics, seasonal metabolic demand changes, hormonal fluctuations) can contribute to the exacerbation of certain conditions. Or factors such as time shifts, environmental conditions, and an increased environmental fungal (e.g. Candida sp.) burden may have induced stress-related immunosuppression, increasing susceptibility to disease over time.

2.4.3.1 Conditions encountered

Infectious conditions:

- Bacterial:
    - Pododermatitis or "bumblefoot" and septic joints. During the winter of 2012-2013, an outbreak of pododermatitis occurred in the 2012 SBS group, with *Pseudomonas sp.* and other enteric bacteria found in foot lesions (O'Brien *et al*., 2015). Treatment involved addressing environmental contamination by frequently replacing and/or disinfecting the sand substrate, cleaning the water systems, implementing regular water changes, and placing additional saltwater trays in aviaries. Contributing factors included high stocking density (due to temporary indoor housing), cold temperatures, increased body weight from pre-migratory changes, and moult.
    - Gut infections: Severe inflammation and infection of the proventriculus and gizzard, with significant bacterial overgrowth - possibly secondary to long-term gut yeast infections - was encountered in several SBS. In some cases, this led to complications such as septicaemia. Treatment, including the use of antibiotics, was administered on a case-by-case basis, with culture and sensitivity testing performed on faeces, as well as, carcass tissue samples.
- Fungal:
    - *Aspergillosis* (obstructive aspergilloma): Although not a common ailment within the SBS flock kept at CBU there was a SBS that had a bronchial aspergilloma accompanied by severe inflammation of the respiratory tract and pneumonia.
    - *Candida sp.*: Main cause of death within this species (possible stress sensitivity), often with secondary amyloidosis. Anti-fungal treatment may have prolonged life but was unable to clear the infection. Culture and sensitivity tests performed to choose the most effective drug. This was repeated to make sure drug efficiency hadn't changed over time.
- Protein deposition disorder (potential infectious component):
    - Amyloidosis: A predominant accompanying condition contributing to the captive SBS's mortality. Amyloidosis is typically caused by the accumulation of a type of protein-deposit, with waterfowl and waders being particularly susceptible. The process is usually triggered by chronic inflammatory conditions which include gut infections (bacterial/yeast), pododermatitis, joint disease and stress among others. In the captive SBS case it was multifactorial with pododermatitis and gut inflammation as potential important contributors.

Non-infectious conditions

- Nutritional:
    - Metabolic bone disease (MBD): MBD in SBS chicks appeared consistent with rickets, with histopathological findings suggesting patterns more typical of low phosphorus (hypophosphataemia) rather than low calcium (hypocalcaemia) bone weakness. In birds, skeletal mineralisation depends on the interaction between calcium (Ca), phosphorus (P), and vitamin D3, all of which are required for normal bone development and growth. The clutches laid generally consisted of thin or soft-shelled eggs, and a couple of chicks that hatched showed signs of yolk infection and skeletal abnormalities, including osteodystrophy and pathological fractures. While maternal calcium deficiency was initially suspected, dietary analyses indicated adequate calcium provision and an appropriate Ca:P ratio, suggesting that phosphorus metabolism or yolk phosphorus utilisation may have played a more significant role. Since SBS are a precocial species, their skeletal development is largely completed within the egg, making maternal nutrition and yolk composition critical determinants of embryonic bone growth (Wilson, 1997). Disruptions in yolk phosphorus levels or its bioavailability may therefore have been more influential than shell-derived calcium availability. Although thin shells could have contributed to increased water loss or microbial contamination, they did not necessarily indicate calcium depletion. Overall, the findings suggest that maternal nutritional imbalances, particularly involving phosphorus metabolism and possibly vitamin D status, may have contributed to abnormal skeletal development in the affected chicks.
    - Gout: Articular and visceral gout is a common diagnosis in captive birds and is frequently linked to high dietary protein and/or calcium levels. The combination of high protein and high calcium was considered the most likely factor predisposing the SBS to disease, particularly gout, although no pathological evidence of calcium toxicity (tissue mineralisation) was found. Additionally, high maternal dietary protein was thought to have contributed to the bone abnormalities observed in embryos and newly hatched chicks, indicating that multiple conditions had likely arisen due to both vitamin D3 deficiency and protein excess. As a result of these findings, the diet was adjusted, including a reduction in high-protein components such as dried shrimp.
- Trauma:
    - Collisions (cases shown in Figures 43a-h):
        - Blunt trauma and collisions during ‘night frights’ were observed on CCTV footage. Video monitoring helped to correlate post-mortem findings with causes of death in some trauma cases.
        - Details of treatments given in Annual Report summaries, Annex 5.
    - Multifocal dispersed lumps were observed across the bill from potential trauma. A definitive cause was not reached; however, bacterial and fungal cultures were negative, and samples taken were also negative for poxvirus. Insect bites and toxic plants were also investigated as a potential cause. Given the number of individuals that presented these lesions; trauma or hypersensitivity were the two most likely aetiologies within the list of differentials.

43a. Keel injury after flight collision

43b. Bill lumps from suspected flight collisions

43c. Eye injury and beak injury from flight collision

43d. Eye injury from suspected flight collision causing ongoing issues during moult, whereby feathers appear to now be growing into eye

43e. SBS LGPL with necrotic toe due to constriction from human hair. Nails also long due to limp/alternative stride from discomfort

43f. SBS LGPL with healing toe dropping off. Also showing pododermatitis on base of feet and inflammation on top of right foot

43g. Possible toe fracture and inflammation from possible flight collision

43h. Dry/cracking skin on feet. Can lead to constriction of toes if not treated

(All photographs credit WWT)

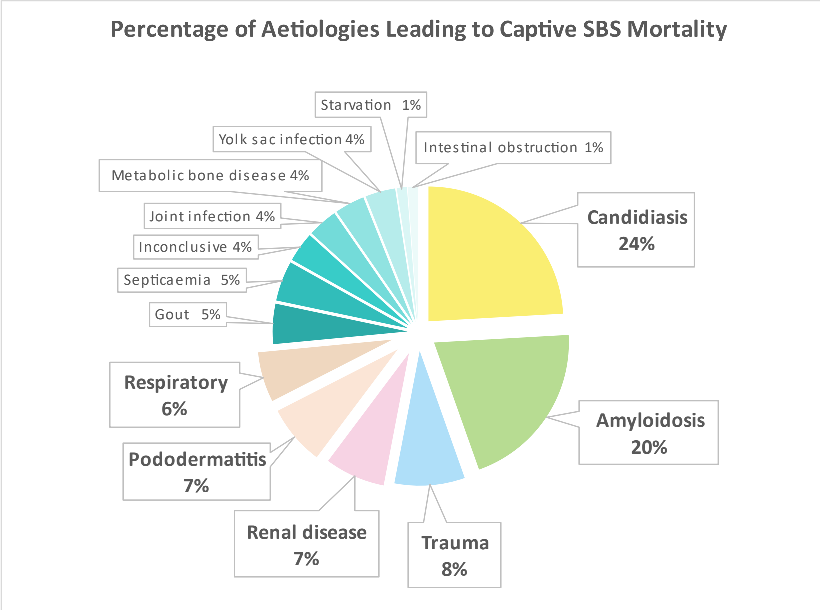
Figure 43 – Photographs of various flight collision injuries and associated afflictions during the project.

2.4.5.1 Causes of death

The main contributors to mortality in captive SBS were Candidiasis, amyloidosis, and trauma, with intermittent complications from chronic pododermatitis. (Figure 44, Table 7).

Any deaths that occurred at WWT Slimbridge were followed by post-mortems carried out by in-house veterinary staff supplemented with histopathology analysis performed by external laboratories. Carcasses were retained for further analysis or research purposes.

Euthanasia was considered on welfare grounds when the bird was unresponsive to treatment, showed rapid deterioration, or was suffering. A decision-making framework was in place, with the decision being made collectively by veterinarians, lead aviculturists and the conservation breeding manager.



Note: The percentages refer to the total number of recorded ailments (cases) identified across the 37 deceased captive SBS between 2011–2023 (incl. chicks). Each percentage represents the proportion of a given ailment among all ailments contributing to mortality, regardless of whether it was a primary or secondary condition.

Figure 44 – Pie chart representing the percentage distribution of different ailments identified in 37 captive SBS mortalities between 2011–2023

Deaths that occurred during the embryonic stage within the egg are often difficult to determine. For eggs/embryos that did not appear to develop it can at least be determined whether sperm was present within the egg, and therefore whether an embryo died, or the egg was infertile (Assersohn *et al*., 2021). Embryonic deaths can be found in Table 8.

Table 7 – Primary aetiologies of death

Bird ID*	Sex	Cohort	Death date	Age	Causes	Additional comments
Hatchling Meinypil'gyno	UNK	2011	Jul 2011	6 d	Undetermined?	No post-mortem examination (PME)
Hatchling Meinypil'gyno	UNK	2011	Jul 2011	3 d	Undetermined?	No PME
Fledgling Anadyr	UNK	2011	Jul 2011	>14 d	Trauma	Night-fright flight collision within pen
SBS0010 Moscow	F	2011	Aug 2011	1 m	Starvation	Inconclusive results to explain anorexia developed
SBS0015 Moscow	F	2011	Sep 2011	2 m	*Aspergillosis*	Poor body condition. Suspected infected.
UNK ID Moscow	-	2011	-	-	Intestinal obstruction	Ingestion of astroturf
Green Right	F	2011	6 Mar 2012	8 m	Amyloidosis and chronic pododermatitis	Intermittent lameness observed
Hatchling	UNK	2012	Jul 2012	?	Trauma	
Green Left	F	2011	27 Sep 2012	1 y 2 m	Amyloidosis	Never fully active and exhibited long-term solitary behaviour. Treated for pododermatitis and lameness. Heart condition suspected but no developmental anomalies identified on histopathology.
Pink-Black Right	F	2012	13 Aug 2013	1 y 1 m	Respiratory and pulmonary disease	Aspergilloma obstructing a bronchus detected as an additional finding
Pink-Light Green Right	M	2012	23 Aug 2013	1 y 1 m	Severe chronic pododermatitis	Euthanasia on welfare grounds – Secondary renal disease detected on PME
Pink-Blue Left	M	2012	21 Jan 2014	1 y 6 m	Trauma	Night-fright flight collision with window
Pink-Yellow Left	F	2012	21 Jan 2015	2 y 6 m	Possible trauma	Histopathology revealed mild gout
Yellow Left	F	2011	27 Oct 2015	4 y 3 m	Trauma	Blunt trauma from collision. Long-term observation of unusual gait ("tiptoe")
Hatchling	UNK	2016	Jul 2016	2 d	Metabolic bone disease (MBD)	Presence of long bone fractures on PME. Hatched from a thin-shelled egg. Potential underlying maternal nutritional problem
Hatchling	UNK	2016	Jul 2016	2 d	Yolk sac infection and MBD	Struggled to hatch, assistance required. Also thin shell egg.
White Left	M	2011	11 Jul 16	5 y	Amyloidosis and chronic limb and foot issues	Long-term pododermatitis, as well as right limb stiffness
Pink-Yellow Right	M	2012	19 Jan 2017	4 y 5 m	Renal disease, chronic pododermatitis (bumblefoot) and potential stress	Visceral gout and renal changes detected on post mortem examination and histopathology. Anorexia possibly caused by ongoing limb condition and handling for injectable medication.
Blue Left	M	2011	29 Jan 2017	5 y 6 m	Gout and secondary renal disease	Rapid increase in high protein diet item (dried shrimps)
Pink Right	M	2011	3 May 2017	6 y 10 m	Trauma	Flight collision into aviary net
Hatchling	UNK	2018	Jun 2018	4 d	Unknown	Slow hatch and slightly lethargic compared to sibling. Yolk infection suspected on PME.
Fledgling	F	2018	Jun 2018	49 d	Trauma	Night-fright flight collision

Bird ID*	Sex	Cohort	Death date	Age	Causes	Additional comments
Black Left	M	2011	7 Dec 2018	7 y 5 m	Candidiasis	Long-term issues with weight loss and struggling to eat crickets. Initially responsive to treatment but then deteriorated.
Orange Right	M	2011	20 Feb 2019	7 y 7 m	Amyloidosis and Candidiasis	Age-related cardiac changes observed on histopathology
Pink-Pink Left	M	2012	2 May 2019	6 y 10 m	Candidiasis	Concurrent conditions: mild amyloidosis, bumblefoot and active keel injury
Hatchling	UNK	2019	May 2019	3 d	Yolk sac infection	Faded within 48 hours of hatch
Pink Left	F	2011	27 May 2019	7 y 10 m	Amyloidosis and Candidiasis	History of pododermatitis and age-related cardiac changes observed on histopathology
Pink-Pink Right	F	2012	3 Jun 2019	6 y 11 m	Amyloidosis and Candidiasis	Regurgitation of live food and lameness. Histopathology revealed age-related deposits in adrenal and heart tissue
Unrung	M	2012	27 Jul 2019	7 y	Amyloidosis and Candidiasis	Intermittent lameness of right limb during moult and last breeding season
White Right	M	2011	6 Nov 2019	8 y 4 m	Amyloidosis and Candidiasis	Skin condition around the uropygial gland
Red Right	M	2011	2 Jan 2020	8 y 6 m	Amyloidosis and Candidiasis	Intermittent lameness prior to death, as well as historic eye condition
Pink-Orange Left	F	2012	28 Jan 2020	7 y 7 m	Candidiasis and secondary bacterial ventriculitis	Sneezing and wet feathers (chest area) observed leading to death
Pink-Blue Right	M	2012	4 Mar 2020	7 y 8 m	Amyloidosis, Candidiasis and renal gout	Euthanasia on welfare grounds – Weight loss, poor feather condition (chest) and unresponsive to treatment
Pink-Red Right	F	2012	2 Apr 2020	7 y 9 m	Amyloidosis and Candidiasis	Intermittent lameness
Blue Right	M	2011	25 Apr 2020	8 y 9 m	Inconclusive	Advanced autolytic changes in samples saved for histopathology *(prolonged delivery process due to COVID restrictions)*
Pink-Red Left	M	2012	17 May 2020	7 y 10 m	Amyloidosis and Candidiasis	During adult years intermittent lameness also observed, (frequently observed during periods of moult
Pink-White Left	F	2012	26 Jan 2021	8 y 6 m	Candidiasis and septicaemia	Received eye treatment. Pododermatitis detected on PME.
Pink-White Right	F	2012	4 Jul 2021	9 y	Amyloidosis, Candidiasis, pneumonia and severe left hock joint infection,	Minor enteritis from lesions caused by invertebrate food (rare observation)
Pink-Light Green Left	F	2012	23 Jul 2021	9 y	Amyloidosis and joint infection	Euthanasia – Mild Candidiasis also detected in the gizzard. Right foot had advanced pododermatitis
Pink-Orange Right	M	2012	2 Oct 2021	9 y 3 m	Amyloidosis, Candidiasis, kidney disease and articular gout	Intermittent lameness observed and poor feather condition around the eyes
Light Blue-Dark Green Left	M	2019	5 Apr 2022	2 y 11 m	Candidiasis and airsacculitis	Some coelomic tissues, including the liver, were preserved for potential future research, therefore confirmation of amyloidosis via histopathology could not be made.
Red Left	M	2011	27 Sep 2022	11 y 2 m	Amyloidosis, Candidiasis, and severe left foot skin and bone condition.	Left foot: toe fracture possibly secondary to chronic pododermatitis and joint condition

Note: * Deaths occurred at WWT Slimbridge unless otherwise stated under Bird ID

Table 8 – Egg failures/embryonic deaths

Year	Egg ID	Death stage*	Fertility	Notes
2011	5:14	Mid-late	Assessed by candling. Spidery veins seen. Confirmed embryo after incubation ceased.	Egg damaged in Anadyr during transit. Egg not dipped in disinfectant solution.
2012	D13	Mid-late	Assessed by candling. Appeared fertile. Confirmed embryo after incubation ceased.	Egg damaged during security check in transit. Egg dipped in disinfectant solution.
	C10	Mid	Assessed by candling. Appeared fertile. Confirmed embryo after incubation ceased.	No post-mortem, unclear why development ceased. Egg dipped in disinfectant solution.
2016 5 of 7 eggs failed to hatch	1:1	Early-mid	Assessed by candling on Day 13. No obvious development seen. Further analysis by an external laboratory found early to mid-stage development.	• Egg put in cold storage for three days prior to incubation start. • Chalky appearance; looked as though it was missing the waxy eggshell cuticle. Not dipped in disinfectant solution. Rapid weight loss during incubation that could not be rectified. • Poor quality egg likely caused cessation in development, from compromised female.
	1:3	Early	Analysis by an external laboratory revealed sperm cells on the surface of the egg yolk, indicating likely fertility.	• Egg incubated soon after collection. • Soft shelled, layering not complete. Not dipped in disinfectant solution. 'Dumped' in pond. • Completely collapsed within a few hours of collection. Could not incubate. • Poor quality egg likely caused cessation in development, from compromised female.
	2:1	Early-mid	Assessed by candling on Day 13. No obvious development seen. Further analysis by an external laboratory found early to mid-stage development.	• Egg put in cold storage for three days prior to incubation start. • Egg appeared normal. Dipped in disinfectant solution. Average weight loss in incubation was slightly low. Compromised female likely contributor to cease in development.
	2:2	Early-mid	Assessed by candling on Day 13. No obvious development seen. Further analysis by an external laboratory found early to mid-stage development.	• Egg put in cold storage for one day prior to incubation start. • Egg appeared normal. Dipped in disinfectant solution. Average weight loss in incubation was slightly low. • Compromised female likely contributor to cease in development.
	2:3	Early-mid	Assessed by candling on Day 13. No obvious development seen. Further analysis by an external laboratory found early to mid-stage development.	• Egg incubated soon after collection. Egg appeared normal. Dipped in disinfectant solution. Average weight loss in incubation was slightly high. • Compromised female likely contributor to cease in development.
2018 5 of 7 eggs failed to hatch	1:1	Early	Assessed by candling, no sign of development. Inconclusive results from external laboratory due to decomposition of egg contents.	• Thin shelled with a small hole and small dent. Hole covered with paper towel and Germolene New Skin. Wrapped in cling film due to rapid weight loss. Put in cold storage for 6 days before incubation start. Average weight loss in incubation was very high and unrecoverable. Not dipped in disinfectant solution. • Compromised female likely contributor to cease in development.
	1:2	Early	Candled several times, no sign of development. Inconclusive results from external laboratory due to decomposition of egg contents.	• Very small hole upon collection, fixed with Germolene New Skin. Put in cold storage for 4 days before incubation start. Not dipped in disinfectant solution. • Average weight loss in incubation was slightly low. • Compromised female likely contributor to cease in development.
	1:3	Early	Assessed by candling, no sign of development.	• Appeared normal? Put in cold storage for 1 day before incubation start. Dipped in disinfectant solution. Average weight loss in incubation was low.

Year	Egg ID	Death stage*	Fertility	Notes
			Inconclusive results from external laboratory due to decomposition of egg contents.	• Compromised female likely contributor to cease in development.
	2:1	Early	Assessed by candling, no sign of development. Inconclusive results from external laboratory due to decomposition of egg contents.	• Appeared normal? Put in cold storage for 2 days before incubation start. Dipped in disinfectant solution. Average weight loss in incubation was very low. • Compromised female likely contributor to cease in development.
	2:3	Mid	Assessed by candling, appeared fertile. Confirmed embryo after incubation ceased.	• Appeared normal? Put in cold storage for 2 days before incubation start. Dipped in disinfectant solution. Average weight loss in incubation was low. • Compromised female likely contributor to cease in development.
2021 2 of 2 eggs	1:1	Early-mid	Assessed by candling, no signs of development. Further analysis by an external laboratory found early to mid-stage development.	• Large/elongated, thin shelled, already dented/damaged on collection. Patched with PVA glue and nail varnish. Later wrapped in cling film. Put in cold storage for 2 days before incubation start - would have been longer but dent collapsed quickly. Not dipped in disinfectant solution. Shell continued to collapse at dent through incubation. Average weight loss in incubation was high. • Compromised female likely contributor to cease in development.
	1:2		Assessed by candling, couldn’t see any veins but had pink hue. No movement seen, darker/foggy at yolk. No definitive structures visible. Analysis by an external laboratory revealed sperm cells on the surface of the egg yolk, indicating likely fertility.	• Egg appeared normal. Put in cold storage for 4 days before incubation start. Dipped in disinfectant solution. Average weight loss in incubation was low. • Compromised female likely contributor to cease in development.

Note: * Early = 1-3 days incubated, Mid = 4-13 days incubated, Late = 14+ days incubated. These death stages follow those recommended by the Avian Egg Incubation Workshop operated by Durrell Conservation Academy.

2.4.6 Stress management

Stress management is a combination of monitoring behaviour and clinical health, as well as mitigating factors that induce stress responses. Between 2011 and end of 2012 the birds were caught regularly for a basic physical health check which included body weights, body scores, plumage condition, and feet assessments. Some were also caught for treatment during this period. With time, methods to monitor health and administer treatment remotely were developed as it became apparent that frequent or prolonged handling had a negative impact to their health. Catching and handling was limited to essential examinations and treatments, and for transfers between aviaries where applicable. Remote body weights and photos of general plumage and feet became a non-invasive and passive approach to obtain quantitative and qualitative data to monitor SBS' health status.

The configuration of the facility gave the option to shut birds in or out of certain locations when possible stressors or health hazards were present in one area or aviary and not another. This could be noise, vehicles, wild animals, fungi build-up, weather, etc.

2.4.6.1 Flight-feather cutting

In periods in which repeated catching of a bird or birds was unavoidable (e.g. for treatment) feather cutting was performed to reduce time spent catching birds. This led to less disturbance of the flock within the aviaries and therefore a less stressful process to the individual being caught and to the other SBS.

All birds of 2011, 2012, and 2019 cohorts had a portion of their primaries and secondaries cut as juveniles when first acquired/fledged to limit flight ability. This was done for ease of catching in the 2011 and 2012 cohorts for regular health checks, and to reduce flight collision risks in the 2019 cohort. This decision was made after the flight collision death of the 2018 fledgling. Primaries and secondaries were cut again the following time they were moulted in. Flight collisions throughout the project were a regular occurrence and accounted for a significant proportion of deaths (10%, or 7 birds, between 2011 and 2023). As flight feathers are thought to aid in balance during copulation feather cutting was only done when deemed absolutely necessary i.e. for fledglings in a new environment, and sick birds in need of regular catching for treatment.

The most effective and safe pattern of feathers to cut for captive SBS was cutting all secondary and the first eight primaries, leaving the outer two primaries un-cut ensured there was no rubbing of sharp quill against feathers and skin (Figure 45). Feathers were cut on both wings to ensure there was zero lift. Bear in mind that feather cutting can increase the risk of foot issues, as they will be walking in place of flying.

(Credit: WWT)

Figure 45 – Example of feather cutting pattern on young SBS

2.4.7 Diet and nutrition

2.4.7.1 Consultation and investigation

The captive SBS diet (how the food was presented) and nutritional content (what the food contained) was based on that used for other small waders from a trial on captive Dunlin *Calidris alpina* reared from wild collected eggs hatched at WWT Slimbridge (before the arrival of the SBS in-house collections) and external private collections. Limited knowledge existed for diets of wild SBS when the captive project began.

Wet (provided in tap water (salt water in first few years)) and dry (provided as is) foods were offered in shallow plastic or ceramic circular dishes on top of towels to catch spillages. Live foods were offered scattered around the occupied areas. For dietary changes through the project, refer to Annual Report summaries, Annex 5. Chicks were offered the same components, though only wet initially, and later weaned to dry. Chicks also had components of the diet scattered on the floor (of contrasting colour) of the brooder to encourage foraging/pecking. Offering multiple food items (over a single nutritionally complete item such as a pellet) does lead to birds selectively eating the items they prefer, but does ensure diversity, enrichment, and overall welfare. As seen in the captive SBS not all birds consumed the optimum proportions of the food items offered due to a dominance hierarchy and individual preference. However, preference consequences were preventable by altering the methods in which they were fed. Some high value items, namely live invertebrates, were fed in controlled quantities and scattered at certain times of the day ensuring all had an opportunity to consume their portion.

In 2014/15 a formal analysis of nutrition was conducted by external experts with comparison made to breeding Leghorn chicken *Gallus gallus domesticus*. The results were unremarkable with the exception that the calcium levels were potentially too low for breeding birds. Iron levels were suggested to be high but likely within tolerable levels for SBS as insectivorous birds. The diet was assessed again after cases of gout were observed in early 2017. This and veterinary advice lead to the overall protein content of the diet being reduced, and some components high in protein or additional vitamins/minerals phased out.

Consultation with an external expert in 2015 at the time suggested SBS may rely heavily on access to specific essential fatty acids at stopover sites for not only completing migration but also reproductive success (pers. comms, Robert Elner), speculated for in other long distance migratory waders at the time. In light of this, the diet leading up to the breeding season was supplemented with plankton and Brine shrimp with added omega-3 annually for the remainder of the project.

Due to the evolving feeding methods (husbandry generally) and food types, as well as type of data recorded throughout the project and serious health issues in the latter years, it is not possible to accurately or thoroughly compare nutrition intake annually or otherwise. What has been noted is that quantity consumed and preference to certain food types differed at certain times of the year including individual preference. The SBS appeared to eat less Insectivorous Feast and more Lundi in spring moult, and more Insectivorous Feast and less Lundi during autumn moult. They generally ate less during the breeding season, increasing during autumn moult, and ate most through winter and into spring moult.

It is possible that by altering the protein content of the diet, from a constant level to offering a higher protein diet during the breeding season and lower protein during winter comparatively (from 2014), that natural annual weight gains and loses expected in migratory waders has been counteracted resulting in a seemingly year-round average weight for individuals and sexes. Food consumption is also known to correspond to temperature (as reviewed by Seibert, 1949). Given the seasons are almost reverse to that which wild SBS experience this could also have some impact to any possible annual weight cycle. Further detail in Section 2.4.4.1.

2.4.7.2 Main components of final diet

Refer to Table 9 and Figure 46 for an overview of diet per month and details of quantities.

Lundi micro: A year-round complete pellet feed for aquatic avian species, available with varying protein contents (%). Lundi micro 20 (i.e. 20%) was used as a staple component and given ad-lib, with Lundi micro 35 (i.e. 35%) replacing a portion on the Lundi micro 20 just prior to the start of the breeding season and phased out towards the end of autumn moult. Offered dry as standard but offered wet during time of illness to improve palatability.

Insectivorous Feast: A complete soft food for softbill species. Given in controlled quantities, most birds preferred this over Lundi micro. Given to supplement Lundi with insectivorous bird feed for variety and lower protein content than dried freshwater shrimp.

Avipro: A probiotic for all avian species. Given from project start until November 2014 then removed on nutritionist advice. Then used sporadically until September 2018 when it became a permanent component of the diet as per manufacturers instructions for use

Grit/Oyster shell grit: Crushed oyster shells for additional calcium provision, and to aid in digestion. Given ad-lib throughout the year.

Zolcal-D: A prevention or treatment for calcium and vitamin D deficiencies. Introduced in 2019, used just prior and during the breeding season in light of thin eggshells and chick deficiencies.

Rat-tail bones: Used as an additional source of calcium. Introduced in 2019 and offered just prior and during the breeding season in controlled quantity to monitor consumption.

Invertebrates (live or frozen): Including bloodworms and crickets to supplement main diet, brine shrimp, plankton, and fruit flies to provide breeding stimulation as chick food source (Poulin, Lefebvre, and McNeil, 1992; McKinnon *et al*., 2012) and to encourage birds to breed with chick food abundance, and mealworms (freshly shed for birds with digestive issues) used to give oral medications to birds who refused crickets (often refused as SBS can identify when they have been manipulated e.g. medicated with drugs). All included in diet to supplement main diet, provide enrichment, or stimulation.

Additional invertebrates: woodlice, wax worms, calciworms, bristle worms, tubiflex worms, daphnia, artemia, krill, and rotifers used to supplement main diet and provide additional/alternative sources of vitamins and minerals, used also for enrichment. Not used as a regular component of the diet due to lack of interest or availability

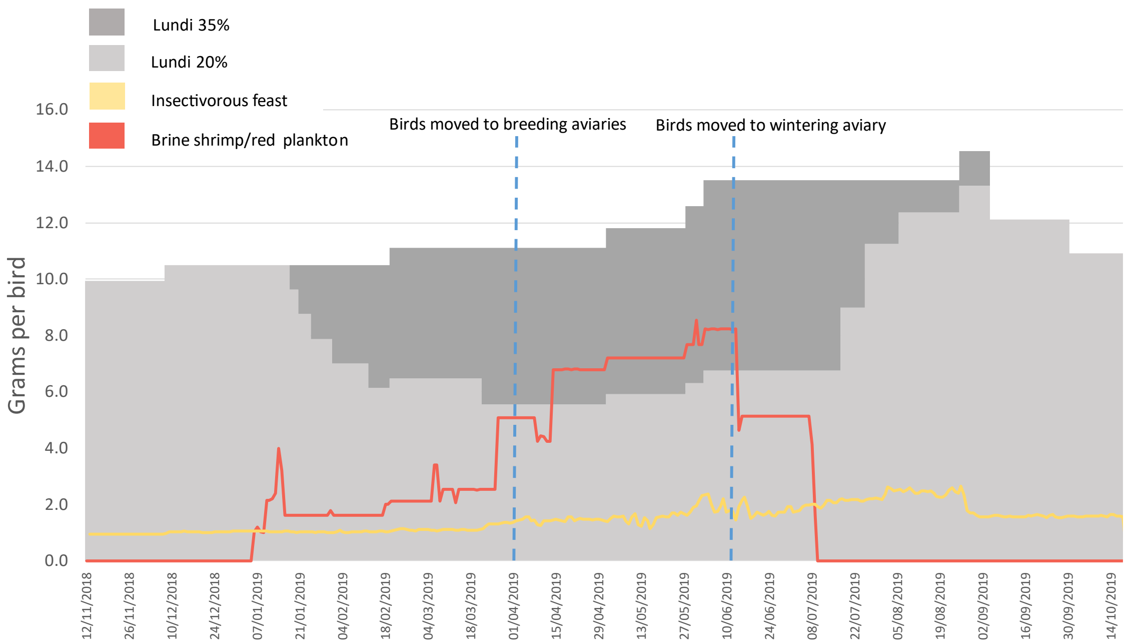
Table 9 – Main components of final adult diet offered by month

Food item/supplement		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
%ratio	Lundi micro **35**	0	↑	↑	50	50	50	↓	↓	0	0	0	0
	Lundi micro **20**	100	↓	↓	50	50	50	↑	↑	100	100	100	100
Insectivorous Feast		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Frozen bloodworms		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Live crickets (brown/black)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Avripro (on dry food)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Oyster shell grit		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Saltwater*		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Live fruit flies		X	X	X	✓	✓	✓	↓	↓	↓	X	X	X
ZolCal D supplement**		X	✓	✓	✓	✓	X	X	X	X	X	X	X
Frozen Brine shrimp + omega3		X	✓	✓	✓	✓	X	X	X	X	X	X	X
Frozen red plankton		X	✓	✓	✓	✓	X	X	X	X	X	X	X
Rat tail bones (autoclaved)		X	X	X	✓	✓	✓	X	X	X	X	X	X
Live mealworms		✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp	✓ for meds /supp

Notes:
Data based on time-shifted photoperiod (24-hour light from April to June approx.)
* Saltwater only provided in breeding aviaries if foot condition of a bird was poor
** Females daily, males every other day

Key

✓	Present in diet
↑	Increased that month
↓	Decreased that month
	Present for 2012 cohort
X	Absent from diet



Note: Data based on time-shifted photoperiod (24-hour light from April to June approx.)

Figure 46 – Quantity of main components of diet offered per bird (Nov 2018 - Nov 2019)

2.4.7.3 Other food items and supplements

Lundi micro 45: Was fed from hatch to April 2012 (for the 2011 cohort). It was thought the SBS (both cohorts) were gaining/maintaining excessive weight so was removed until April 2014 and used throughout the breeding season (first breeding season in breeding aviaries). It was added again during the breeding seasons of 2015 and 2016. It was permanently removed thereafter after the first occurrence of gout. In addition, Lundi micro 35 contained a higher level of calcium compared to Lundi micro 45 (and Lundi micro 20) at time of analysis.

Avimix: A vitamin and mineral supplement. Used in early years of the project and removed permanently in January 2017 after the first occurrence of gout potentially related to over supplementation of vitamins and minerals.

Guardian angel: A comprehensive supplement for sick or stressed birds. Used in 2013 only from September to December during moult.

Feather-up: A feather conditioning supplement. Used during autumn moult in 2013. Then again for autumn moult in 2019 and spring moult 2021 when the SBS appeared to be struggling with other health issues (other occurrences may not have been recorded).

Nutrobal: High calcium balancer and multivitamin/mineral support. Used in June and July 2016, then again in November and December. Removed from diet in January 2017.

Dried freshwater shrimp: A natural food item used to supplement diet. Removed in January 2017 due to effects seen after excessive quantities eaten leading to gout, and subsequently mortality.

2.4.7.4 Health and nutrition

During periods of ill health, on a case-by-case basis, individual SBS were often given additional nutritional and hydrating supplements injected into live foods and target fed. Individual cases are detailed in Annual Report summaries, Annex 5. This was usually when weight loss exceeded more than 10% of average body weight, or during periods of treatment. Maintaining hydration and weight appears key to recovery but depends on the individual's appetite and symptoms.

Caution was taken to avoid offering excessive live food in one sitting, as some SBS appeared to gorge themselves when presented with large quantities. This was a particular concern for birds with known gut conditions, as overconsumption could place additional strain on the digestive system and potentially lead to further complications. Symptoms manifested as lethargy at times, discomfort to swallow, and hunched posture, with affected birds resting immediately after gorging - typically on both legs without tucking their bill into their scapulas. This was most observed in individuals with pre-existing health issues.

Metabolic disease and/or nutrition-related concerns were identified as health issues in various post mortem examination reports. While these may have been primary conditions in some birds, they were also likely secondary to gut disease in others. Nutritional-related conditions in the captive SBS arose from multiple factors throughout their lifespan, including parental deficiencies, developmental issues during incubation, and malabsorption due to gut disease. Diet adjustments were made based on the flock’s overall weight trends, seasonal demands, and health status.

2.5 Reproduction

The purpose of establishing a captive population of SBS was for conservation breeding purposes. There were only nine viable breeding seasons, i.e. possible attempts, to breed the SBS during the project at WWT Slimbridge. This chapter gives an overview of breeding outcomes, explains strategies used to facilitate breeding, and dissects what may contribute to successful breeding and what may inhibit it.

2.5.1 Breeding ecology

The below information is derived from personal conversations with Evgeny Syroechkovskiy, Elena Lappo, Pavel Tomkovich, Nikolai Yakushev, Egor Loktionov, between 2010-2021.

Spoon-billed sandpiper breed along coastal tundra of far eastern Russia in June-August. Males typically arrive first, usually returning to and defending the same territory. Females arrive a few days later and usually form the same pairs annually. Their first breeding attempt is usually in their second summer (Tomkovich and Loktionov, 2021). Some first year birds do migrate to the breeding grounds and breed, though this is not common. Males perform flight displays (approximately 20m from ground level) and ground displays with chirring calls and songs to attract females and deter other males. Males scrape shallow nest cups pushing substrate away with their feet with their chest pressed to the ground. Several nest cups are made for the female to inspect. The chosen nest scrape is then lined by both birds with vegetation from the immediate surrounding area. Females lay clutches of four slightly pointed heavily mottled khaki coloured eggs over a period of four to five days. Each egg weighs approximately 6g.

Incubation typically begins once the third egg has been laid. Both males and females share incubation duties for the whole 19-21 day period of incubation, females typically incubate during the 'night' and males during the day. At approximately 17-19 days into incubation the chick makes an external pip in the shell (internal pip into the airspace shortly prior). Over the next three days the chick within gradually rotates 'unzipping' the shell pushing with its bill. From external pip to full emergence takes three days typically. The clutch of eggs tend to hatch in synchrony within a 24-hour period, stimulated by the calling parents and hatched/hatching siblings calling back. Soon after hatch, the females begin migration south leaving the male to rear the chicks alone. The chicks are brooded frequently in the first few days and both male and chicks gradually disperse from the nest site, traveling a few hundred metres a day to several kilometres a day. As the chicks disperse and become self-reliant the parent male leaves for southward migration. The remaining chicks stay slightly longer forming larger groups with other small migratory waders. Eventually they leave, joining other juvenile waders passing through on southwards migration. They make multiple stopovers for refuelling and moult before settling for their first winter and second calendar year around the Yellow Sea and other wintering sites. Some then transition into first-summer plumage in their second calendar year and even migrate northwards to the breeding grounds, though this is not common. Spoon-billed sandpiper typically reach reproductive maturity at two years of age. First time breeding males establish a territory and attract a female to begin the breeding process. Males will move to different areas in one season if no females can be found.

2.5.2 Outcomes and overview

With every season throughout the conservation breeding project, the level of breeding activity (aggressive encounters, following/chasing, displays, singing, nest scraping occurrences, etc.) generally increased (Table 10), with the first eggs being laid in 2016. In the years with no eggs laid, significant events have been identified which contributed to this result. In 2017 the males which bred the previous year had died meaning new pairings were formed which appeared less compatible (known by trial and error in healthy birds). In 2020 birds were burdened with a yeast infection, killing some paired birds during the breeding season and leaving the remainder in poor health. If these events had not occurred the likelihood of breeding in every year of the project, and more of the pairs breeding each year, would be higher. 2013 as a viable breeding season is not shown here as no birds were paired and limited activity was observed.

Table 10 – A summary of different aspects of breeding success over relevant years

	2014	2015	2016	2017	2018	2019	2020	2021
Sex ratio (at start of breeding season for birds of breeding age)	16:9	16:8	16:7	13:7	12:7	10:7	6:4	5:2
Active males	✓	✓	✓	✓	✓	✓	✓	✓
Nest scraping	✓	✓	✓	✓	✓	✓	✓	✓
Active females	✓	✓	✓	✓	✓	✓	✓	✓
Copulation	X	X	✓ 2 pairs	X	✓ 2 pairs	✓ 1pair	X	✓ 1 pair
Egg laying	X	X	✓ 7 eggs (from 2 pairs)	X	✓ 7 eggs (from 2 pairs)	✓ 3 eggs	X	✓ 2 eggs
Fertile eggs	X	X	✓	X	✓ inconclusive results	✓	X	✓
Healthy eggs	X	X	✓ (1 clutch thin shelled)	X	✓ (2 thin shelled)	✓ (all possibly thin shelled)	X	✓ (1 thin shelled)
Heathy chicks	X	X	✓ (2 hatched but died soon after)	X	✓ (2 hatched, 1 died soon after)	✓ (3 hatched, 1 died soon after)	X	X

Note:

Majority
Limited
None

It is difficult to compare exactly the level of breeding activity between years. The methods and means used to record such activity as well as the observation periods varied significantly between years. It is difficult therefore to judge more precisely what factors may have influenced activity between years. We do know that breeding activity increases with increasing photoperiod (and other husbandry changes leading up to the breeding season) and in years without a 24-hour light period activity appeared generally lower, though other factors are likely to have influenced this in addition. We can look at timing of key events during the breeding season and factors that influenced these with comparison to timings for the same events in wild birds (Table 11).

Similarly to wild SBS, peak activity in the captive birds was just prior to egg laying becoming much quieter during the egg laying period. Separating the sexes prior to moving them into breeding aviaries as pairs was done only once in 2016, the first year they bred. In other years they bred, they were moved straight from a mixed sex flock to pairs, though moving males to aviaries first was trialled other factors in addition likely influenced breeding success.

Table 11 – An inter-annual comparison of breeding activity timelines

Year	Photoperiod	Activity began	Average date moved into breeding aviaries	Approx peak activity	First egg of clutch laid	Activity ceased	Average date moved out of breeding aviaries	Average number of days as pairs	Notes
2011	Slimbridge, UK photoperiod	-	-	-	-	-	-	-	No breeding activity noted
2012	12 hours on/off cycle to April, then Slimbridge, UK photoperiod	-	-	-	-	-	-	-	Some heightened aggression during breeding season only
2013	Slimbridge, UK photoperiod No 24-hour periods	-	-	-	-	-	-	-	2011 cohort separated into two groups in annexe (altered to provide breeding habitat) and room. Group reformed same day as birds very pacey
2014	Slimbridge, UK photoperiod, plus 24-hour light period during breeding season Lights left on mistakenly overnight late April	Early April	10 May	Mid-May	-	Late May/early June	20 June	42 ays	P#2 housed 4:4 birds, some singing but largely acted as a flock rather than forming any pairs, defending territory etc. Birds in P#1 shuffled multiple times before left as pairs. Some additional moves later in season.
2015	Slimbridge, UK photoperiod No 24-hour light period	Late April	29 April	Late May	-	Early-mid June	8 July	71 days	All birds put straight into breeding aviaries as pairs. Two females swapped later to form better pairings
2016	Slimbridge, UK photoperiod, plus 24-hour light during breeding season	Early April	17 May	Late May	5 June 5 June	Mid-late June	23 June	67 days	Three males and three females moved into breeding aviaries as single sex groups two days before forming pairs with own aviaries. Multiple moves/swaps in P#1 throughout the season.
2017	Slimbridge, UK photoperiod No 24-hour light period	Mid-May	16 May	Early June	-	End June	16 July	61 days	4:3 birds moved to a breeding aviary in P#1 one day prior to being spilt into pairs with own breeding aviaries. No additional moves/swaps of birds.

Year	Photoperiod	Activity began	Average date moved into breeding aviaries	Approx peak activity	First egg of clutch laid	Activity ceased	Average date moved out of breeding aviaries	Average number of days as pairs	Notes
2018	Short winter 2017/18 6-week time-shift 13 weeks 5 days breeding season	Early March	11 March	End April/start May	28 April 5 May	Mid-late May	9 June	90 days	All birds put straight into breeding aviaries as pairs. No additional moves/swaps of birds.
2019	Very short winter 2018/19 8-week time-shift 9 weeks 1 day breeding season	Early March	1 April	Early-mid May	28 April	End May	10 June	70 days	All birds put straight into breeding aviaries as pairs. Two females swapped later to form better pairings.
2020	8-week time-shift 8 week breeding season	March	25 March	Early-mid May	-	End May	23 June	90 days	All birds put straight into breeding aviaries as pairs. Some birds swapped/moved through the season after several deaths occurred.
2021	Longer winter 6-week time-shift 8 week breeding season	Early April	3 April	Early-mid May	14 May	End June	26 June	84 days	All birds put straight into breeding aviaries as pairs. The two females were swapped early in the season to form better pairings.
WILD for reference	-	Early June	Arrive to breeding grounds Late May/early June	14 June*	10 June	Mid-late June	Females appear to leave breeding grounds soon after hatch, mid July Males leave breeding grounds after chick rearing early-mid August	Approx. 6-7 weeks (approx. 45 days). Females arrive later and leave earlier than males	Not unknown for pairs to ‘divorce’ but not thought to be common. Some instances of males with additional females observed.

Note: * Individual to the bird. Captive birds in dense population make ‘peak’ activity more apparent

We can obtain a rough idea of what may contribute or hinder breeding by looking at consistencies or inconsistencies throughout the project (Figure 47). Generally being with the same partner in the same aviary increases breeding activity by that pair annually, occasionally producing eggs (PLGL/2018,PPR/2016). However, being paired with the 'right' bird, a pair that interacts/bonds well, appears to better this with three occasions seen where pairings were new but produced eggs in their first year together (PWR/2016,PWR/2021,PRR/2018). Also, in only one of these instances was at least one of the birds (of males and females) in the same aviary the previous year, supporting pair compatibility over consistent territory/aviary. Birds bred in years they were regularly moved/swapped as well as in years of no moves; finding a compatible pair also appears to outweigh disturbance in this sense.

It is not clear what exactly makes a pair compatible. Though fitness/health appears to be a strong factor. We do know that of the five pairings that produced eggs, at least three were unrelated (unable to determine relatedness between two pairings involving the 2011 cohort).

Annex 4 provides more detail on bird moves prior to pairings and health status and of birds involved.

Female	2014	2015	2016	2017	2018	2019	2020	2021
YL	WL / **Annexe A#1**	RR / **P#2BA#3**						
PL	OR / WR / **P#1BA#3**	BlackL ~ / **P#1BA#3**	PDGR ~ / **P#1BA#3**	BlackL / **P#1BA#3**	OR / **P#1BA#3**	POR / **MA**		
PWR	PDGR POR BlueR PWL PL **P#2**	BlueR / **P#2BA#2**	PR + (4) **P#2BA#1**	BlueR ~ / **P#2BA#1**	BlueR / **P#2BA#1**	PBlueR / BlueR / **P#2BA#1** -later swapped to **P#2BA#2** with BlueR /	BlueR / (died) PRL / (died) **P#2BA#1** -later moved to **P#2BA#2** -later moved to **P#1BA#3**	LBDGL / PDGR + (2) **P#1BA#1** later swapped to **P#1BA#2** with PDGR +
PWL	PDGR POR BlueR PWR PL **P#2**	PR POL **P#2BA#1** -later moved to **MA/Annexe A#1**	RR + **P#2BA#4**	RR / **P#2BA#3**	PPL / **P#2BA#2**	RR / **Annexe A#1**	POR PRL **P#1BA#3**	
PYL	PDGR POR BlueR PWL PWR **P#2**							
PPR	BlueL + **P#1BA#2**	BlueL + **P#1BA#2**	BlueL + (3) **P#2BA#3**	PDGR / **P#2BA#2**	RL / **P#2BA#3**	RL + **P#2BA#3**		
POL	PR / **P#1BA#4**	PR / (PWL) **P#2BA#1** -later swapped to **P#1BA#1** with RL	BlackL / **P#2BA#2**	OR / **Craneland**	BlackL / **Craneland**	BlueR ~ **P#2BA#2** later swapped to **P#2BA#1** with PBlueR /		
PLGL	PDGR POR BlueR BlackL PWL PWR PYL **P#2**	PDGR / **P#2BA#4**	BlueR ~ / **P#1BA#1**	PRL / **P#1BA#1**	PRL + (3) **P#1BA#1**	PRL + **P#1BA#1**	PDGR + **P#1BA#2**	PDGR **P#1BA#2** later swapped to **P#1BA#1** with LBDGL /
PRR	RL + **P#1BA#1**	RL / **P#1BA#1** -later swapped to **P#2BA#1** with PR	RL + **Craneland**	RL + **P#1BA#2**	PDGR + (4) **P#1BA#2**	PDGR + (3) **P#1BA#2**		

Notes:

Highest Lowest None	: Observed breeding activity (relative to all other birds that year)
WX YZ	: Males/females housed with
+ Positive (4) No. of eggs / Neutral ~ Negative	: Response to male
Bold font	: Location
	Not consistent between years
	Some variation between years
	Consistent between years
	Paired previously

Figure 47 – Female pairings and location timeline

2.5.3 Breeding strategy

Given the ecology and lifecycle of wild SBS it was decided to house the birds as a flock when not breeding, approximately early August to late May, and confined as pairs into separate breeding aviaries during the breeding season, approximately June to July. The facility was designed based on this strategy. This timing matched that of wild SBS breeding in order to have the option of taking eggs or chicks produced here to Chukotka, Russia, if a self-sustaining population was established. In later years breeding became priority over taking any eggs back, resulting in time-shifting the birds to breed earlier. The summer seasons were also extended to increase chances of second clutches.

2.5.3.1 Pre breeding season activity

Observations

In the weeks leading up to the breeding season there were observable differences in the SBS triggered by seasonal environmental changes. They moulted into summer plumage and aggressive encounters for resources increased in number as the season progressed. Both males and females would 'sing' and display to defend resources. Males would additionally sing and display to proclaim and defend territory, court the female he was paired with, and nest scrape. The variety and type of calls and song were numerous, many sounding similar but with seemingly different meanings.

Song types

Contact calls
Single or continuous peep-like calls when foraging, resting, interacting. This doesn't usually merit attention from other birds but appears to serve as note of presence or vicinity. Can overlap with alarm calls.

Alarm calls
A sharper peep-like call done in succession often to denote alarm. This is used when predators are seen, when alone and seeking for others, or when generally unsettled. Overlaps with general contact calls and doesn't always appear to cause alarm to other birds. Responses to alarms calls from other birds include, crouching immediately, running to cover then crouching, immediate flight, flocking and heightened alert, or no response. Likely subtle variances in calls that humans cannot distinguish.

'Singing'
Songs vary between individuals and serve several different purposes, likely subtle variation in song type humans cannot distinguish. Typically, it is a rapid descending trill; preeer-prr-prr-prr-prr. Singing predominantly is heard in spring and summer, though will be used at any time on occasions with strong stimuli creating excitement. 'Songs' are used to resource guard in both sexes. Males use songs to attract females and proclaim territory. Females usually sing in response to male partners, often then singing in unison. Other males will also sing in response to defend territory. Surplus males housed together in an aviary will also sing in response which appears more automatic/instinctive. Singing is often coupled with visual displays, with wings either held straight up or out to the sides with head bowed low and tail fanned, often chasing another bird.

Song extensions
A typical song may end in a prolonged buzzing, or trill, prr-rr prr-rr prr-rr. It can also lead to nest scraping or frog-calling.

Nest scraping
The nest scrape songs sound similar to the latter parts of general songs. It's a continuous multiple-pitched bubbling call performed by males whilst forming or tending a nest scrape. Its purpose appears to be to invite the female to the nest, his head is low and tail high, he continues the call whilst she inspects. Copulations have been noted to follow nest scrape invites, though not exclusively. Nest scrape songs are not performed every time the male tends to the nest.

'Frog-calling'
Frog-calling appears later in the breeding season once pairs appear to have been established. The call is low in pitch, short and repetitive, urrrr-urrr-urrr, somewhat similar to a frog. The males' throat appears to swell during the call/display, his head is bowed to the floor and his tail points to the sky revealing the white ventral feathers. This is done by the male often from a high spot in the breeding aviary. It doesn't appear to warrant attention from other birds.

Wild SBS will perform flight displays and songs, but the aviaries in the SBS facility did not facilitate this.

2.5.3.2 Pair selection

A few attempts were made throughout the project to allow males and females for form natural pairings, but the majority of the SBS in mixed sex groups of three or more leading up to and during the breeding season behaved as a flock with little obvious attempt made to form pairings. Activity was also generally low in those housed as a group during the breeding season. Groups of surplus males have been known to display to each other and tend the same nest scrape.

Pairs are selected artificially based on several factors. In no particular order: moult score, plumage condition, current health, historic health, previous pairings and compatibility, relatedness, and dominance. Number of times caught, treatments given, and foot condition, were also ranked in early years to assist decision making.

2.5.3.3 Breeding aviaries

Several different sizes and configuration of aviary have been trialled throughout the project (further details found in Annual Report summaries, Annex 5). It is difficult to determine exactly what the ideal may be, as numerous other factors have influenced the breeding outcome for each pair every year. For example, pairing, health, weather, disturbance, etc.

Every breeding aviary had at least one 1m x 1m fresh water filtrated pond with watercress (salt water in trays only provided if foot issues occurred). The substrate generally consists of holm sand used as a base, the majority then covered in low maintenance turf (some well-established, some replaced annually), then sporadically placed sedum species, ornamental grass species, and heather species. Some areas were left with bare sand. The aviaries were landscaped to form small hills and depressions (some lined to form shallow pools), and in later years furnished with large plastic piping covered in sand and turf to act as both shelter and display points. In the latter years of the project each aviary also had a UV light unit which food dishes were placed underneath upon towels.

Pairs were assigned to breeding aviaries based on a few factors, including previous assignment (particularly for males), how well they settled, quality of the aviary, and temperature of the aviary. It was also in part determined by new hypotheses and trials of size and locality.

2.5.3.4 Possible determinates for breeding at WWT Slimbridge (in no particular order)

It is difficult to make direct comparisons between pairs in any given year to determine exactly what leads to successful breeding and what inhibits it due to the continued changes in environment and pairings. We can make educated guesses using knowledge gained during the project and knowledge of wild SBS breeding ecology. Different factors are discussed below with suggestion of significance on breeding success.

Timing

The timing of moving pairs to breeding aviaries was largely determined by photoperiod, but also in part by behaviour. The birds were separated into breeding aviaries at least by the time the predetermined photoperiod schedule reached 24 hours in day light; in essence the photoperiod experienced by wild SBS on arrival to the breeding grounds. Pairs were moved sooner on one occasion based on behaviour when persistent fighting between two males was observed. The 'time-shift' from 2018 (Section 2.2.2.3) brought the breeding season forward in time to avoid the heat of summer. Other than temperature, photoperiod and behaviour, no other factors were used to determine when to move pairs into breeding aviaries**. Timing of moving the birds appears significant.**

'Migration'

The physical act of migration, particularly long-distance migrants like SBS, likely contributes to preparing the birds for breeding. Wild SBS do not appear to lose significant mass during migration northwards, they may be losing fat reserves and mass in some organs but will be gaining muscle and increasing organ mass in others. Stopovers for refuelling likely to contribute to mass maintenance as well. The SBS facility was not equipped to provide this element of migration. Nor were the birds physically moved any great distances, only a few metres in a southerly direction. Changes in diet, photoperiod, and habitat were used to simulate migration only. The captive SBS still bred regardless of the limitations so the measures provided appear at least adequate to achieve breeding. **Simulating migration appears significant; diet/nutrition (Section 2.4.7) during this period may be very significant.**

Monogamy

We have seen that birds paired in consecutive years are likely to exhibit increased breeding activity, sometimes eventually leading to egg laying. Wild SBS are more or less monogamous, only seeking a new partner if their former does not return to their breeding territory. Though some cases of divorce have been recorded. In the case of the captive SBS we have seen pairs breed in the first year as a pair, suggesting that compatibility trumps monogamy. Though it is not clear if a bird is distressed hearing its former partner elsewhere. **Monogamy is likely significant to continued breeding of pairs that are compatible.**

Territory

It appears that males housed in the same breeding aviaries annually are more likely to exhibit breeding activity. Wild SBS are more or less site faithful, returning to the same area to breed annually, also known on occasion to use the same nest cup. We have seen in the captive SBS, in both males and females, that they will breed when in a new territory/aviary for the first time, providing the pair are compatible. **Territory is likely significant to continued breeding of pairs that are compatible.**

Pair compatibility

Pair compatibility could only be assessed once the pair was in a breeding aviary. This is recognisable in the behaviour of both birds. Some chasing on initial introduction in the breeding aviary appears normal from either the male or the female. The male typically chases the female with wings spread and head low as he sings. The female should quickly be responsive and receptive to the male's singing, often singing in unison. For apparently incompatible pairs chasing by either the male or female will continue in a more aggressive manor for a prolonged period. One bird may begin pacing in the aviary and show signs of stress. The female will not be responsive to the male's singing or display. Pairs that have gone on to breed showed strong pair compatibility from initial introduction in the breeding aviary. It is important to note that incompatible pairs who have had females swapped between aviaries early enough in the season have been known to go on to breed. **Pair compatibility appears to be very significant, trumping multiple other probable factors.**

Competition

Though the SBS have bred in close proximity in aviaries within the SBS facility it has been observed that males could become agitated when other birds were in sight regularly in the adjoining aviaries. Partitions between aviaries had an approximately 30cm opaque border on the base which sagged to SBS height in places if misaligned or not taut. The rest of the partition material up to the ceiling was tightly woven mesh but was semi opaque. The SBS could see each other through this somewhat if they stood on high mounds within their aviaries, which did incite territorial singing. Males would also trigger each other with singing or calls even when out of visual contact. If one male was displaying vocally others would move close to the source or to their mound and sing in response. The Craneland Aviary (Section 2.1.2.1) was developed to test whether distance between pairs increases activity, but a number of other factors contributed to the level of activity in this case, including pair compatibility, how well they settled, and temperature. A certain level of competition is likely healthy and necessary for breeding success but an optimum distance or level of contact between pairs has not been determined here. The closest known distance between two simultaneously active nest in wild SBS is 79m (pers. comms, Egor Loktionov). **Competition is likely significant, though the upper and lower levels that inhibit breeding are unknown.**

Disturbance

Generally, disturbance to pairs was reduced to a minimum. Aviaries were still serviced twice a day to refresh and top-up food, though faeces collection and general cleaning was reduced to bare minimum and avoiding nest scrapes. This did vary between years and was often based on the birds' behaviours at the time.

It was not possible to eliminate/reduce all external sources of disturbance. Vehicles were stopped from driving in close proximity to the facility, however, aeroplanes, helicopters, microlights etc. could not be controlled, those these often actually triggered singing/displays. Wild birds flying over could not be controlled well during the breeding season either, and hawks, owls, gulls were regularly seen around the facility.

Human presence (care staff), both within the aviaries and in the corridor joining the polytunnels, did not appear to subdue breeding behaviours but actually stimulated them to some extent. It was regularly noted in every year that the SBS would sing at initial appearance of staff in the vicinity of the breeding aviaries. Copulations have also been witnessed whilst inside the aviaries. It is not clear why they were stimulated by staff presence (see 2.3.4). It is difficult to determine whether human presence overall effects breeding outcomes positively or negatively. Limited testing was possible as a certain level of human 'disturbance' was required in this particular facility to maintain adequate husbandry levels. It is important to note that 2012-2014 had high visitation of the facility by electricians and other contractors to complete relevant works such as lighting installations and rewiring (4-8 months per year had at least one visit). 2015-2018 was quieter (2-3 visit-months), with visits mainly carrying out required checks or adjusting lighting provision. 2019-2021 had more electrical checks and repairs (5-8 visit-months). **Disturbance is likely significant though the upper and lower levels that inhibit breeding are unknown.**

Diet and nutrition

The final diet had a gradual alteration leading up to the breeding season to become richer in protein and more abundant in invertebrates (both live and frozen). This was provided to meet the demands of high energy use during the breeding season, and to simulate suitable rearing habitat with high numbers of invertebrates.

From early 2018, and every breeding season after, the birds were given vitamin D supplements as poor egg quality and poor chick health in years prior had been linked in part to lack of calcium in the females due to inadequate lighting. The eggshell thickness was compared for hatched eggs of captive and wild birds in 2016 and 2018 and overall found captive to be thinner, even after the introduction of the vitamin D supplement. Rat tail bones were offered (not necessarily eaten) from early 2019 and every breeding season after as an additional source of calcium as it has been documented that arctic calidrids eat lemming bones and teeth as a source of calcium in the wild (MacLean, 1974). Eggshell thickness was not measured for captive eggs hatched in 2019, but their general appearance and health of the chicks suggested there was improvement on previous years.

Wild SBS don't appear to lose weight as readily as the captive birds do through the breeding season. Wild SBS also appear to arrive at the breeding grounds heavier than the captive SBS relatively. Weight data for wild SBS is restricted to June-July and September so it is impossible to say what happens between these times for comparison to the captive SBS. But it appears likely that protein and fat availability at certain times of the year differs between captive and wild SBS. It is worth noting that weight changes in the captive SBS will also be in part due to environmental factors that could not be controlled. Data is available regarding food abundance and type in both the wintering and breeding grounds though this has not yet been looked at comparatively. There is some evidence to suggest that the captive SBS self-regulate their protein and fat intake depending on their needs (Section 2.4.7). However, their dietary needs in captivity (likely largely dictated by climate) were different to that of wild SBS. **Diet is likely significant, though more research is required looking at both wild SBS and captive waders.**

(Sun)light provision

Light generally is a strongly influential factor in multiple areas of husbandry and breeding. A correct photoperiod contributes to circadian/circannual rhythms, adequate ultraviolet light to aid vitamin synthesis, full spectrum light provided for good avian colour vision, and the appropriate levels of all light types at appropriate times.

Photoperiod. The birds experienced a slightly different photoperiod each year of the project. Changes were made annually for the betterment of the birds as knowledge and experience increased. The birds appeared to respond most positively in terms of breeding in years they experienced 24 hours of light during the breeding season. In 2018 the photoperiod was altered most drastically to shift the breeding season earlier in the year, allowing the birds to breed in the cooler months of spring. This had a desirable effect though it potentially contributed to higher stress levels and poor health of the birds in the longer term.

Ultraviolet light. Special attention was not paid to UV light provision until 2016 when it became apparent the females were lacking enough calcium/Vitamin D to breed successfully. The birds have always had UV lighting provided but this was not monitored closely. This appeared to be a strong influencing factor on successful breeding, combined with other factors; as UV provision increased so too did the quality of the eggs and chicks produced.

Light quality. It was known in the early years of the project the light quality could be improved in the sheltered parts of the facility. After multiple consultations with various experts in the field, high quality lighting was installed in all occupied areas of the facility in 2015. This continued to improve over time with the use of wider spectrum and better-quality bulbs, and with continued consultations with external advisors. This may have contributed to the higher breeding activity and better health of eggs and chicks in later years.

Wherever possible it was ensured that the birds were provided lights which did not flicker, and any bulbs/fittings found to do so were replaced. **Lighting (photoperiod, type, and quality) appears very significant.**

Climate/weather

The UK climate appeared to effect breeding activity significantly (and general health and welfare throughout the year). The UK climate is not comparable to what SBS experience in the wild, in fact seasons are more or less reversed. During the breeding season temperatures were high and exacerbated by the facility structure/materials. Breeding activity/effort reduced as temperatures rose, with the SBS becoming almost inactive on the hottest days. Mitigation had limited effect with the most effective measure, the misting system, potentially inhibiting breeding by continually saturating/wetting more than 50% of the suitable substrate almost every day from early morning to late afternoon. In contrast, UK winters are wet and cold when wild SBS would naturally have intense and prolonged direct sunlight, possibly required or at least in part attributed to successful breeding in terms of egg production. **Climate appears to be a significant factor in breeding success, as well as for health and welfare.**

Parental incubation and rearing

Every egg that was laid at the facility was replaced with a dummy (unless soft shelled). Once the clutch was complete the dummies were removed and the nest scrapped almost immediately in hope the birds would relay. The majority of the pairs have not had an opportunity to incubate and none had the opportunity to rear chicks. Removing eggs was done due to the high temperatures in the facility compromising eggs. Eggs were often visibly thin shelled (lack of waxy cuticle) and liable to be damaged by the adults if left in the nest (toe holes and dents seen in some eggs). Removing eggs did not appear to deter the birds from breeding or laying in later years regardless of pairing or aviary. Repeated annual removal of eggs from wild SBS nests for headstarting does not appear to effect breeding prospects. **Parental incubation and rearing does not appear to be significant to subsequent breeding attempts, though data is limited.**

Habitat/substrates

The captive SBS generally formed nest scrapes in the turf (both old and new for that year) at the edges of the aviaries, though there were exceptions. No obvious pattern has been identified as to chosen locations of nest scrapes; not being near particular aviary features (water bodies, tunnels, mounds, valleys) or vegetation (tall grass, shrubs). The nest scrapes which were chosen for laying typically were closer to the centre of the facility, i.e. the corridor between the polytunnels, regardless of which polytunnel they were in. They were often lined with dried grass and leaf litter (Dwarf willow leaves provided specifically for this purpose) depending on what was in the aviary/vicinity of the nest. Small stones would be picked up and used if within the immediate area as well. An example of a nest scrape shown in Figure 48. **Suitable substrates and nest linings are required for the formation of nest cups. A variety of aviary features (scrubs, grasses etc.) and landscaping (mounds and scrapes) may or may not have impact on nest location. More sheltered areas i.e. away from direct exposure to ‘outdoors’ may be a preferred choice when choosing a**

final nest to lay in though this does not appear to affect a male's choice where to initiate nest scraping.


(Credit: WWT)


(Credit: WWT)

Figure 48 – Photographs showing SBS nest scrape examples

Displaying

The captive SBS were able to perform ground displays, but the facility/aviary design did not enable them to perform song flight displays; which are standard in wild SBS display/courtship. Giving the SBS additional height in the aviaries would likely have come at a great cost in losses through flight collisions, enabling them to gain speed making collisions more deadly. No attempts to perform song flights were seen, but some male SBS did use higher vantage points within the aviary to sing from. Wild SBS are also known to use discarded man-made objects littering the tundra to display from. **Displaying is very important for courtship but the risks of enabling aerial displays appear too great to warrant. Ground displays appear adequate for successful courting.**

2.5.4 Incubation

At WWT Slimbridge any eggs laid could not be left in the nest due to high temperatures in the facility. Many eggs were also thin shelled and at risk of damage by the parent birds if left in the nest. As soon as eggs were found they were collected and placed in a cooler e.g. herp nursery at approximately 13-14°C and 55% relative humidity. When a clutch was complete, they were then removed and placed on a table to raise their temperature gradually. They were then placed into an incubator to start incubation in synchrony. This avoided chicks hatching alone, reducing imprinting risks.

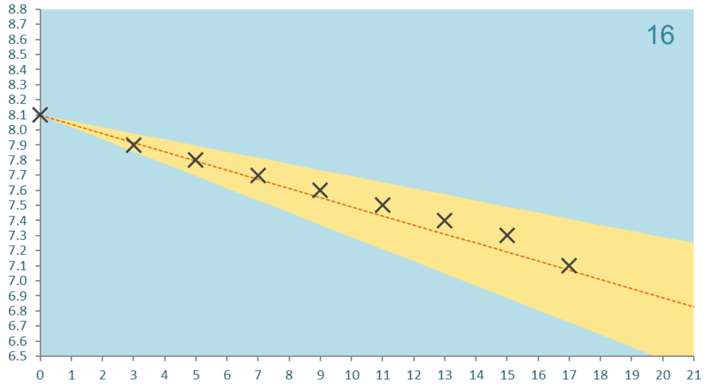
The ideal artificial incubation parameters for SBS eggs are 37.4-37.5°C and approximately 50% relative humidity. Eggs were generally turned 180° every 90-120 minutes automatically by the incubators, though this varied throughout the project with different leading staff. Some years they were also turned manually end to end twice a day. In order to make sure that the incubators ran at consistent temperatures the incubation room was maintained at less than 20°C using a portable air conditioner. Figure 49 shows a typical setup for the incubation room.


(Credit: WWT)

Figure 49 – Typical incubation room setup (2016)

Note various different machines were used throughout the project.

Once set in the main incubator with the standard parameters indicated, eggs were weighed at least every second day to monitor their weight loss closely. All weights were plotted on a weight loss chart with predicted overall weight loss defined (Figure 50). A healthy egg should lose approximately 15% of its original mass over the course of the incubation period of approximately 19-21 days for the chick to hatch successfully. To ensure any deviations in weight loss could be corrected, three incubators were needed. A 'main' incubator for standard parameters; for eggs exhibiting a normal rate of weight loss. A 'dry' incubator for eggs that need to increase their rate of weight loss, with a relative humidity (RH) of 30%. And a 'wet' incubator, for eggs which need to decrease their rate of weight loss, with 70% RH. The temperature for all three incubators remained the same. The type and brand of incubators used varied throughout the project. An additional incubator was set up with standard parameters in case of 'bad' eggs i.e. eggs that appeared to have stopped developing, or eggs that were broken or damaged. This was done to avoid potentially contaminating 'good' eggs. A back-up generator was located onsite in case of any power outages. Incubators were checked regularly throughout the working day.



Notes:
Y axis is weight (g) and X axis is number of days incubated
Red dotted line indicates a 15% trajectory from initial egg mass
Yellow shaded area indicates a 10% loss (upper margin) and 20% loss (lower margin)

Figure 50 – Real example of egg weight loss chart for headstarted SBS

After approximately 17 days the hatching process begins. The chick makes a visible 'pip' in the shell. Note the drop in weight in Figure 50 towards the end of incubation. This is caused by the external pip, speeding up evaporation i.e. weight loss. Some hours prior to this the chick breaks into the air cell, though this is difficult to observe in candling due to the dark and mottled shell. At this point the egg and the rest of its clutch (assuming incubation start date was the same) are moved to another machine, the 'hatcher' (Figure 51). This was usually a modified incubator set to run at 37.2°C and 70%RH, with no further turning of the eggs. Eggs are placed pip side up and monitored closely. From external pip it usually takes the chick three days to fully emerge, rotating inside the egg pushing/breaking the shell as it goes.

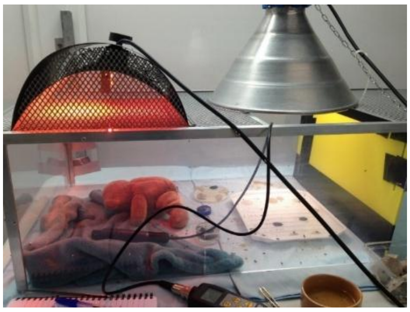
(Credit: WWT)

Figure 51 – Inside a hatcher with newly hatched SBS chick

Once the chick hatches it is examined (in case of protruding yolk, deformities etc.), weighed, and the navel coated in iodine. It is then given identifying rings or markings and placed in a 'drier'. A machine similar to an incubator with more space to stand and move around. Temperature is set to 36.9°C and ambient humidity in the room. Pieces of screwed up blanket are placed in the drier for the chicks to brood underneath. From start of incubation to this point, when not in the room, lights were generally switched off.

2.5.5 Chick rearing

Between 24-36 hours in the drier, the chicks are normally ready to be moved to brooders in groups of two to four (Figure 52). The brooders are 100cm x 50cm with opaque walls (to stop pacing behaviours). They have a UV light and a thermostatically controlled heat source at one end of the brooder initially set to approximately 36.6°C. Heat is gradually reduced by 0.3°C every morning until weaned off heat completely (outside temperature/weather dependant). The brooders are lined with various mats, towels, and non-slip fabric; chosen to maintain foot condition of delicate wader feet and provide grip without fibres to get nails stuck on. These are replaced twice a day. Chick diet is largely the same as the adults although offered in smaller pieces initially and wet only. Food is also scattered on the substrate to encourage initial feeding. More detailed chick rearing protocols can be found in the Spoon-billed Sandpiper Headstarting Guidelines (in prep.) or upon request through the Spoon-billed Sandpiper Task Force.



(Credit: WWT)

Figure 52 – Typical brooder setup

Here the area has been decreased to restrict movement.

Chicks were moved into a brooder within an empty breeding aviary (with a heat source) as soon as temperature/weather allowed, and they were feeding readily; from approximately five days (Figure 53). Eventually one side of the brooder was removed and a new perimeter fence made, increasing the area the chicks had access to over time. Chicks fledge/begin to fly by approximately 17 days, by which point the chicks did not need heat and had access to the whole aviary without the brooder inside. The first chick to reach fledgling died shortly after from a night-fright collision, soon after being introduced to the wintering aviary with the adult flock. The decision was then taken to feather-cut all future fledglings to reduce flight capabilities and risk of collision injuries/deaths. The idea being that when they next underwent wing moult flight capabilities would be gradual and in an environment they were familiar with, in addition to life experience.

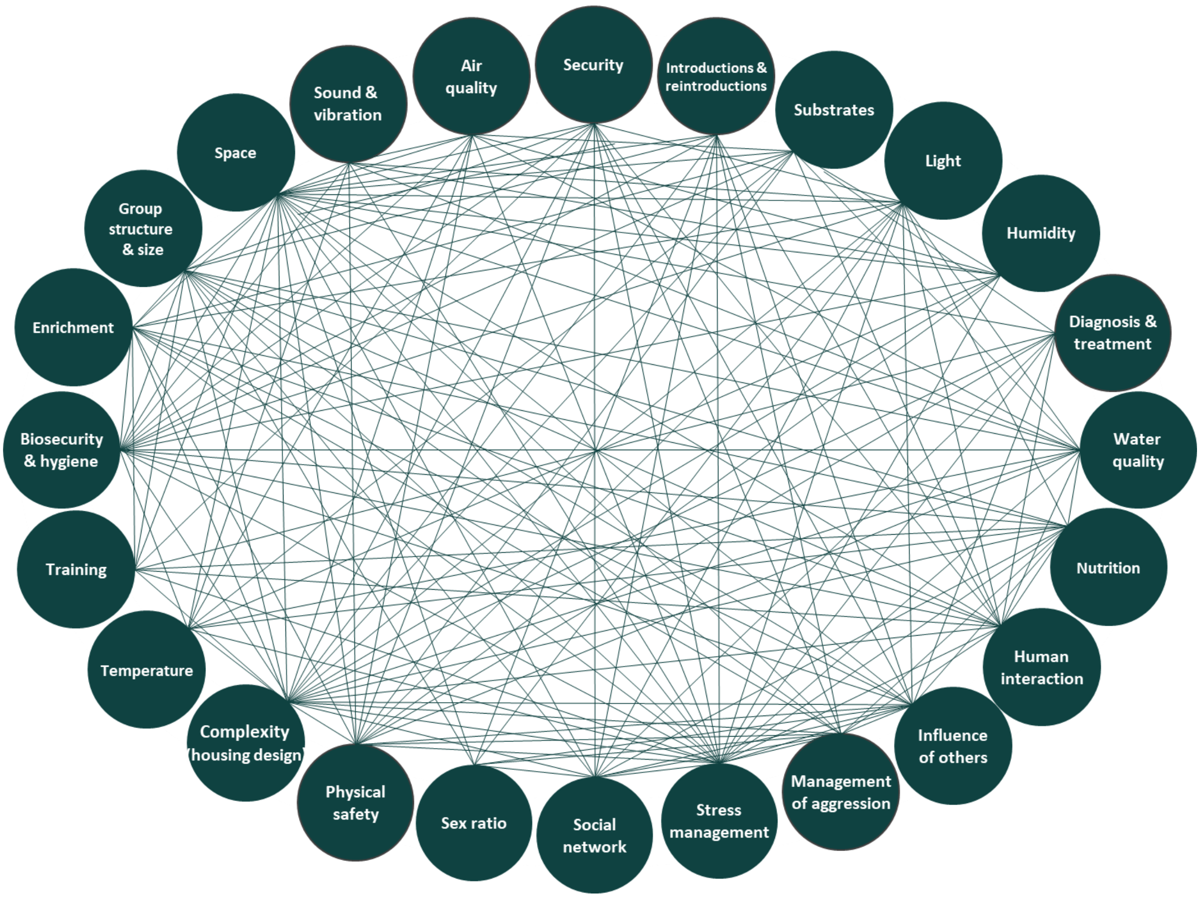
(Credit: WWT)

Figure 53 – Typical setup for chicks pre fledging

3. Considerations and Recommendations

It is important to take into consideration that almost every aspect of husbandry for captive animals is linked to multiple others, therefore altering one will almost certainly affect another. In Figure 54 each circle indicates a factor contributing to survival, welfare, and breeding. The figure shows the interconnectivity that you can expect. This is not an exhaustive list.

Future attempts to establish a captive population of SBS should have a clear statement of purpose and justification linked to an ultimate benefit to the conservation status of the species. To give the best possible chance of establishing a self-sustaining and growing population of captive SBS, WWT offer the following advice based on our 10-year experience of keeping and breeding SBS at WWT Slimbridge and an additional three years caring for several males. Table 12 summarises WWT's considerations, recommendations and lesson learnt.



(Credit: Rebecca Lee)

Figure 54 – Graphical representation of interconnected elements of captive breeding

Table 12 – WWT considerations, recommendations and lessons learnt

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
Record keeping	• Have an online record keeping system/data base in regular/daily use e.g. ZIMS where all data can be stored for continued analysis and research. • Consider using a tablet/laptop for daily records in the database in place of paper sheets. • Make lists of daily, weekly, monthly, and annual routines which are updated regularly (with past copies saved) to maintain continuity and high standard/expectation. • Write monthly and annual reports analysing data for future decision making, long-and short-term. • Consider the value of photos, videos, and sound recordings in addition to written data.	For the early years of the project, including egg collections, records are sparse and paper based, often spread across many sheets/diaries/notebooks in multiple formats, and in some cases are missing. This was in part due to the hastened nature to get the birds into captivity quickly and partly due to inevitable human error. Data type and format collected also developed over the years making analysis difficult in some cases. A continuous online (and backed-up) database would have been extremely useful with continuity in formatting and data type. It is also worth recording the reason behind any changes to husbandry; this was often left out and vital to understanding the decision making. Information of value (not included already in this report) include: • Diet and nutrition. Standardise how 'amount offered' and 'amount eaten' are recorded, including for wet foods. • Breeding behaviours. Standardise how breeding behaviours are recorded in a quantitative way that can be compared within and between years for individuals and pairs.
Impact on the wild population	• Continue to monitor the total wild population and local breeding population(s) to be able to conduct annual impact assessments for egg collecting on both the total wild population and local breeding population(s). • Identify other breeding populations as possible sources of eggs (and possible release sites) for genetic diversity and pair compatibility within a captive population, for both long- and short-term impacts. • Use monitoring data and impact assessment results to calculate when egg collections for a captive population should be completed. This could also inform when a 'no regrets' scenario will occur (based on decreasing local breeding populations and total population) factoring in time before inbreeding occurs.	Impact assessments were conducted once prior to the conservation breeding project to determine the potential effect of taking eggs (and/or adults) from the wild population. The project would have benefited from prior population modelling to determine how many eggs should be collected over how many years for the best chance of a stable starting population. The captive population of two cohorts had a skewed sex ratio in favour of males; further staggered collections may have rectified this. No population modelling was conducted as this was considered a 'no regrets' rescue mission, given the rapid rate of decline suggested at the time. It is not currently known when the last opportunity might be to collect eggs for any new conservation breeding population, particularly considering only one viable population to collect from realistically is currently known about.
Egg/chick collections	• It is strongly recommended to collect eggs for transportation to arrive at the host destination before hatching occurs. • It is recommended that a person with experience is responsible for the eggs transport and handling.	The 2011 cohort was brought to WWT Slimbridge as chicks. Individuals were raised in various locations and caught and transported multiple times; considered detrimental to their health both long and short term. They also had to undergo quarantine and examinations prior to all travel. As a result, fewer birds arrived to Slimbridge than compared to number of eggs arriving the following year (2012 cohort), with a similar hatch rate. Collection of adult birds for a captive population will negatively impact the wild population (counter-productive to starting a conservation breeding programme) increasing the rate of

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
		decline significantly (breeding adults are vital to maintaining the population considering the low recruitment rate seen in SBS). This should not be considered an option particularly as egg collections were successful (reduced transport time, reduced biosecurity risk, reduced stress to chicks/embryos) and resulted in a higher number of chicks at their final destination (compared to transporting chicks).
Host choice	• Hosts and staff should have prior experience in long-term breeding of avian species, preferably small waders, and be practiced in rigorous biosecurity protocols. • Hosts should have prior affiliations with relevant conservation networks/governing bodies. • Host should expect to have support, involvement, and/or consultation with the EAAFP SBS Task Force/Conservation Breeding Working Group in all stages of the conservation breeding project to aid in long and short term decision making. • Hosts should have a clear understanding of the purposes of hosting a captive population and understand the commitment level involved (e.g. financial and longevity, and evolving purposes to eventually take eggs/chicks bred in captivity into the wild population).	The project benefited from having a host and staff with an extensive historical and relevant ongoing experience in other avian conservation action projects with other partner organisations. For example, The Great Crane Project (with RSPB) and establishing the Madagascar pochard population (with Durrell Wildlife Conservation Trust). It also benefited from having experience in husbandry of other wader species. The project also benefited from being connected to an already established network of conservation organisations, governing bodies, and individuals for knowledge/data, advice, and support. Being members or associates of governing bodies ensured a certain standard and reputation for all stakeholders involved. Very few organisations have been approached about hosting a conservation breeding population, nor has it been thoroughly investigated what climate/location might best suit a captive population of SBS (based on the fact natural sunlight/weather is extremely important). The EAAFP SBS Taskforce may wish to develop an informative document for potential hosts outlining justification for setting up a new captive population, aims of the programme, support available, and draft Terms of Reference.
Location (global and local positioning)	• Consider the implications that climate, weather systems, disease risk, and possibly altitude may have on the health and welfare of the SBS when assessing location (global and local). • Be aware that breeding causes additional stressors and therefore further welfare implications, both long and short-term. This applies to the initial/primary host to establish a self-sustaining population and secondary hosts that may act as intermediaries or house SBS whose offspring may be destined for release. • Consider location, particularly for secondary hosts, in terms of long-term conservation purposes e.g. getting eggs/chicks back to the wild population. • Consider logistical ease, reduction of photoperiod mismatch, and potential for host to act as an intermediary station for receiving/transporting eggs from other hosts.	The facility at Slimbridge was located adjacent to other captive bird collections and nature reserves with high numbers of migratory birds as this was the most suitable place at the time, meaning the facility was designed largely with biosecurity in mind. A location away from other captive and wild birds would be more suitable. The location in terms of climate was also not ideal but could have been acceptable if the design of the core structure could control temperature and humidity. Given the purpose of a captive population of SBS will initially be to establish a self-sustaining ark population, location will likely be determined by suitable hosts. The variety of climates SBS experience over a one-year period makes it difficult to suggest a single global location to cater for their climatic needs. Significant seasonal or total artificial climate manipulation within the facility they are housed in should be considered, or at a minimum, a strategy with maximum flexibility and adaptability with precautionary temperature mitigation measures already in place. Hosts (and therefore facility design) should be assessed and altered on a chance by case basis.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Investigations (and trials if deemed viable) should be made to determine whether it is viable to release SBS at sites and life stages other than as fledglings on the breeding grounds (a tested method), which may determine location of hosts. • Consider local location in terms of pollution, with crossover between: o Air pollution e.g. proximity to factories, motorways, composting sites. o Noise and vibration/disturbance e.g. public areas, building sites, airports, predator breeding sites.	
Facility and Utilities: design, layout, and materials	• All facilities and utilities should be built to completion in advance of any egg collections. • Ensure no electrical equipment is exposed to weather (sun/UV and precipitation), or at least weatherproof. • Facility design must consider the host's climate in relation to that of wild SBS. E.g. wintering areas may need to consist of outdoor and indoor facilities, for good and bad weather respectively: outdoor to ensure exposure to natural sunlight (likely key for SBS in winter particularly), and indoor to provide required heat and shelter. A completely indoor climate-controlled facility may be needed depending on hosts/locations for either wintering or summer, if not all year-round. • Ideally the facility should be used solely for the conservation breeding project i.e. only SBS housed here (unless trialling a multi-species cohabitation), and built on fallow ground. Any repurposed facilities to be used should be fallow at least one year prior to housing SBS. • It is recommended to build upon a concrete base (with appropriate drainage incorporated) to prevent weeds damaging structures, avoid flooding, and reduce likelihood of ground pest/predators entering. • Ideally the project should have dedicated staff allocated for the SBS facility, alternatively have strong protocols in place to reduce cross-contamination from other species/aviaries (see the Project Godwit headstarting manual for details; Hiscock & Costa, 2023).	The SBS facility at WWT Slimbridge was not complete before the birds' arrival. The small indoor areas used for the first several years, coupled with other factors like inadequate lighting, regular catches for health checks and aviaries moves, did not give the SBS the best start to a life in captivity with potential long lasting effects on health. The core structure of the outdoor facilities at WWT Slimbridge coupled with the materials initially used, exacerbated summer temperatures compromising the welfare and chances of breeding. Measures taken to mitigate the temperatures, also caused additional disturbance to the birds without fully solving temperature issues. However, the facility's primary design was to be as biosecure as possible, which was ultimately achieved. This was also in part due to the biosecurity protocols and associated staff knowledge, and incorporation of an entrance portal to remove any external items of clothing. It was beneficial to have and maintain pest/predator-proofing of the whole facility. In unprotected aviaries deaths from predators are common with significant losses. Though mice were occasionally seen within the SBS facility these were dealt with quickly. There were no deaths of SBS by pests or predators (ground or avian species) in this facility. However, the SBS were spooked by birds of prey perching close to or on the facility, causing collision injuries and possibly collision deaths. The SBS at WWT Slimbridge did show some signs of migratory responses (roosting at southerly or northerly positions depending on the time of year, alongside migratory restlessness) so positioning of winter and breeding aviaries could be meaningful. Over time, every solid wall/object that could be removed was softened or replaced with net due to frequent collisions, some resulting in death even after softer materials were used. One-way glass was useful but deemed unsafe with flight-capable birds. The PVC coated mesh used in outdoor areas appeared to act as a sail in the wind, causing load-bearing straining wires to snap and pulling itself out of the ground. The hexagonal knotless

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Ideally have only one entrance portal/point for staff (other entrance points available for machinery, substrates, etc). • Consider orientation of facility and position of winter and breeding areas in terms of north-south migration, as well as weather systems. • The facility should be built completely pest- and predator-proof. Double netting should be used for areas exposed to outside with large gauge externally to allow for airflow and exposure to light and weather, but finer gauge internally to stop possible escapes. • Avoid where possible solid structures/walls, particularly glass, in bird occupied areas. Explore alternative soft netting options that are weather and UV proof if used outside or under UV lighting e.g. Zoomesh. • Exposure to the elements (particularly natural sunlight) is recommended for the health and welfare of the birds (and the aviary vegetation and substrates) but climate and epidemiology in the area need to be carefully considered in parallel. • Ideally all bird areas are interconnected (for birds use) to reduce handling needs. • Have a layout of aviaries that cater for a variety of housing strategies being mindful of wintering, migration, and breeding needs. Consider separate migration/staging aviaries. • Ideally dedicated incubation, rearing and quarantine/isolation areas should be present in the facility. • Consider having CCTV cameras in every aviary to remotely observe breeding behaviours and discern causes of death.	micromesh was soft enough to reduce collision risk on the walls but had a trampoline effect on the apexed ceiling. Birds flying at speed were thrown to the ground when they connected with this top net, causing injuries and deaths from the tension (and possibly angle). This mesh degraded rapidly in the elements and needed replacing at least annually at great cost; time, money, and disturbance to the birds. It was also used around UV lighting, again degrading very rapidly. The plastic sheeting covering the outdoor aviaries was ideal for biosecurity purposes but caused unexpected temperature and lighting issues affecting breeding chances, female health, and egg quality. Though gradually replaced with better options, it was not enough and not in time to secure the population long-term. It's also worth noting that zipped doors between the aviaries broke quickly, clogged with sand and were degraded by foot dip solutions with regular use. 10m x 5m aviaries appeared a suitable size aviary for a pair of SBS; they also bred in aviaries approx. 4m x 2m, but appeared more prone to disturbance/stress (from each other and staff entering). The larger size aviary also gave them enough space to get away from staff for a comfortable distance. The layout of the facility was adequate generally but would have benefited from a dedicated quarantine/isolation area to house and care for sick or injured SBS. Dedicated incubation and rearing areas would have also been ideal rather than these spaces being used for isolation bays out of the breeding season; eggs and chicks were known to have died with sepsis though this could be down to low quality/more susceptible eggs rather than poor biosecurity. Layout in terms of breeding strategy was adequate for birds housed in aviaries connected to the wintering areas as they could be walked through pop-holes, but any birds moved to breeding aviaries not connected to the wintering areas had to be caught (causing stress at a critical time). It also meant that there were limited choices for swapping partners unless prepared to catch the birds mid-season. Although methods were developed to reduce stress to the flock i.e. picking up distracted birds one by one, any handling is stressful; the only time a wild bird is caught is by a predator.
Aviary design and substrates	• Consider what breeding/housing strategies are to be executed for optimal aviary design. E.g. will any birds be housed as pairs year-round? Will males and females be separated prior to the breeding season? Will there be a 'staging' aviary? • Ensure aviary substrates/surfaces are either 'washable' (can be wiped down or sprayed with disinfectant) or replaceable. Bear in mind it is possible that all substrate will need replacing occasionally e.g. in an infection outbreak.	Wintering and breeding aviary design may depend on what strategy/strategies are to be executed and what climate is faced. At WWT Slimbridge we had to mitigate for cold wet winters and hot dry summers, housing the SBS as a flock in winter and as pairs in the summer. *Wintering* Generally, damp holm sand (used in the wintering areas occupied most of the year) appeared to be adequate to maintain good foot condition when birds were generally

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Avoid large areas of dry/damp micro gravel as it sticks to the birds' feet with faeces resulting in poor foot condition, unless submerged under water. • Have foot dips at the entrance to every aviary (in addition to the facility entry portal). *Wintering* • Wintering areas should resemble tidal mudflats with a large body/bodies of water. Large areas of damp sand substrate appeared suitable, with some areas of dry substrate. • Consider adding points of interest in the wintering aviaries, for example a wave machine/tide simulation, to encourage natural behaviours and reduce unnatural behaviours (pacing). • Gain further knowledge and advice on typical captive wader substrates that would maintain good foot condition. • If indoor areas are required for heat and shelter, use a durable soft mesh tent suspended within the room e.g. PVC coated polyester mesh. Ensure the room has adequate ventilation. *Breeding* • Breeding aviaries should resemble coastal tundra, with damp and dry areas. Landscaping with mounds and scrapes, with some higher places for display points appeared suitable. • Have an opaque base border on mesh between breeding aviaries at ground level where applicable, ensuring birds cannot see each other constantly. In addition, provide vantage points that are higher than this border so visual contact when stood here only. • Consider having one larger pond in each breeding aviary close to the service door to reduce disturbance from walking round whole aviary. • Be mindful of vegetation types used in breeding aviaries. Ensure at least half of coverage consists of very short varieties with some taller shrubs and grasses to provide visual barriers, cover, and shade. • Consider using easy to maintain natural vegetation rather than artificial plastic vegetation in all cases of need. Be mindful of watering needs, consider irrigation system in covered areas.	healthy. However, foot issues (cracked feet, calluses, bumble foot) did still occur. Limited other substrates were trialled for winter use. The wintering areas were relatively plain and flat. Pacing did occur usually associated with poor health which was mitigated to some extent with the addition of strategically placed sand piles, water trays and artificial Christmas trees. Having a large pond (7m x 3m) in the centre of the aviary (10m x 5m) was ideal for cleaning substrates surrounding it giving the birds a barrier between you and them while moving around. However, the birds retreated to different aviaries whilst cleaning the pond itself, presumably feeling there was not enough space between you and them when in the middle of the aviary. In addition, they did not like the long-handled brush used to clean it throughout the entire project (with the exception of ill birds that would often become tame/fearless). *Breeding* A mixture of sand and turf appears adequate for SBS to nest scrape despite this being significantly different to habitat and substrate type on the breeding grounds (Figure 55). One downside was the grass grew quickly in summer and needed to be cut for manoeuvrability of the birds, i.e. disturbing breeding birds; SBS appear to struggle in long grass. It appeared beneficial to have the breeding aviaries heavily landscaped with scrapes and undulations with the addition of shrubs. This broke up the landscape giving pairs more 'distance' when needed and gave males elevation for displays. Having two ponds at opposite sides of the aviary meant staff had to walk the length of the aviary in order to maintain them, which is not ideal for ground nesting birds in the breeding season. Having an opaque border to reduce contact between birds during the breeding season appeared to work well, avoiding pacing to get to other birds. However, some mounds added in later years meant that birds could see each other (to some extent, given the rest of the mesh was semi opaque) which appeared to induce territorial behaviours. This didn't seem to have any negative impacts e.g. too distracted by other pairs, pacing, etc.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
		 Figure 55 – Examples of breeding habitat for SBS Environmental monitoring occasionally yielded burdens of undesirable pathogens, but the substrates used were replaceable and could be disinfected. The artificial Christmas tree used in most aviaries degraded overtime shedding plastics into the substates which was not ideal.
Water (systems, quality, and precipitation)	• Use closed filtration systems within the facility with UV sterilisers to provide fresh water. • Consider a closed saltwater filtration system with ponds in all aviaries (for wintering and breeding). Alternatively provide saltwater in trays/dishes year-round. • Consider a wave machine/tide simulator for the wintering area. • Consider a misting system to simulate seasonal precipitation. • Consider providing artificial snow at the start of the breeding season to simulate arrival to the breeding grounds.	The water systems and ponds used throughout the project appeared adequate for seasonal needs. The birds would possibly have benefited from having access to quality saline water all year round as wild SBS do and/or a better-quality filtration system removing chlorine, microplastics, etc. Hair algae was prevalent in ponds in summer as were oily films on water surfaces, which was removed manually and/or pond were bailed out intermittently, with some disturbance to the birds during the breeding season. Many ponds were only partially lined with substrates (to allow the birds access in and out of the ponds) with much of the black plastic/butyl exposed. This caused the water to heat up significantly in summer exacerbating the algae issue. The use of chemicals to remove algae specifically was avoided. Concrete ponds were used initially but eventually covered with butyl; concrete it has been known to cause foot issues. The misting system was installed to mitigate against very high temperatures in the facility in summer, however, to be effective it needed to be continually in use from early morning to late evening. The birds had areas that the misting system did not reach, but more than 50% would be constantly saturated/'rained' on which potentially impacted breeding by reducing suitable nesting habitat. The SBS could often be seen standing in the rain or underneath the misters but as mentioned, had space to retreat when desired also. The SBS had a natural attraction to snow when exposed to it at WWT Slimbridge, naturally occurring and artificial.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
Temperature	• Consider providing temperatures (corresponding to provided photoperiod) within the facility to match that of wild SBS, particularly for secondary captive population that may breed birds for release. This is partly dependant on location of the host and/or the design of the facility; this is not an issue if the facility is entirely indoors and where photoperiod and climate are completely controlled but will be an issue if birds are exposed to host's own climate/temperatures (given no one location/host can provide all seasonal climatic needs without manipulation). For approximate temperature data for wild SBS refer to Section 2.2.1. • At minimum, provide heat for the captive birds where photoperiod provided corresponds to late autumn and winter, and cool areas in corresponding spring and summer. • Have temperature mitigation measures in place before the birds' arrival even if they are not used.	Temperature and photoperiod in normal circumstances go hand-in-hand but the SBS at WWT Slimbridge were exposed to temperatures that conflicted with associated photoperiodic location. i.e. it was hot when it needed to be cold and vice versa. Despite this, enough temperature mitigation was in place to enable some pairs to breed. However, extreme heat (relatively to wild SBS) in summer rendered them mostly inactive and no second clutches were produced. This also can be attributed to other additional factors. Photoperiod manipulation to move the breeding season into cooler months of spring worked effectively, bringing moult on earlier as well as breeding behaviours and eggs. However, this, coupled with extending the breeding season (i.e. shortening the winter), appeared to have a negative impact on health with a shorter recovery time (which occurred annually) in which to moult twice as well. This seemed to leave them vulnerable to disease; the Candida sp. infection began shortly after the time-shift occurred. Temperature mismatch with regards to associated photoperiod location appears to impact SBS significantly. Bear in mind that climate and weather is evolving rapidly globally and may need to be mitigated for now to utilise later.

Light	*Photoperiod*
	• As mentioned above, if applicable, consider starting the initial captive population on a photoperiod enabling them to breed in appropriate temperatures. For secondary populations consider using a photoperiod that matches that of wild SBS to breed birds suitable for release (Figure 23).
	• Keep one annual photoperiod throughout life of the SBS.
	    o Avoid lengthening the breeding season i.e. shortening the winter season, through photoperiod manipulation.
	    o Avoid altering photoperiod during adulthood. Altering photoperiod in adulthood appears to cause additional stressors seriously affecting health and welfare, particularly altering the length of the seasons.
	• Research the effects of twilight on birds and decide how to incorporate it into photoperiod.
	
	Lighting
	• Provide full spectrum lighting within the facility in locations and density able to provide seasonal intensity in all areas the birds occupy.
		Photoperiod was considered extremely important to the welfare and breeding of the SBS at WWT Slimbridge dictating when they would moult and breed. As mentioned above, it can be manipulated to alter timings of moult and breeding but likely compromises health and welfare disrupting circadian and circannual cycles, particularly if seasons are extended or shortened. It could be that hatchlings exposed to a gradual change in natural photoperiod to that of the desired photoperiod, experience little effect, providing the photoperiod remains the same annually thereafter. Bear in mind that hosts/location photoperiods may be in conflict with the photoperiod you wish to provide if they are exposed to it. It is worth keeping in mind that the 2019 cohort only ever experienced a time shifted photoperiod and appeared not to show any side effects.
		
		From late adulthood the SBS appeared to have adequate lighting for health, welfare and breeding needs, but for the first several years of life the lighting was not sufficient for successful breeding, though this is also attributed to several other factors. In line with biosecurity precautions integrated within the building's design, and to guard against potential disease risks, they had limited access to direct, non-filtered sunlight.
		
		The UV light units were good but had to be suspended on large structures within the aviaries covered with mesh to avoid collisions, this also reduced UV exposure to the birds significantly.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Provide additional UV lighting at correct seasonal readings, ideally positioned in areas of high traffic such as pop-holes or over food dishes. • Consider housing all light units outside of the aviaries in small annexes to remove the risk of collisions with light units and fittings. Access doors can be added from staff side to replace towels/dishes avoiding entering aviaries at critical times. Additional research is needed for alternative mesh to use underneath UV lights. • Ensure all light fittings and bulbs do not produce a flicker. For example, ballasts used for fluorescent tubes and metal halide lamps are electronic, not magnetic. • Have a permanent dedicated ambient light that can be used during the breeding season 24 hours a day. • Consider fading lights on/off as opposed to switching on/off.	For the small aviaries trialled for breeding, UV units annexed to the main aviary were fitted (Figure 56). This was done as the aviary size was already small and introducing flight hazards were avoided where possible. This appeared to work well reducing time spent in the aviaries themselves as well given the service door on the back, reduced collision risk, and reduced amount of mesh and time spent replacing it. Having a permanent dedicated ambient light for use in the breeding season would have been beneficial to provide 24 hours of light without the intensity of keeping all other aviary lights on. Though during the breeding season they have 24 hours of light, the intensity is much lower for several hours during the night. (Credit: WWT) Figure 56 – Example UV light units situated external to main aviary

Behavioural and Social Management	• Consider trialling a number of housing strategies.
	  ○ Keep a pair together year-round (from breeding age using a compatible pair. Long term this will save a lot of resources and make captive breeding more accessible if SBS can stayed paired year round).
	  ○ House as a flock during winter months (tested strategy).
	  ○ Separate a proportion of the flock into sexes (at migratory stage/aviaries) before pairing into aviaries for the breeding season, possibly trial different lengths of time.
	• Consider housing other small steady waders nearby to encourage breeding by a locational/communal safety effect.
	• Consider housing with other small waders during the winter to reduce flighty-ness.
	• Reduce human contact to what is necessary to maintain good health and welfare, including training to obtain health data in
		Aggression between the captive SBS was generally low with one or two cases of male-on-male aggression leading up to the breeding season. Females are more dominant generally; males would likely benefit from being separate from females leading to the breeding season to improve condition through reduced competition (heavier birds breed better) and make the meeting of a female at the start of the breeding season more novel to encourage/initiate breeding. The captive SBS did not appear to show any signs of choosing partners leading up to the breeding season or when housed as a small group through the breeding season, though trials were limited.
		
		The captive SBS were in close proximity to other waders year-round which potentially aided in settling the birds and encouraging breeding.
		
		Human contact was limited to clean/feed routines and necessary maintenance work. Arguably contact was higher than it would have been if the facility was complete upon arrival with temperature mitigation measures already in place. This could have contributed to their generally calm nature. The SBS generally appeared amenable to people and their activities. It was also clear to see human presence in the breeding season provoked singing and displaying (even copulation) in some pairs.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	place of catching e.g. walk onto scales to take remote body weights, come to staff when called/whistled for. • Consider the use of enrichment to encourage naturalist behaviours. • If flock number reduces to two or three individuals consider housing with another small wader species (if there is no other opportunity to house with other SBS).	Although a small flock of two to three birds appeared just as calm as a flock of 20+, the remaining two and eventually one bird would have benefited from not being alone, likely even if it was housed with another species.

Monitoring	• Make dedicated time to sit and observe the birds once a day for physical and behavioural observations of interest (positive and negative) and input to database.
	• Use weekly body weight data, weekly moult scores, and monthly moult/plumage photographs (input to database) to remotely assess health overtime, mapping individual and group norms.
	  ○ Consider collecting feathers daily/record numbers for moult monitoring purposes (moult scores vary between staff).
	• Consider making a mirrored box or camera box to assess birds' feet remotely. E.g. using remote weighing technique (Section 2.4.4.1) replacing scales with a mirror or camera with clear acrylic on top of box. See Figure 57 for video still from Alaska Sealife Centre puffin foot monitoring.
	• Consider regular faecal and environmental monitoring for pathogen build-up.
	• Work closely with in-house vets with regular remote health checks/visits. Make vet visits a non-stressful experience by desensitising them early without jeopardy.
	• Ensure all bird deaths are followed by a post-mortem and histopathology analysis to aid in determining the causes. Sex can also be confirmed here. Carcasses should also be stored for further analysis and future research.
	  ○ Egg/embryo mortalities should also undergo post-mortem, with eggs that show no development tested for presence of sperm to ascertain fertility.
	• Consider cutting flight feathers if a bird requires regular handling for treatment administration to minimise catching stress/time.
		Annual moult cycles for wild SBS are not well known so comparison cannot be easily made. Replicating wild diet closer than what was provided to the SBS at WWT Slimbridge would be beneficial, and may alter annual weight cycles closer to what wild SBS experience.
		
		Moult is reasonably well understood at least for wild adult SBS. The two chicks that reached adulthood at WWT Slimbridge both went through different moult patterns so typical moult for fledglings to adulthood remains largely unknown.
		
		The SBS at WWT Slimbridge had regular ongoing foot issues which worsened in times of stress. Monitoring feet specifically was difficult with binoculars and photographs, though not impossible, but often resulted in the individual being caught to assess. Given the birds' willingness to walk on scales they would likely walk on clear acrylic with some conditioning/training.
		
		
		(https://www.facebook.com/watch/?v=568878407795243)
		Figure 57 – Puffin foot remote examination through camera box
		
		In light of the *Candida sp.* infection, and other previous pathogen outbreaks in the SBS facility at WWT Slimbridge, it is worth screening regularly, particularly if aviaries are not rotated or substrate is not regularly changed or cleaned.

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Monitor aviary temperatures closely, as well as UV outputs.	It was not often possible to quarantine or separate sick birds from the main flock, but when possible, another bird was quarantined along with it to avoid housing alone (separating a healthy bird with a sick bird is an issue in itself; the next poorest ranking individual was chosen previously, though they were not necessarily sick). When separation was not possible, catching events for one bird would disturb the whole flock. This was mitigated in part by temporarily separating the bird in another area via pop-holes to be caught. The individual was then feather cut for easier catching going forward if needed. Separation need was assessed on a case-by-case basis but generally was avoided if possible.
Diet and nutrition	• Offer 'wet' and 'dry' diet items to adult SBS year-round. • Scatter feed, or at least spread out, highly prized food items. • Use towels underneath food dishes to catch spilt food, washing daily. Consider dipping in disinfectant before use in aviary to maintain foot health. • Collate/inquire/conduct research into SBS diets on wintering, stopover, staging, and breeding grounds. Conduct a new dietary analysis based on this amending the current diet where necessary.	Wild SBS feed on 'wet' food items much of their lives. It is worth noting that birds with gut issues were less likely to take dry food items as well. The main component of the SBS diet was Lundi which was offered both wet (in water) and dry by the end of the project. High valued food items were spread over multiple dishes/aviaries and/or scatter fed to avoid gorging and ensure its accessibility to all birds. Shallow ceramic dishes were ideal for ease of cleaning, weighted in case weather and footfall, and eliminated microplastic risks. However, some were not shallow enough for weak birds or birds with foot/leg issues, which should be considered. Towels were necessary under dishes as birds walk through food regularly treading it into the substrate. Although the SBS diet/nutrition at WWT Slimbridge was adequate to maintain health, welfare, and enable breeding, it would be valuable to reassess based on the latest research (as well as findings in this report) in wintering (Aung *et al*., 2022; Lu *et al*., 2022) and breeding site (ongoing/unpublished) food resources of SBS, as well as other long distance migratory waders diet/nutrition. The SBS had a typical annual weight cycle, as anticipated, in the early years of life but this plateaued after a few years. Likely multifactorial reasons contributing to this e.g. diet, no physical migration, and more. There is also some indication that wild SBS are typically heavier on arrival to the breeding grounds than the captive SBS were when moved into breeding aviaries, and that heavier captive SBS bred better. There are also knowledge gaps in SBS diet/nutrition; where it is known many shorebirds rely heavily on diatomaceous biofilm rich in fatty acid, key to migration and breeding success, (Baird, P., 2022) which the SBS too could be reliant on and were missing in the captive diet at critical times i.e. just prior to breeding.
Reproduction	• Use a decision matrix to initially choose which birds to pair. Ranking current health, historic health, weight, moult score, plumage condition, dominance, relatedness (no particular order). • Base timing to move pairs to aviaries on photoperiod and behaviour.	Pair compatibility is likely the most influential factor determining breeding success but using a decision matrix was a good starting point to choose pairings. It was essential to monitor pairs closely when first put into aviaries, within a few days you can usually determine whether a pair is compatible or not. Females were swapped so males could remain on territory. At WWT Slimbridge compatible pairs were not split up intentionally, only if one of the pair died or was very unhealthy. There were cases of males and females

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make

	• Chose the 'best' aviary for the 'best' pair. Assess by habitat quality, position in facility, temperature, weather exposure, etc.
	  ○ Mimic breeding habitat as closely as possible.
	• Monitor pairs closely, particularly after initial introduction, to determine compatibility and swap females accordingly. Birds which have bred successfully previously should be paired in subsequent years (assuming genetic diversity can be maintained).
	• Place males in the same breeding aviaries every breeding season but monitor how well they settle when placed there initially.
	• Consider separating males and females prior to introducing into breeding aviaries, suggestion of one week minimum. Suggested to separate sexes for one week in 'staging' aviaries, then placing males in breeding aviaries approx. one day before females. Dependant on males' behaviour (could become pacey/stressed alone).
	• Consider having some breeding aviaries in proximity to the main facility (not within).
	• Consider pairing first year birds.
	• Monitor breeding behaviours remotely with CCTV e.g. nest scrapes, copulations, egg laying, incubation start.
	  ○ Consider using AudioMoth loggers to record type and frequency of calls for each pair. Consider quantifying all breeding behaviours data for comparative purposes.
	  ○ Consider using playbacks of SBS songs during the breeding season only if deemed necessary e.g. significant reduction in activity and no females appear heavy. Use songs of individuals not encountered previously i.e. wild SBS or WWT Slimbridge SBS.
	• Providing the eggs laid are good quality and temperatures are suitable, collect eggs for artificial incubation soon after the clutch is complete (use dummies after each laying event if eggs are compromised).
	  ○ Consider leaving second clutches for parent rearing
		producing eggs with a new partner, so swapping partners to increase genetic diversity may be possible, though if they can hear former partners, it is possible they will not settle with the new partner. Wild SBS are generally site faithful and pair faithful. The SBS were also moved to breeding aviaries before the start of the 24-hour daily photoperiod but were moved even sooner if birds were particularly aggressive/fighting.
		
		Separating sexes prior to moving into breeding aviaries was not extensively used/tested at WWT Slimbridge largely restricted by the facility/aviaries available and handling required to do so. Males could be moved to breeding aviaries before females but this would mean birds are alone in aviaries, they may or may not settle but may be distracted enough by drive to breed, particularly if once they have established a territory (first/second year of breeding in same aviary). Separating sexes for one week+ reduces competition, allowing birds to build condition, and makes the meeting of the opposite sex novel/exciting, hopefully inciting breeding activity.
		
		Again due to facility limitations the idea that pairs in close proximity can inhibit breeding at least for some less dominant pairs was not well tested. Though a separate aviary was built away from the main facility this aviary had temperatures that exceeded even the main facility, and likely the pairs were incompatible and not in proper condition to breed (the 'best' pairs remained in the main facility).
		
		First year birds were never paired at WWT Slimbridge, it was not possible for the 2011 or 2012 cohorts due to facility limitations, and the 2019 cohort remained separate (though still within the main facility) from the main flock in an attempt to reduce exposure to the yeast infection the adults were experiencing. It is not unknown for wild SBS to breed in their first year, and pairing in the first year may give some early indications of pair compatibility.
		
		Monitoring breeding behaviours was useful within the season and for year-on-year comparison, it established knowledge and experience to be able to distinguish between good pairings and less ideal pairings to be able to act swiftly increasing chances/opportunities for breeding success.
		
		Playbacks of SBS songs were used when SBS appeared to go 'off the boil'. It provoked territoriality and breeding activity; it was used carefully/sparingly. It may be ideal for use after first clutches are laid.
		
		Any eggs laid by SBS at WWT Slimbridge had to be taken away from nests and replaced with dummies as soon as they were found due to the high temperatures seen in the

Consideration	Recommendations	Lesson(s) learnt / Reflection / Points to make
	• Consider the role of physical migration on breeding condition/outcomes.	breeding aviaries, and because many were thin shelled and easily damaged by the parents. Dummying didn't appear to stop the SBS from completing the clutch and some were seen to incubate them (before the nest was scraped to encourage second clutches). The SBS were still capable of breeding despite not undergoing a physical migration, and post-mortems conducted during the breeding season revealed well developed reproductive organs. The muscle mass developed through migration may contribute to breeding condition, likely coupled with a good diet, appropriate photoperiod etc. which can more easily be replicated in captivity comparatively. In summary, pair compatibility is a key factor to breeding success. Consistency in husbandry also appears to be highly influential. Putting compatible pairs in the same territory/aviary annually likely contributes to the pair's chances of breeding. Keeping a regular annual photoperiod is likely significant to maintaining circadian/circannual rhythms. Light type and quality are significant at all times of year, as is diet and climate. Overall success of a self-sustaining population requires consistent, quality year-round care.

Terminology

Adult - A bird beyond its second calendar year

An#1/An#2 - Annexe One or Annexe Two

BA#1/BA#2/BA#3/BA#4 - Breeding Aviary One, or Breeding Aviary Two, or Breeding Aviary Three or Breeding Aviary Four

CBU – Conservation Breeding Unit

Juvenile - A bird hatched that calendar year

MA - Mixing Aviary

P#1/P#2 - Polytunnel One or Polytunnel Two

QS – Quarantine station

Room #1 / Room #2 – Room One or Room Two

SBS - Spoon-billed sandpiper

SBS facility - WWT Slimbridge Spoon-billed sandpiper facility

Second calendar year bird - A bird in second calendar year after hatch

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Annex 1: SBS polytunnel planning drawings 2012

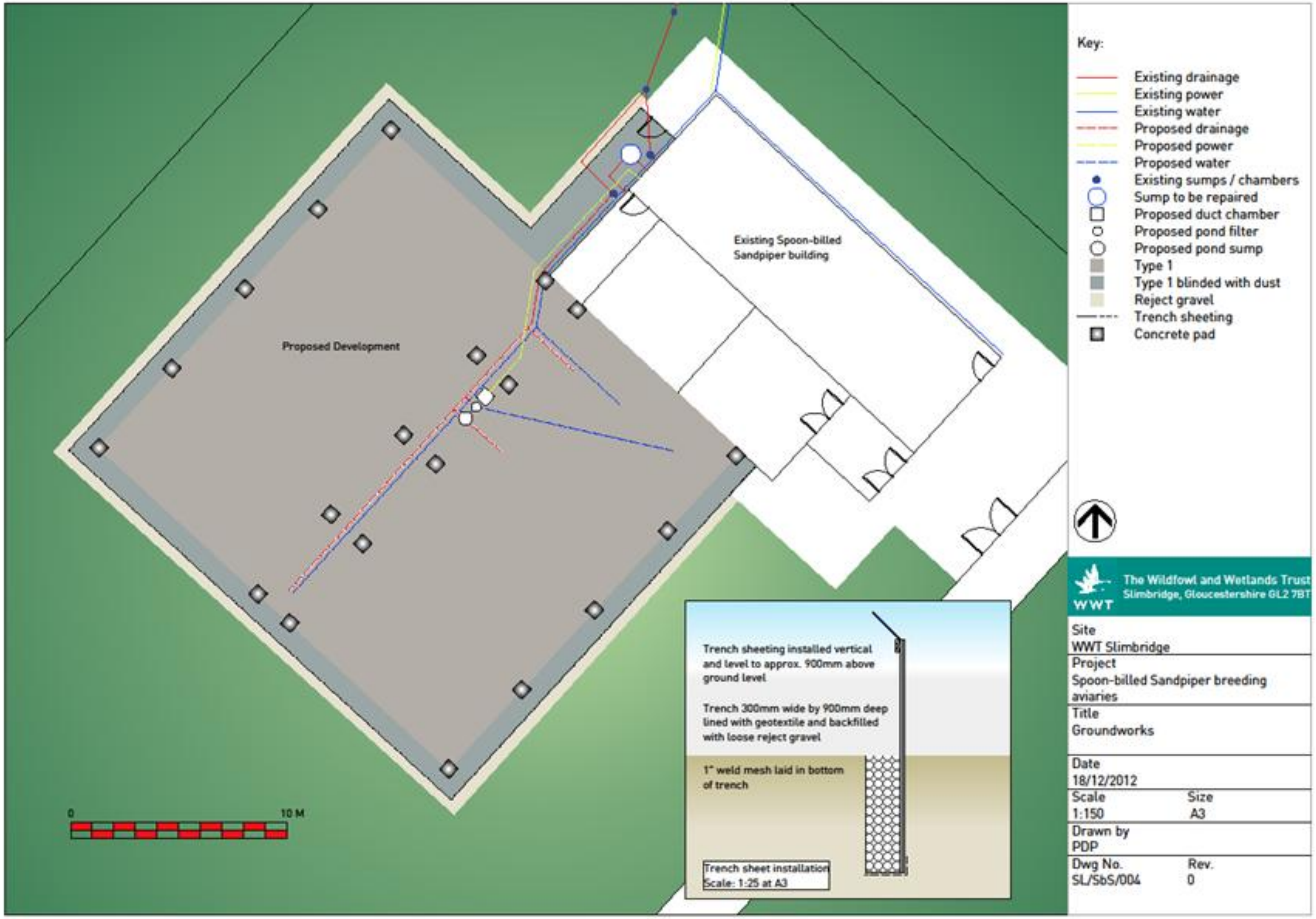

Figure 58 – Drainage and pest/predator fencing

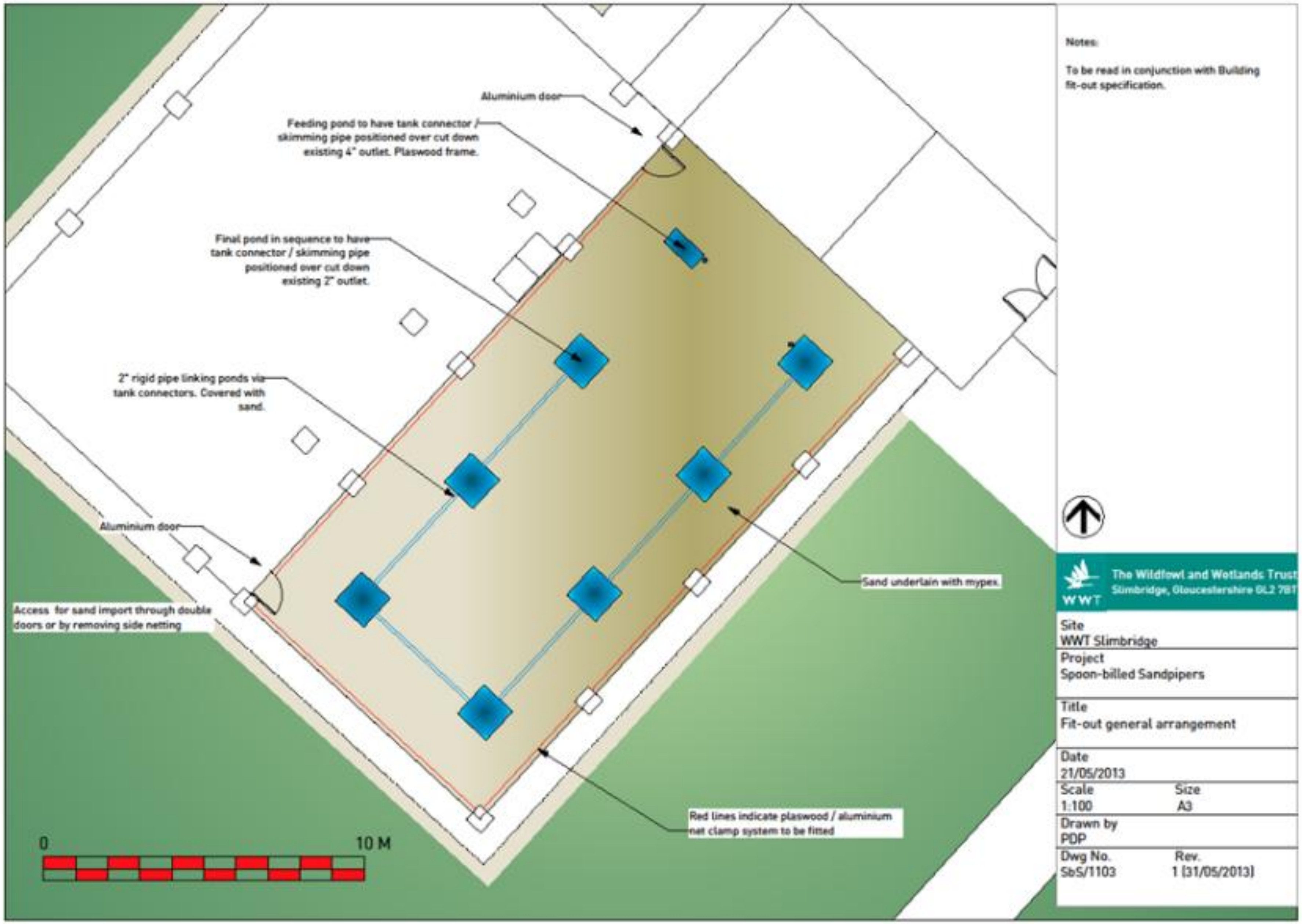

Figure 59 – Initial polytunnel water system

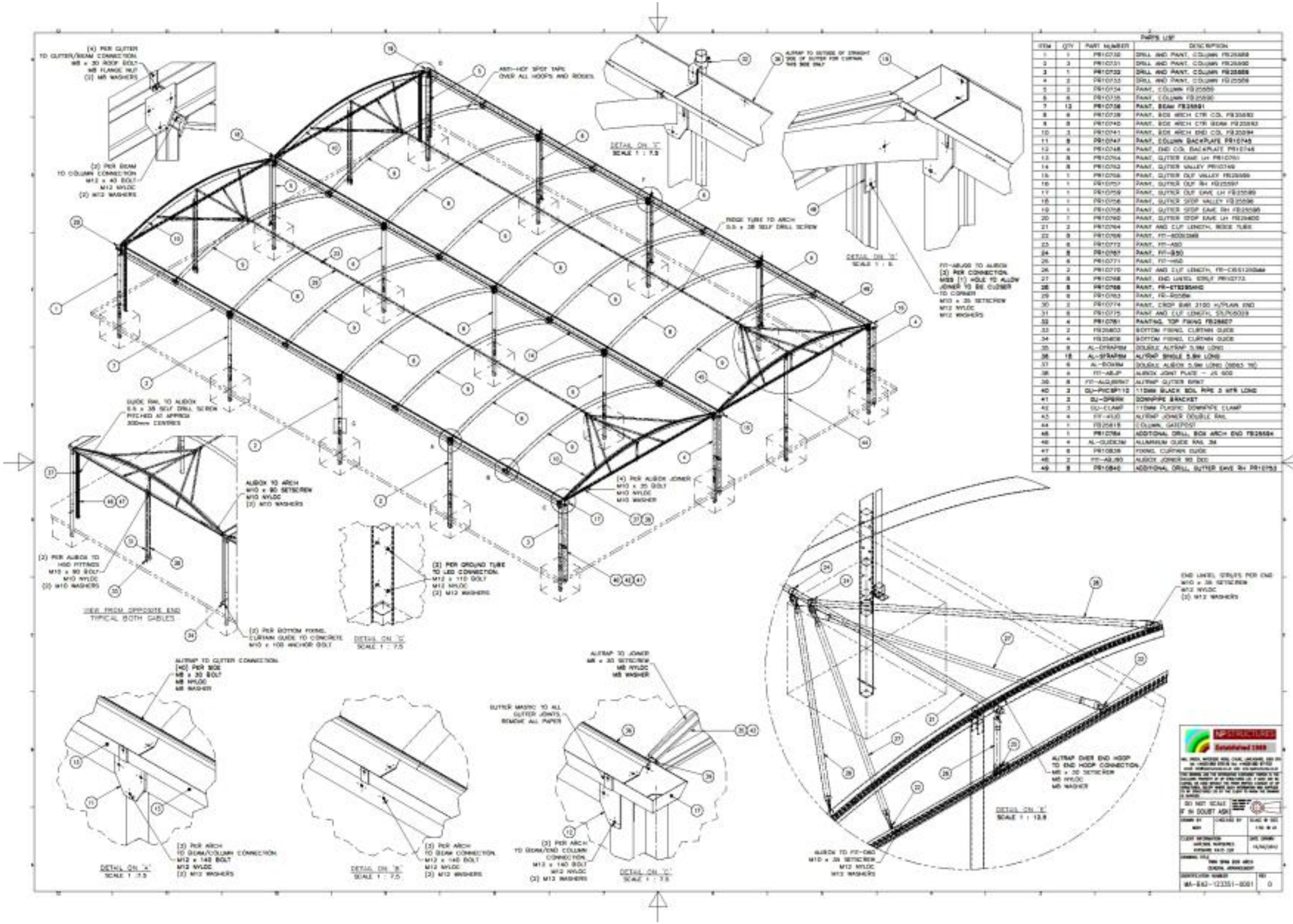

Figure 60 – Polytunnel structure 3D

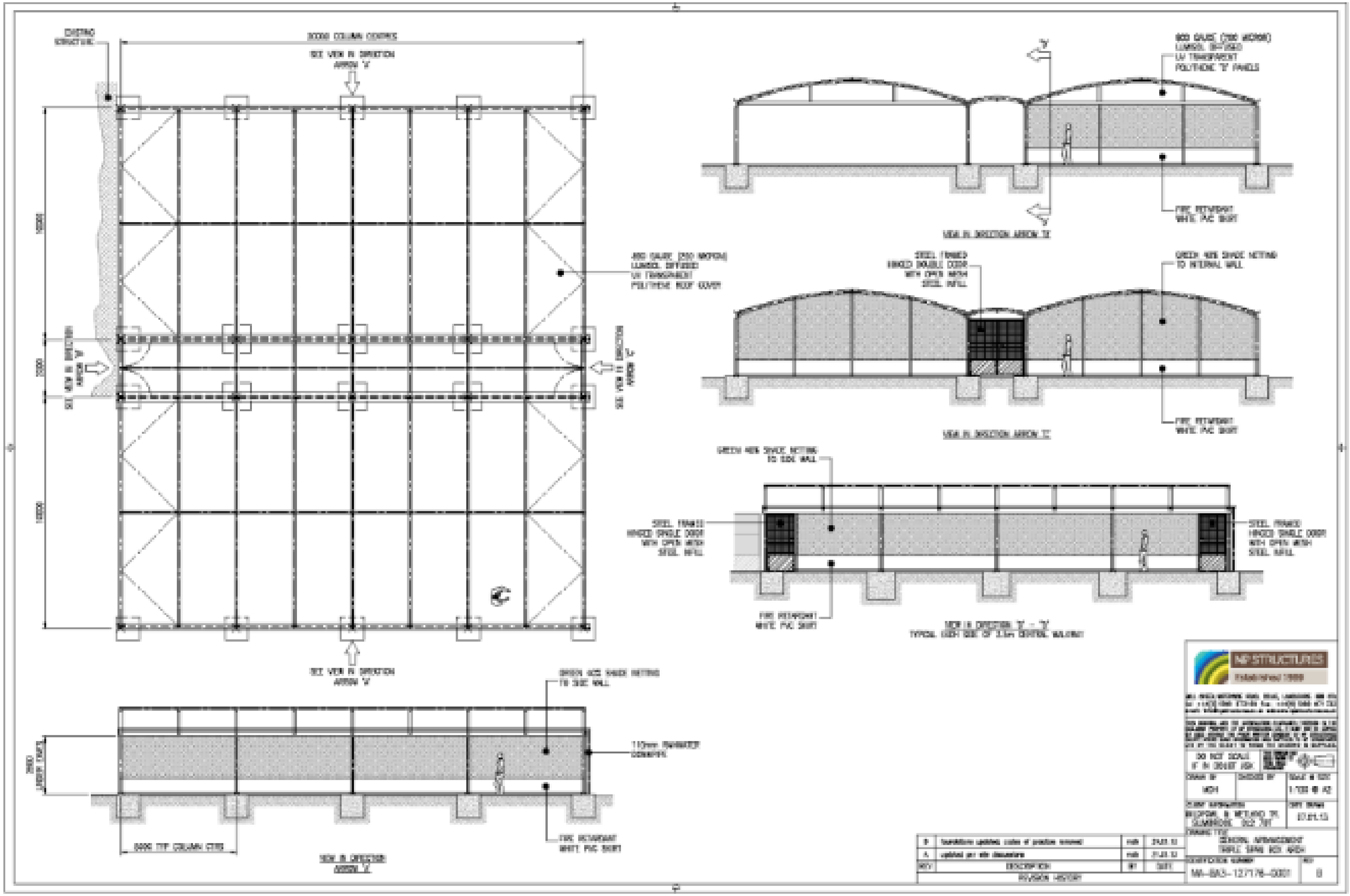

Figure 61 – Polytunnel structure 2D

Annex 2. SBS facility construction photos


62a. Foundation for the main indoor building


62b. Roofing main building


62c. Annexe construction from within


62d. Annexe construction external view


62e. SBS facility under construction


62f. SBS facility under construction


62g. Laying foundations for the polytunnels


62h. Foundation for polytunnels. Permanent annexe's structure with temporary structures can be seen within (2012)


62i. Pest/predator fence installation


62j. Fence and foundations complete


62k. Polytunnel delivery


62l. Polytunnel supports in place


62m. Roof structure and linings added

(All photographs credit: WWT)

Figure 62 – Photographs showing outdoor/polytunnel construction

Annex 3. Example of a Daily Record Sheet

Date: ____________

Weather notes: ____

Bird ID	Present	BAR	Notes	BC
Blue R (M)				
Red R (M)				
Red L (M)				
Pink L (F)				
Black L (M)				
Orange R (M)				
White R (M)				
P Pink R (F)				
P Pink L (M)				
P Blue R (M)				
P Red L (M)				
P Red R (F)				
P White L (F)				
P White R (F)				
P L Green L (F)				
P D Green R (M)				
P Orange R (M)				
P Orange L (F)				
UNR (M)				

Time	Behaviour notes

	AM		PM	
	Feast	Lundi	Feast	Lundi
A1				
MA				
BA1 PT1				
Room				

AM	L20		L35		Feast		Crickets		Frozen tabs	
PM					Feast		Bloodworms		Frozen tabs	

Treatments	
Bird ID	Notes

Additional Notes

____

____

____

Annex 4. Female breeding outcomes with additional details

Female	2014	2015	2016	2017	2018	2019	2020	2021
YL	WL / **An#1** Conjunctivitis Oct	RR / **P#2BA#3** Conjunctivitis Jan and Jul, Died of collision Oct.						
PL	OR / WR / **P#1BA#3** (previously P#1BA#3/4 with various males/females) Bill lumps Jul	BlackL ~ / **P#1BA#3**	PDGR ~ / **P#1BA#3** Multiple birds moves in P#1 Trauma injury to head Jan and Apr,	BlackL / **P#1BA#3** Trauma injury to eye Jun	POR / **P#1BA#3**	POR / **MA** Died of Amyloidosis and Candidiasis in May		
PWR	PDGR POR BlueR PWL PL **P#2** Largely acted as a flock. (BlackL and PLGL later) Debris in eye Aug	BlueR / **P#2BA#2**	PR + (4) **P#2BA#1** Multiple birds moves in P#1	BlueR ~ / (PR died May 2017) **P#2BA#1**	BlueR / **P#2BA#1**	PBlueR / BlueR / **P#2BA#1** later swapped to **P#2BA#2** with BlueR /	BlueR / BlueR died in Apr, replaced with PRL / **P#2BA#1** -Moved to **P#2BA#2** due to heavy rain -moved to **P#1BA#3** when PRL died	LBDGL / PDGR + **P#1BA#1** later swapped to **P#1BA#2** with PDGR + Died in July Amyloidosis, Candidiasis, pneumonia, and severe left hock joint infection
PWL	PDGR POR BlueR PWR PL **P#2** Largely acted as a flock (BlackL and PLGL added later) Bill lumps Jun	PR POL **P#2BA#1** later moved to MA/An#1 with surplus males Toe infection Apr, collision abrasion Apr	RR + **P#2BA#4** Trauma injury to head Jan, Severe limp Nov	RR / **P#2BA#3** Limping Sept	PPL / **P#2BA#2** Severe limp Jan, Jun-Sept, Dec., trauma injury to eye Oct	RR / (PPL died in May2019) **An#1** Severe limp Jan, Jun, Aug, Sept	POR PRL (RR died in Jan 2020) **P#1BA#3** Largely acted more as a flock. Ongoing eye issues from historic trauma Feb, Jun, Oct-Nov constriction of toes May, and again in Dec.	Died in Jan Candidiasis and septicaemia
PYL	PDGR POR BlueR PWL	Died of collision Jan						

Female	2014	2015	2016	2017	2018	2019	2020	2021
	PWR **P#2** Largely acted as a flock (BlackL and PLGL added later) Collision injuries to keel and head Jan, bill lumps Jul, Sept flight collision abrasion to wing Sept							
PPR	BlueL + **P#1BA#2** Early June birds in P#1BA#1/2 mixed for one day Flight collision abrasion to head Jan	BlueL + **P#1BA#2**	BlueL + (3) **P#2BA#3** Trauma injury to toe Jul	PDGR / (BlueL died Jan 2017) **P#2BA#2**	RL / **P#2BA#3** Candidiasis symptoms Oct	RL + **P#2BA#3** Died of Amyloidosis and Candidiasis in June		
POL	PR / **P#1BA#4** (P#1BA#3/4 with various males/females in May)	PR / (PWL) **P#2BA#1** -later swapped to **P#1BA#1** with RL Broken growing quill from collision Feb	BlackL / **P#2BA#2** Constricted toe Jan,	OR / **Craneland Aviary**	BlackL / **Craneland Aviary** Prolonged limp Oct-Nov	BlueR ~ (BlackL died Dec 2018) **P#2BA#2** later swapped to **P#2BA#1** with PBlueR / Candidiasis symptoms June-Jul	Died of Candidiasis in Feb	
PLGL	PDGR POR BlueR BlackL PWL PWR PYL **P#2** Largely acted as a flock	PDGR / **P#2BA#4** Cracked feet Sept	BlueR ~ / **P#1BA#1** Multiple birds moves in P#1 Severe limp Aug,	PRL / **P#1BA#1**	PRL + (3) **P#1BA#1** Prolonged limp Oct-Nov, trauma to toe Dec	PRL + **P#1BA#1** Prolonged intermittent limp from trauma Jan, Apr, Sept-Nov, Candidiasis symptoms June-Jul	PDGR + (PRL died in May 2020) **P#1BA#2** Candidiasis symptoms May-Jun, and Aug-Dec	PDGR **P#1BA#2** later swapped to **P#1BA#1** with LBDGL / Euthanised in Jul, Amyloidosis and osteomyelitis

Female	2014	2015	2016	2017	2018	2019	2020	2021
PRR	RL + **P#1BA#1** Bill lumps Jul	RL / **P#1BA#1** -later swapped to **P#2BA#1** with PR	RL + **Craneland Aviary**	RL + **P#1BA#2** Gout Jan	PDGR + (4) **P#1BA#2**	PDGR + (3) **P#1BA#2** Cracked feet Jan	Died of Amyloidosis, Candidiasis and enteritis in April	

Notes:

Highest Lowest None	: Observed breeding activity (relative to all other birds that year)
WX YZ	: Males/females housed with
+ Positive (4) No. of eggs / Neutral ~ Negative	: Response to male
Bold font	: Location
Red font	: Health issues

Annex 5. WWT Annual Report summaries from 2009 to 2021

(Separate document)

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