Current trends and future directions in swan research: insights from the 6th International Swan Symposium

KEVIN A. WOOD[1,*], LEI CAO[2], PREBEN CLAUSEN[3], CRAIG R. ELY[4], LEHO LUIGUJÕE[5], EILEEN C. REES[1], JEFFREY SNYDER[6], DIANA V. SOLOVYEVA[7] & RADOSŁAW WŁODARCZYK[8]

[1]Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire GL2 7BT, UK.
[2]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China.
[3]Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, DK-8410 Rønde, Denmark.
[4]Alaska Science Centre, United States Geological Survey, Anchorage, Alaska, USA.
[5]Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, Kreutzwaldi 1, Tartu, Estonia.
[6]Department of Biology, Western Oregon University, Monmouth, Oregon, USA.
[7]Institute of Biological Problems of the North, Far East Branch Russian Academy of Sciences (FEB RAS), 18 Portovaya Str., Magadan, 685000, Russia.
[8]Department of Biodiversity Studies and Bioeducation, Faculty of Biology and Environmental Protection, University of Łódź, Banacha 1/3, 90-237 Łódź, Poland.
*Correspondence author. E-mail: kevin.wood@wwt.org.uk

Abstract

Given their popularity with researchers and public alike, together with their well-documented importance in aquatic and terrestrial ecosystems, fundamental and applied research on swans continues to develop in the 21st century. The 6th International Swan Symposium (6th ISS), was held at the Estonian University of Life Sciences in Tartu, Estonia, in October 2018. The symposium brought together 101 delegates from 17 countries, with presentations on a range of topics on *Cygnus* and *Coscoroba* species, including monitoring, habitat and resource use, demography, movements and migration, and threats and conservation. The proceedings of the 6th ISS in this special issue of *Wildfowl* include select papers on swan research presented at the 6th ISS, covering a wide range of species, systems and issues. This paper presents a synthesis of the 6th ISS and an overview of current trends and future directions in swan research. Despite progress on many topics, southern hemisphere swan species continue to receive less attention than their northern hemisphere counterparts, whilst facing many of the same pressures. It is clear that, given the challenges facing swan researchers in the twenty-first century, international cooperation will continue to be vital. Swans are highly mobile animals and many populations undertake migrations spanning thousands of kilometres, and crucially do not recognise human geographic and political borders. Such international collaborations will be particularly important in coordinating future monitoring and conservation activities. The IUCN-SSC/Wetlands International Swan Specialist Group (SSG) will continue to facilitate international collaborations and communication among the global network of swan researchers, through its activities, website and annual newsletter. Given the substantial challenges and knowledge gaps documented here, there is no doubt that swan researchers will continue to benefit from regular symposia to share information and develop collaborations towards understanding and addressing emerging conservation issues. As such, we recommend holding International Swan Symposia every 4–5 years.

Keywords: conference proceedings, *Cygnus* spp., conservation, research priorities, perspective, swans, trends in research.

Swans are among the best studied and most extensively monitored species in the world, and are the subjects of numerous long-term research programmes (Rees & Bowler 1996). Collectively, swans are birds of the family Anatidae and span two genera: *Cygnus* and *Coscoroba*. There are six extant species in the *Cygnus* genus: Black Swan *Cygnus atratus*, Black-necked Swan *C. melancoryphus*, Mute Swan *C. olor*, Trumpeter Swan *C. buccinator*, Tundra Swan *C. columbianus* and Whooper Swan *C. cygnus*. The Tundra Swan is further subdivided into two sub-species, the Whistling Swan *C. c. columbianus* of North America and the Bewick's Swan *C. c. bewickii* of Eurasia. The Coscoroba Swan *Coscoroba coscoroba* of South America belongs to the monotypic genus *Coscoroba*. As charismatic and easily viewable animals, swans are popular among wildlife watchers and the public, contribute to wildlife tourism (Smith 2017; Frew *et al.* 2018), and so have the potential to act as umbrella species to aid the conservation of wetlands and their flora and fauna. Indeed, Sladen (1991) argued that "*swans are special emblems of wetland conservation*".

Swan research in the early 21st century faces both challenges and opportunities. Trends in research activity reflect, at least in part, the environmental pressures on the birds and their habitats, technical advances and developments in wider fields including ornithology, ecology, animal behaviour, conservation and environmental management. Current research is set against a background of pervasive and rapid climatic change, in particular in the Arctic (Barber 2008), as well as rising human resource use, habitat destruction and degradation, pollution and the spread of invasive species (McGill *et al.* 2015).

Research is also fundamentally a human endeavour, which means that the work of swan scientists is shaped by economic and socio-political forces and legislative drivers. The global financial crash in 2008 exacerbated difficulties in obtaining research funding in many countries (Evans *et al.* 2012). Researchers across the globe are also facing increased political barriers to their work (Pettorelli *et al.* 2019). However, in the early 21st century tools such as the internet, email and social media mean that communication between researchers has arguably never been easier. Ornithologists have embraced social media platforms such as Twitter, Facebook and ResearchGate to help develop networks of collaborators and to allow them to share their results with other researchers, practitioners, policy-makers and the public (Dudley & Smart 2016). The rise of open-access science also presents opportunities and challenges for swan scientists. The greater availability of scientific information that can be accessed freely has arguably resulted in increases in both the quantity and transparency of evidence available to decision-makers and stakeholders. However, most journals that offer open-access options have transferred costs directly from the readers to the authors, with limited options for fee waivers, and so the costs of publishing in such journals may be prohibitive to many scientists. The problem is likely to be most acute for those swan researchers who are not professional scientists and so have limited access to funding. Even among professional scientists, a lack of available funding may limit their ability to publish open-access articles. In light of these issues, journals such as *Wildfowl* that offer articles freely to both readers and authors will have a valuable role to play in the dissemination of science.

Both national and international legislation and policy continue to influence the field of swan research. In the United States of America, changes in 2018 to the Migratory Bird Treaty Act (MBTA) of 1918 (as amended) reinterpreted the Treaty's protections to apply only to *purposeful*, and not *incidental*, killing of birds; while it remains too early to assess the consequences of these weakened protections for Trumpeter Swans shot during Whistling Swan harvests, the change has prompted concern from a wide range of conservation organisations (Mitchell 2018). In Brazil, research and conservation efforts on Black-necked Swans and Coscoroba Swans will not be helped by the recent freeze on research funding and reduced protections for the environment (Escobar 2018, 2019). The United Kingdom's 2016 vote to leave the European Union has led to a protracted period of uncertainty regarding the conservation of wildlife, including swans. Currently in the UK, as across all EU member states, EU legislation underpins the protection of the swans themselves (EU Birds Directive 2009/147/EC) and their important sites (EU Habitats Directive 92/42/EEC). Maintaining the standards of protection established by these directives will be critical to wildlife conservation in future years. Despite these issues, there have also been positive developments. In 2016 the EU's Regulatory Fitness and Performance Programme (REFIT) process concluded that both the Birds and Habitats Directives were fit for purpose and had demonstrably benefitted nature conservation in EU member states (Milieu *et al.* 2016). Indeed, many key sites used by swans within the EU are currently protected under these directives (*e.g.* Beekman *et al.* 2019). Moreover, amongst the three swans native to Europe (Bewick's, Mutes and Whoopers), only Mute Swans are huntable in the EU, and only in Germany and Austria, according to the Birds Directive. In 2018, the Measures for Protection and Management of Coastal Wetlands was announced by China's State Oceanic Administration, which stated that commercial development of coastal wetlands will be prohibited (Stokstad 2018); enhanced protection of coastal areas will benefit Bewick's Swans and Whooper Swans that overwinter in wetlands in this region (Jia *et al.* 2016). Globally, progress in the efforts to phase-out lead in ammunition in sports shooting will benefit swan populations by reducing lead poisoning. In addition to restrictions in parts of North America, a recent review by Mateo & Kanstrup (2019) found that lead shot use has now been legally restricted (at least partially) in 23 European countries, and further progress towards the complete phasing out of lead ammunition and angling weights is expected in the next few years (Cromie *et al.* 2019).

It was against this background of opportunities and challenges that swan researchers gathered for the 6th International Swan Symposium (ISS). Following each of the previous swan symposia, presenters have had the opportunity to publish their research in a symposium proceedings, typically in *Wildfowl* or another ornithological journal/publication (*e.g.* Matthews & Smart 1981; Sears & Bacon 1991; Rees *et al.* 2002a), which are also available through the website of the IUCN-SSC/Wetlands International Swan Specialist Group (http://www.swansg.org/resources/conference-proceedings/). The proceedings of the symposia have also offered an opportunity for researchers to synthesise recent developments in swan research (*e.g.* Earnst 1991). The aims of this paper are to synthesise progress on major topics relevant to fundamental and applied swan research and to highlight the work presented at the symposium, including papers published here in the resulting proceedings and those published elsewhere.

The 6th International Swan Symposium

The 6th ISS followed five earlier swan symposia at Slimbridge (UK) in 1971, Sapporo (Japan) in 1980, Oxford (UK) in 1989, Warrenton (USA) in 2001 and Easton (USA) in 2014. Held at the Estonian University of Life Sciences in Tartu, Estonia in October 2018, the 6th ISS featured 101 delegates from 17 countries. As the host country, Estonia had the most delegates (52, including 30 students), with the UK (10), Russia (8), Germany (6) and the USA (6) also relatively well represented (Fig. 1).

The symposium featured three days of oral and poster presentations grouped around the following themes: censuses and monitoring trends in numbers, habitat and resource use, demography, movements and migration, and threats and conservation. These presentations focused largely on Bewick's, Mute and Whooper Swans, with the other species less well represented (Fig. 2a). To assess whether these patterns were representative of wider efforts in swan research, we searched within Web of Science to identify the number of papers published on each swan species between 2003 (the year following the proceedings of the 4th ISS; Rees *et al.* 2002a) and 2018, inclusive. All databases were searched for

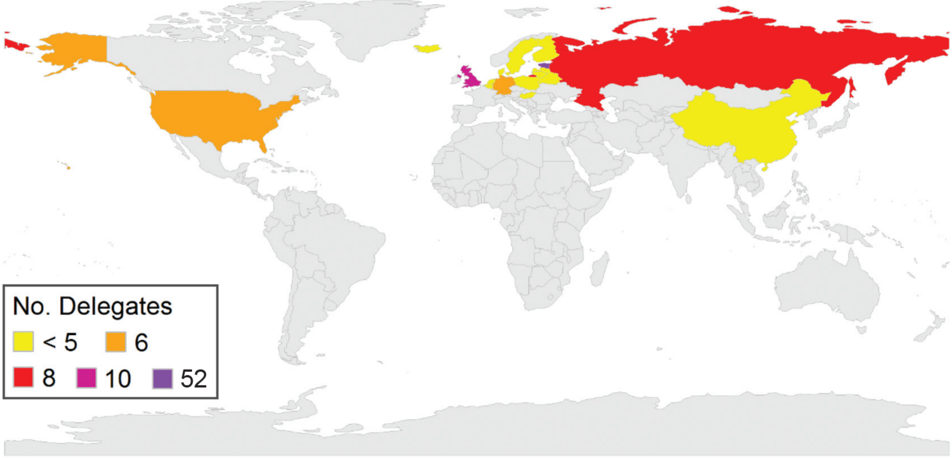

Figure 1. The numbers of delegates from each country that attended the 6th ISS. The map was created using the '*rworldmap*' package (South 2011) in Program R version 3.5.1 (R Development Core Team 2018).

papers that included both the species' common name and scientific binomial in the topic field; for Bewick's Swans we also searched for a common alternative presentation of the name (Bewick Swan *Cygnus bewickii*) in addition to the correct Bewick's Swan *Cygnus columbianus bewickii*. Overall, the pattern of species-specific research effort presented at the 6th ISS matches that seen in the published literature, with Mute and Whooper Swans the most represented species (Fig. 2b). However, given the number of papers published on Black Swans, research on this species was under-represented at the 6th ISS, which may reflect the geographic distance of the symposium location (Estonia) from the main range countries of the Black Swan (Australia and New Zealand). Conversely, Bewick's Swans featured in 35% of presentations at the 6th ISS but only in 12% of published papers between 2003 and 2018. This discrepancy was likely due to the final day of the 6th ISS being devoted to a workshop on Bewick's Swans and a review of progress on the implementation of the International Single Species Action Plan (ISSAP) for the Northwest European population (Nagy *et al.* 2012).

Monitoring

Repeated surveys of swan populations, recording information such as the numbers of birds and their locations, have been a foundation of swan research for over half a century (*e.g.* Campbell 1960). Monitoring of numbers at some sites has been carried out for much longer; for instance, the Mute Swan population on the River Thames in the UK has been counted in almost every year since 1823 (Cramp 1972). Such surveys allow researchers to assess trends in population dynamics, phenology and distributions at local, regional, flyway and

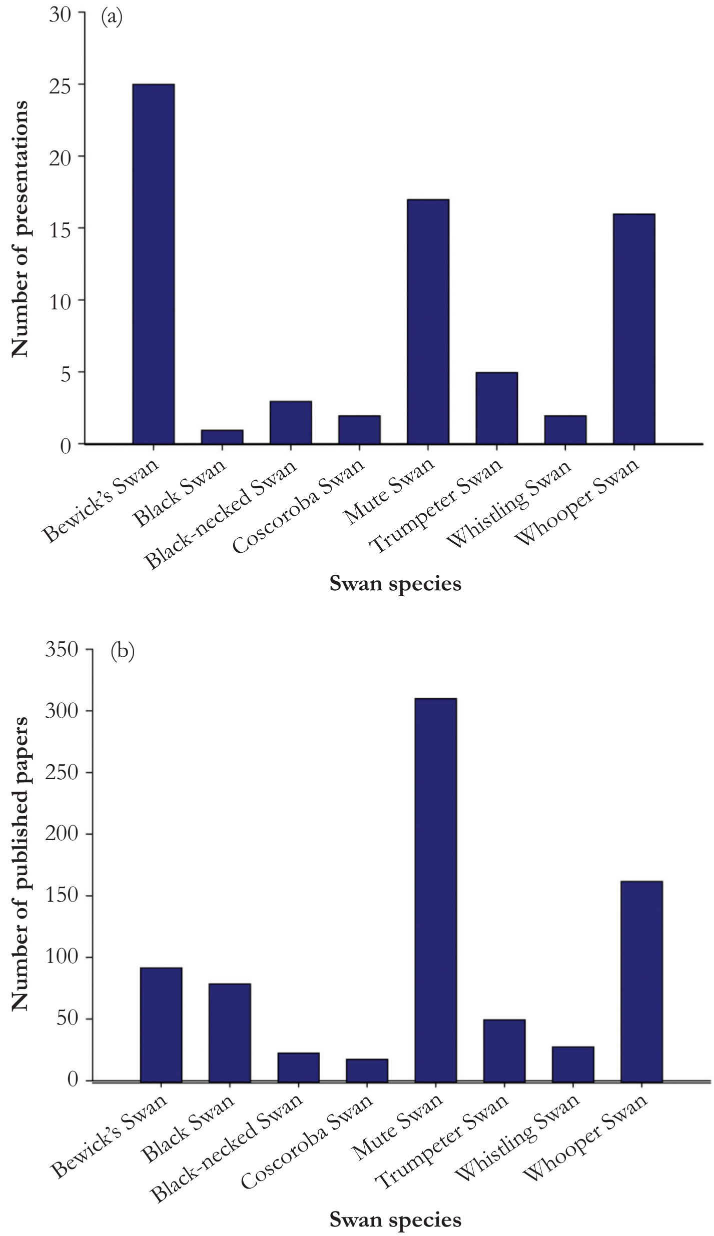

Figure 2. The number of (a) presentations at the 6th ISS on each of the swan species and subspecies (*N.B.* the sum exceeds the total number of presentations given as some presentations covered more than one species), and (b) published papers on each of the swan species and subspecies between 2003 and 2018 (inclusive).

global scales (*e.g.* Wieloch 1991). Some populations, in particular those in Europe and North America, have been subject to regular censuses to monitor population size and distribution (*e.g.* Beekman *et al.* 2019; Laubek *et al.* 2019). The situation in Far East Asia is improving, where annual waterbird censuses in China now supplement longer data series from Japan and Korea. Yet monitoring of some other swan populations remains limited, including Coscoroba Swans and Black-necked Swans in South America (review in Rees *et al.* 2019).

The 6th ISS provided an opportunity for a workshop on population censuses, ahead of the planned mid-winter censuses in Europe of the Northwest European Bewick's Swan population and both the Icelandic and Northwest Mainland European Whooper Swan populations. This is scheduled to extend to include Black Sea and Caspian populations of these migratory swans in January 2020. The traditional approach to monitoring many swan species has been site-based, coordinated counts (*e.g.* Hall *et al.* 2016; Jia *et al.* 2016; Beekman *et al.* 2019; Laubek *et al.* 2019). However, concerns were raised by participants at the workshop regarding whether it was becoming more difficult to use traditional full population census methods given the rising numbers and expanding distribution of some species, most notably Whooper Swans in Europe. Census counts are undertaken by a network of volunteers, which may become overstretched by having more sites to survey and more birds to count. In addition, climate change may also affect swan phenology, distribution and migratory routes, impacting the ability of researchers to undertake counts effectively (Fox *et al.* 2019). There are also outstanding questions pertaining to the accuracy of population estimates based on single censuses, as the numbers of birds that may be missed during censuses is seldom estimated. Such problems are compounded by the inability to estimate confidence intervals or similar measures of uncertainty associated with the total population size derived from such data (Laubek *et al.* 2019).

A number of alternatives to full population censuses could be evaluated in future monitoring assessments. One example is the use of stratified sample surveys that have been used to survey some swan populations in North America (*e.g.* Conant *et al.* 1991). Alternatively, population size could be estimated from mark-recapture/-resight data or harvest information, as has been done for goose populations (*e.g.* Sedinger *et al.* 2019; Clausen *et al.* in press). However, harvest information will only exist for a minority of populations for which hunting is permitted, such as Whistling Swans in North America or Black Swans in New Zealand, as most swan populations are now fully protected from hunting (Sladen 1991; Frew *et al.* 2018). The emergence of new technologies may also offer novel options for designing and undertaking monitoring programmes; for example, Lyons *et al.* (2019) demonstrated that drones could be used to count bird numbers, even where individuals were aggregated. There will clearly be an important role for research in developing and testing census methods, both in terms of field methodology and subsequent statistical analyses. This work will include the comparisons and inter-calibration of different techniques. For example, Marchowski *et al.* (2018) found close agreement between ground-based and aerial-based surveys of the numbers of Mute Swans and Whooper Swans in the estuary of the River Odra in Poland.

Regardless of specific census methods used, effective population censuses require that adequate coverage is achieved across all countries used by swans in at least one part of their annual cycles. In light of the changes in swan distributions linked to changes in climate and land use, this may necessitate bringing new countries into existing census schemes (Fox *et al.* 2019). Here, we reiterate the recommendations of previous symposia that international cooperation across flyways is vital to effective monitoring of swan populations (*e.g.* Moser 1991; Rees *et al.* 2002b). It is particularly important that such monitoring efforts continue to include countries that are not currently signatories to international agreements; for instance, countries such as Poland and Russia that are not signatories to the African-Eurasian Waterbird Agreement (AEWA). Furthermore, it is important to note that all monitoring programmes are constrained by their available survey effort, with limits to the number of counters that can be deployed, the number of sites that can be visited, and the number of birds that can be counted. As such, future research that addresses how to deploy limited professional and volunteer survey effort most effectively, to obtain accurate assessments of population size and their uncertainty, would be very valuable. Additionally, by comparing the different existing schemes it may be possible to improve our understanding of how to be most effective at recruiting and retaining individuals that undertake volunteer and citizen science-based monitoring, to help maximise the effort available for these programmes. This should also include assessing the most effective ways of ensuring timely submission and collation of collected data, including the greater use of online submission options.

During the 6th ISS, delegates heard many applications of monitoring to the world's swan populations. For example, Zaynagutdinova *et al.* (2019) carried out repeated surveys of the Gulf of Finland and found that numbers of Bewick's, Mute and Whooper Swans recorded at key sites had declined in recent years, likely due to habitat loss and degradation linked to construction activity which made these sites less attractive to the birds. An issue highlighted during the symposium was that major international monitoring schemes such as the International Waterbird Census (IWC) may not cover all sites or all birds, and so may underestimate population size and extent (*e.g.* Laubek *et al.* 2019). Hence, there is a need to understand how the total number of swans recorded by local or regional schemes relate to the true population size, and whether such data can be used to produce robust trends and detect declines in population size.

Several presentations at the 6th ISS focused on the continued expansion of the distribution (including breeding range) of many northern hemisphere populations. This was most evident for Mute Swans and Whooper Swans in Europe, which concurred with results in recent published literature (Butkauskas *et al.* 2012; Kampe-Persson *et al.*

2012; Boiko *et al.* 2014; Dudzik *et al.* 2015; Dale 2016; Elts *et al.* 2019).

Habitat and resource use

A major aim of swan scientists throughout the 20th and early 21st centuries has been to understand how swans use habitats and the resources required to survive and reproduce (Davis *et al.* 2014). Long-term studies of diet and use of food resources, especially during key parts of the migratory cycle, can provide valuable evidence with which to assess responses to anthropogenic impacts and environmental changes.

Whilst all swans reproduce in aquatic habitats and typically return to wetlands each evening to roost, some species such as Bewick's Swans, Mute Swans, Trumpeter Swans, Whistling Swans and Whooper Swans are frequently observed feeding in terrestrial habitats such as agricultural fields during the day (Laubek 1995; Nolet *et al.* 2002; Luigujõe *et al.* 2002; Tijsen & Koffijberg 2015; Augst *et al.* 2019; Wood *et al.* 2019b). During the 6th ISS Augst *et al.* (2019) highlighted increased use of maize *Zea mays* stubbles by foraging Bewick's Swans during their wintering and staging periods. As an agricultural crop, maize has been cultivated more widely in northwest Europe in recent years and swans and other herbivorous waterbirds have begun to use maize stubbles as a source of food (*e.g.* Clausen *et al.* 2018; Wood *et al.* 2019b). For example, in an area of eastern England used by overwintering swans the area of maize crops increased from 241 ha in 2000 to 3,219 ha in 2016 (Wood *et al.* 2019b). Similarly, flooded rice *Oryza* sp. fields have also become an important feeding habitat for some swan populations during winter in parts of the Middle East, East Asia and North America (Miller *et al.* 2010; Kim *et al.* 2013; Somura *et al.* 2015; Eggers 2018). Many species of swans are known to use a combination of natural and man-made habitats throughout their annual cycles, in particular Mute Swans (Gayet *et al.* 2013) and Black Swans (Murray *et al.* 2013). In northern Europe the recent growth in the numbers of artificial reservoirs, built to supply water for crop irrigation, has resulted in valuable new secondary roosting habitat for overwintering Bewick's Swans, allowing them to remain closer to foraging habitat that is further from their main roost (van Gils & Tijsen 2007). The adoption of novel food resources and habitat suggests a level of adaptability among swans to changes in their environment. As such, future research which identifies the conditions under which swans switch from traditional to novel food resources and feeding habitats (*e.g.* Włodarczyk & Janiszewski 2014; Clausen *et al.* 2018) would improve our understanding of how swans respond to environmental change.

It has become increasingly evident that swans can deplete their food resources substantially, especially where large flocks of swans gather (Wood *et al.* 2012; Gayet *et al.* 2014; Gayet *et al.* in press); moreover, a meta-analysis of waterbird grazing studies found that swans cause greater *per capita* reductions in aquatic plant abundance compared with smaller-bodied ducks and rails (Wood *et al.* 2012). As such, resource-use by swans can have negative impacts on human interests; grazing damage to arable crops and pasture affects agriculture

(Laubek 1995; Colhoun & Day 2002; Crawley & Bolen 2002), whilst similar damage by foraging swans to riparian habitat can affect fisheries (Wood *et al.* 2013). Furthermore, swans can reduce water quality via faecal inputs of nitrogen and phosphorus and increased concentrations of harmful bacteria (Hussong *et al.* 1979; Somura *et al.* 2015), but the magnitude of such inputs, compared to fertiliser run-off from agriculture and human wastewater, is poorly investigated. Such impacts can lead to conflicts between different stakeholder groups over how best to manage the impacts of swans (Redpath *et al.* 2015). Research will continue to be needed to provide evidence to help identify and manage such impacts.

One point of debate at the 6th ISS was whether the increasing numbers and ranges of many swan populations would result in increased intraspecific and interspecific competition for shared resources, including food and nest sites. Such competition could include both interference competition (*i.e.* aggressive interactions) and depletion competition (*i.e.* reduced food availability). Most notably, swan researchers have highlighted the need for greater study of interactions between Trumpeter and Whistling Swans in North America (Schmidt *et al.* 2009), as well as between Bewick's, Mute and Whooper Swans at wintering, stopover and breeding sites in Eurasia, especially with the northward expansion of the breeding range of the latter two species (Butkauskas *et al.* 2012). Some evidence has suggested that Whooper Swan pairs are displacing Mute Swan pairs from breeding territories in parts of the Baltic (Butkauskas *et al.* 2012), but the potential for competition for breeding sites at higher latitudes has not yet been examined. In North America, there has been considerable concern regarding the potential effects of the invasive Mute Swan populations on other waterbirds, including Trumpeter and Whistling Swans (Jager *et al.* 2016; Gayet *et al.* in press). In Maryland, USA, a newly-established Mute Swan moulting flock displaced a mixed breeding colony of Least Terns *Sterna antillarum* and Black Skimmers *Rynchops niger*, two species of local conservation concern (Therres & Brinkler 2004). The swans unexpectedly took over the site and trampled nests, eggs and chicks, which resulted in the terns and skimmers abandoning their traditional site. However, for many waterbird species rising numbers of swans may not have noticeable effects. Recent work by Pöysä *et al.* (2018) found that trends in Eurasian Wigeon *Mareca penelope* abundance did not differ between lakes where Whooper Swans were present or absent, indicating no evidence that either aggression or overgrazing of shared food resources by the resurgent Whooper Swan population were linked to falling numbers of Eurasian Wigeon. Earlier research by Pöysä & Sorjonen (2000) also found no evidence of adverse impact by Whooper Swan colonisation on population densities of dabbling and diving ducks on boreal lakes in Finland. Similar comparisons of breeding duck abundances and brood sizes between ponds in France with and without Mute Swan pairs found no consistent effects of swan presence (Broyer 2009; Gayet *et al.* 2011). Furthermore, two studies from the USA and France found no evidence that smaller waterbirds alter their habitat use in the presence of Mute Swans (Conover & Kania 1994; Gayet *et al.* 2016). Numerous studies of both free-living and captive individuals have documented aggression by swans towards both conspecifics and heterospecifics (*e.g.* Stone & Marsters 1970; Tingay 1974; Burgess & Stickney 1994; Gurtovaya 2000; Włodarczyk 2017), especially during the nesting and brood-rearing phases of the annual cycle during which swans are typically highly territorial (Ely *et al.* 1987; Burgess & Stickney 1994). Arguably this has led to swan species being regarded as highly aggressive animals, yet some authors within the last decade have questioned whether this reputation is deserved (*e.g.* Gayet *et al.* 2014; Włodarczyk & Minias 2015). Indeed, a recent meta-analysis concluded that swans do not spend more time than other waterbirds engaged i n aggressive interactions (Wood *et al.* 2017). Moreover, the majority of aggressive interactions involving swans are intraspecific rather than interspecific; as examples, Conover & Kania (1994) and Włodarczyk & Minias (2015) found that 59% and 80%, respectively, of all aggressive interactions by Mute Swans involved conspecifics. Future behavioural research on swans which quantifies the frequency of aggression during different phases of the annual cycle, the species that are involved, and the conditions under which aggression is most frequently observed, would improve our understanding of the causes and consequences of swan interactions with both other swans and other animals.

Demography

Knowledge of demographic rates such as survival and productivity is fundamental to understanding changes in population size and structure (Koons *et al.* 2014). In this regard, swans are arguably among the best studied species in the world (Scott 1988; Bacon & Andersen-Harild 1989; Bart *et al.* 1991; Koons *et al.* 2014). A recent analysis of global patterns in vertebrate demographic data by Conde *et al.* (2019) found that comprehensive demographic data are lacking for most avian species, but that the information available for swan species was generally relatively good, with Mute Swan and Tundra Swan ranked as the most data-rich of the swans. Some information on productivity was available for all species, whilst some information on survival rates was available for most swan species, but was notably absent for Coscoroba Swans and very limited for Black-necked Swans (Conde *et al.* 2019). The relative lack of survival data for many key wildfowl species was highlighted by an earlier meta-analysis by Roberts *et al.* (2016). Even among the relatively data-rich swan species, however, there is still much scope for new research to assess temporal trends, regional differences, effects of age and sex, and environmental drivers of demographic rates (*e.g.* Włodarczyk *et al.* 2013; Wood et al. 2018a). We need to improve our knowledge of how increased use of human-modified habitats for foraging (*e.g.* agricultural fields) and breeding (*e.g.* artificial waterbodies) is likely to affect survival and reproduction; for example, a recent study by Włodarczyk & Minias (2016) suggested that human activities at artificial waterbodies may limit the ability of swans to assess territory quality reliably. Understanding spatial and temporal variation in demographic rates, and the causes of such variation, is critical to understanding trends in swan population dynamics (Bart *et al.* 1991; Koons *et al.* 2014).

Several authors presented work at the 6th ISS on the regulation of swan productivity. For example, Solovyeva *et al.* (2019) used repeated surveys on the breeding grounds to demonstrate density-dependent regulation of productivity among the Eastern population of Bewick's Swans. Similarly, Knapik *et al.* (2019) presented evidence for density-dependent productivity in a Mute Swan population in the USA. As Mute Swans are an invasive species in North America (Gayet *et al.* in press), such demographic data are particularly needed to help understand their spread and to inform their management (Ellis & Elphick 2007).

As with all animals that are relatively long-lived and have relatively low annual reproductive output, the survival rates of swans have a greater influence than productivity on population trends (Ellis & Elphick 2007; Wood *et al.* 2013). Swan research continues to benefit from advances in statistical methods that allow survival rates to be estimated from data on marked birds, including Bayesian methods that can be used even where data are incomplete or strongly influenced by multiple covariates (*e.g.* Colchero *et al.* 2012). Similarly, Integrated Population Models (IPMs) offer a new approach to population modelling that allows the researcher to combine demographic and count data to model population trajectories whilst accounting for uncertainty in the estimates of vital rates and numbers with a joint model likelihood (Schaub & Abadi 2011); hence, IPMs could allow the swan research community to build on the insights offered by traditional population modelling approaches including Matrix Population Models (*e.g.* Watola *et al.* 2003; Ellis & Elphick 2007; Wood *et al.* 2013).

In order to be able to use novel and emerging methods in the future, it is vital that long-term studies are maintained, in particular ringing or banding studies that mark individuals and collate recapture, resightings and recovery data, as this remains the primary method of obtaining accurate estimates of survival rates in bird populations. Maintaining long-term studies may become challenging for populations that have undergone sustained increases in size and distribution and are no longer considered as priorities, given the scarcity of resources such as funding and volunteer assistance (Matrozis 2019). Yet continued demographic monitoring of populations with existing long-term data can be particularly valuable, as such datasets allow inter-annual variation in numbers and vital rates to be assessed and related to environmental drivers with increasing statistical power. Such research programmes would be aided by analyses that assessed the optimal trade-offs between the amount of data that needed to be collected (in terms of the numbers of birds marked on each sampling occasion, as well as the total study length), and the resulting statistical power and uncertainty associated with the parameters (*e.g.* survival) that could be estimated. In some cases it may be possible to incorporate the collection of data on demographic and related variables into existing census schemes, such as those where observer networks are already monitoring swan numbers, with valuable additional data on age classes and brood sizes perhaps obtainable with minimal additional effort or financial investment. In light of the limited resources available, understanding how sample size relates to statistical power and the ability to detect a desired magnitude of trend in vital rates would help researchers design demographic studies that optimise the effort required and information gained.

Movements and migration

Tracking studies that identify the directions and timings of movements within a landscape, or migratory routes between wintering and breeding grounds, are vital to improving our knowledge of issues such as conserving important sites, understanding responses to environmental change, as well as the role of swans in crop damage and as disease vectors. For example, Li *et al.* (2018) combined satellite tracking of swans with phylogenetic analyses of viruses to demonstrate that Whooper Swans were a vector in the transmission of H5N1 along a migratory route between China and Mongolia. In another example, Vangeluwe *et al.* (2018) and Wang *et al.* (2018a) demonstrated the previously unknown connectivity of Bewick's Swans breeding in the Yamal Peninsula (northwest Russia) with winter quarters in China, where they mix with breeders from the Russian Far East.

Capturing and marking swans with uniquely-coded leg-rings, neck-collars or wing-tags, so that marked individuals can be resighted or recovered, has long been a key methodology used in studies of swan movements and migrations (*e.g.* Ogilvie 1972). At sufficiently large spatial scales, marker-based studies have been used to help inform the delineation of swan populations (*e.g.* Ely *et al.* 2014). The 6th ISS showed that use of ringing has continued to be a useful technique to understand swan movements (*e.g.* Matrozis 2019). Yet ringing studies can often be limited by resighting or recovery effort. Hence, this approach benefits from new approaches and techniques that can increase the number or efficiency of resightings. Recently, Brides *et al.* (2018) demonstrated that camera traps could be used to identify individual geese marked with leg-rings or neck-bands, an approach that could reduce the field effort needed to resight marked swans. Compared with smaller birds, the swans' large body size has been found to result in a higher chance of the camera trap being triggered successfully (Randler & Kalb 2018). Citizen science schemes also offer a way of increasing the probability of resighting marked birds whilst also engaging the public in swan research, as demonstrated by Mulder *et al.* (2010) for urban Black Swans. Indeed, since the late 1980s the advent of digital cameras with powerful lenses has allowed citizens to provide researchers with high quality photographs of marked swans assuring higher quality encounter data than was available in the past.

Beyond traditional ringing studies, research on swan movements has benefitted from the development of GPS data loggers, geolocators and other bio-logging and telemetry devices in the last few decades (Bridge *et al.* 2011; López-López 2016). The large body size of swans made them ideal candidates for the early relatively heavy models of satellite transmitters introduced in the 1980s. An initial trial in North America using a 180 g prototype on a Mute Swan in 1983 (Seegar *et al.* 1996) was followed by tests using refined models on Whistling and Trumpeter Swans in 1984 (Strikwerda *et al.* 1986), and in 1990 tracking of Bewick's Swans was conducted both in east Asia (Higuchi *et al.* 1991) and in Europe (Nowak *et al.* 1990). Since these initial studies, devices have become smaller and increasingly affordable, which has provided a suite of valuable tools for the study of swan movements (Lehrke *et al.* 2018), and helped to improve our understanding of the extent and timing of swan movements, from localised patterns of habitat use within a site, to long distance migrations within major flyways (*e.g.* Nolet *et al.* 2014; Nuijten *et al.* 2014; Chen *et al.* 2016; Ely & Meixell 2016; Vangeluwe *et al.* 2018; Wang *et al.* 2018a). In Far East Eurasia, these devices are currently helping to resolve previously unknown links between breeding, moulting, staging and wintering areas (*e.g.* Wang *et al.* 2018a). In doing so, these devices identify migratory strategies and wetland sites of particular significance in the annual cycle of the swans, which will help to safeguard cohesive networks of key sites for these populations in the future. The use of such devices was evident at the 6th ISS, with tracking studies by Boiko & Wikelski (2019) and Stenschke *et al.* (2019) both demonstrating hitherto unknown long-distance moult migrations of up to *c.* 2,500 km undertaken by GPS-tracked Whooper Swans in Europe.

Years of experience in capturing and fitting markers and tracking devices has allowed best-practice guidelines to be developed (*e.g.* Swan Study Group 2005). As such, capturing swans is typically associated with very low levels of injury or mortality; O'Brien *et al.* (2016) reported only three fatalities from 4,899 swans caught as part of a long-term ringing programme in the UK. In contrast, there has been little published research on the possible adverse effects of different tracking devices and attachment methods, and the extent to which the tracking devices attract the attention of hunters thought to have shot tagged swans is also not known. As tracking technology continues to develop it will be essential to ensure that new devices minimise adverse effects on the swans, to ensure that accurate data can be collected without jeopardising the welfare of the birds (Lameris & Kleyheeg 2017). Collaborations between swan researchers and aviculturists should be encouraged so that possible marker effects can be identified on captive birds before field testing.

Threats and conservation

In common with many other waterbirds, swans face a wide range of threats across their range. These include habitat loss and degradation (*e.g.* draining of wetlands), climate change, human disturbance at roost and feeding sites, collisions with infrastructure (*e.g.* wind turbines and powerlines), pollution, lead poisoning and disease, as well as illegal persecution (including shooting) and vandalism (Ma & Cai 2002; Ramey *et al.* 2012; Wilson *et al.* 2013; Johnsgard 2016; Luigujõe 2018; Rees *et al.* 2019). The 6th ISS highlighted some of the work that scientists have undertaken to identify and mitigate these threats. From the presentations it was clear that conservation efforts continue to focus largely on the Trumpeter Swans and the Northwest European Bewick's Swan population.

In North America the Trumpeter Swan has been the subject of long-term efforts to recover the numbers and restore the range of the population, after overhunting had brought the population to the brink of extinction in the early 20th century (Shea *et al.* 2002; Handrigan *et al.* 2016). Increased legal protection of both the birds and their habitats, together with releases of captive-bred birds, have allowed the species to recover a considerable portion of its former range (Shea *et al.* 2002). The current population size of *c.* 76,000 (Rees *et al.* 2019) therefore represents a true conservation success story, with further plans underway to undertake targeted reintroductions to help connect currently isolated subpopulations.

The Northwest European Bewick's Swan population underwent a decline in winter numbers of almost 40% between 1995 and 2010 (Beekman *et al.* 2019), which led to the development of a Bewick's Swan Single Species Action Plan through the African-Eurasian Waterbird Agreement (Nagy *et al.* 2012). Substantial research effort has been devoted to identifying the causes of the population decline and possible mitigation; a review of progress was held on the final day of the 6th ISS. In addition to the overall fall in numbers, monitoring has revealed evidence of an eastward shift in the distribution of the swans on their winter grounds, with rising numbers in some countries in the eastern part of the winter range, in particular Germany and Denmark, whilst numbers in western-most countries such as Ireland have shown the greatest proportional decreases (Augst *et al.* 2019; Beekman *et al.* 2019; Nielsen *et al.* 2019). There are also interesting patterns in population dynamics in other parts of the species range. In particular, winter numbers of Bewick's Swans at the Evros Delta in Greece have been rising in recent years (Litvin & Vangeluwe 2016; Beekman *et al.* 2019). This may reflect an expansion of the wintering area of the Caspian Flyway, especially as migratory numbers of Bewick's Swans in the Volgograd region of southern Russia have also been increasing (Belik *et al.* 2012; Belik & Gugueva 2016), although more research is needed before this can be confirmed. Evidence presented at the 6th ISS, based on counts and tracking data, suggests that there may be more interchange between the different Bewick's Swan flyway populations than was previously assumed (Rozenfeld *et al.* 2019). Among the wintering Northwest European Bewick's Swan population, breeding success has not declined over time, although surveys have periodically recorded some years with very low percentages (*i.e.* < 5%) of cygnets within the wintering population (Wood *et al.* 2016; Beekman *et al.* 2019). In contrast, apparent survival rates have fluctuated broadly in line with trends in population size, but the drivers of survival rates remain unknown (Wood *et al.* 2018a). In light of these findings in population dynamics and demographic rates, research continues into possible factors which could explain a recent fall in survival. Assessments of the conditions at key winter feeding sites has found no evidence of any link between falling swan numbers and changes in food resources (Tijsen & Koffijberg 2015; Wood *et al.* 2018b, 2019b). The finding that *c.* 31% of Bewick's Swans x-rayed on the winter grounds were carrying embedded shot (Newth *et al.* 2011) has prompted research into the causes of illegal shooting and possible mitigation. At the 6th ISS, Newth *et al.* (2019) reported social surveys of hunting communities within the swans' breeding area in the northwest Russian Arctic that found that only 14% of hunters could distinguish a Bewick's Swan from other swan species with lower levels of legal protection, indicating that misidentification could be one cause of the illegal shooting of Bewick's Swans.

Effective swan conservation relies on education of the general public, as well as specific stakeholder groups that have impacts upon swans, such as hunters. In Denmark, by 1925 the Mute Swan breeding population had been reduced through shooting to only 4–5 known pairs, yet after full legal protection was granted in 1926 the population underwent a sustained increase to 758 pairs in 1954 (Paludan & Fog 1956) and 5,000 pairs in 1993–1996 (Grell 1998). While protection of the birds at their breeding sites thus seemed quite effective, it took a longer time for near-coastal wildfowlers to stop shooting, as evidenced from repeated x-ray studies of swans that died during winters; Andersen-Harild *et al.* (2002) showed that the proportion of swans with embedded shot declined from 12% in 1979 to 5% in 1996, and explained the difference as reflecting improved compliance with general hunting laws as well as nature reserve regulations, together with reduced near-coastal hunting activity.

Lead poisoning from sources such as shooting ammunition or angling rigs remains a major cause of injury and mortality among swans, as the birds ingest discarded lead whilst foraging for food and grit (Blus 1994; Newth *et al.* 2013; Grade *et al.* 2019). Studies have shown that ingested lead has a range of consequences for swans, including reduced body condition, increased probability of flying accidents, and increased risk of mortality (Blus 1994; Kelly & Kelly 2005; Newth *et al.* 2016; Grade *et al.* 2019). Newth *et al.* (2013) reported that 23% of Bewick's Swans found dead and examined *post mortem* in the UK between 1971–2012 had died of lead poisoning. For migratory swan species that use habitats in multiple different regions over their annual cycle, research that examines spatial and temporal variability in lead concentrations in tissues of different age classes can help to identify the locations where the birds are most at risk of poisoning, and hence where conservation interventions are most needed (*e.g.* Ely & Franson 2014).

Evidence was presented at the 6th ISS that replacing lead with non-toxic alternatives can benefit swan populations; Wood *et al.* (2019a) demonstrated that following the ban of the import, sale and use of key sizes of lead weights used in angling in 1987, Mute Swan mortality due to lead poisoning fell from 34% to 6% and population size more than doubled. Given the widespread problem of lead poisoning (Blus 1994), further restrictions on the use of lead would benefit swan populations globally. This requires the effective implementation of multiple international nature protection agreements, which during the 1990s and 2000s each called for the phasing out of lead shot, but to date the implementation by many of the signatories to these agreements has been slow and partial (see review by Mateo & Kanstrup 2019).

Despite the relatively high levels of legal protection that most swan populations have, some populations remain the targets of poaching and vandalism. In particular, in China Bewick's, Mutes and Whooper Swans, along with other waterbirds, are subject to persistent and widespread poaching, including the use of poisons, nets and a range of other methods, despite laws protecting these species (Ma & Cai 2002; Liu & Ma 2017; Wang *et al.* 2018b). Swans targeted by poachers are eaten, sold on to restaurants, or sold alive to wild bird markets (Liu & Ma 2017). In a particularly serious case in the Inner Mongolia Autonomous Region (northern China) in January 2016, 233 Bewick's Swans were killed with carbofuran, a poison commonly used by poachers (Liu & Ma 2017). To help understand the scale of the problem, and inform potential solutions, there is a need for better information on when and where such poaching occurs and the numbers of individuals and species affected, coupled with improved enforcement of anti-poaching legislation.

Previous swan symposia have highlighted the risk of swans' collisions with energy infrastructures such as wind turbines and power lines (*e.g.* Larsen & Clausen 2002) and the 6th ISS also featured research on this topic. Locally, the powerlines at Väike Väin in Estonia were highlighted as a threat to swans moving through this important migratory area (Luigujõe *et al.* 2013; Luigujõe 2018). At the 6th ISS, delegates also discussed the earlier work of Griffin *et al.* (2016) on the results of satellite-tracking of Bewick's Swan migration routes in relation to offshore and onshore wind farm sites. As numerous studies have now provided evidence that swans may collide with wind turbines and power lines (Rees 2012; Moriguchi *et al.* 2019; Taylor *et al.* 2015), there is a clear need for assessments of cumulative risks of collision and mortality to inform the current and predicted future impacts on populations and advise the sighting of new infrastructure away from sensitive areas. In addition to collision risk, there may also be effects of displacement and lost feeding habitat to be quantified (Fijn *et al.* 2012).

Climate change is having widespread, pervasive effects on wildlife across the globe (Walther *et al.* 2002), and swans are no exception. For instance, rising spring and summer temperatures can increase productivity by increasing plant growth (and thus food supply for swans) and reduce thermoregulatory costs (Schmidt *et al.* 2009; Wood *et al.* 2016). Swan phenology and patterns of migration may also be affected by the variation in weather conditions associated with climate change, for example by affecting their food supplies. Stirnemann *et al.* (2012) reported that increased February grass growth in warmer years enabled earlier departure of migrating Whooper Swans from Ireland. Similarly, unpredictable regional weather patterns such as the El Niño Southern Oscillation have been shown to affect swan migration phenology (*e.g.* Xu *et al.* 2017), as well as numbers and productivity (*e.g.* Vilina *et al.* 2002). Climate change has been most pronounced in the polar regions (Barber 2008), and so Arctic-breeding swan species may be most affected by recent and future changes. Research is needed to assess the extent and impact of future changes in swan population dynamics, distribution and phenology in light of the continued effects of climate change, including rising temperatures, altered weather patterns and sea level rise.

Habitat loss and degradation continue to be a major concern for all taxa associated with freshwater and coastal habitats. Globally, an estimated 64–71% of wetlands have been destroyed since 1900, with greater losses for inland relative to coastal wetlands (Davidson 2014; Kingsford *et al.* 2016). Whilst the rate of wetland loss in Europe has slowed somewhat (but see Zaynagutdinova *et al.* 2019), and in North America has remained relatively low since the 1980s, the high rates of wetland loss continue in Asia, due to large-scale and rapid conversion of coastal and inland wetlands (Davidson 2014). Even within remaining wetlands, degradation due to factors including pollution and loss of aquatic vegetation can reduce habitat quality for swans. Swans are known to be sensitive to changes in habitat quality (*e.g.* Artacho *et al.* 2007; Norambuena & Bozinovic 2009; Lumsden *et al.* 2015). For example, Jaramillo *et al.* (2018) reported that Black-necked Swans at a wetland in southern Chile showed reduced body mass, elevated iron loads, histopathological liver abnormalities and higher mortality, following a decrease in water quality and loss of aquatic vegetation linked to pollution from a new pulp mill upstream. Declines in aquatic plant abundance are accelerating globally, particularly in large (> 50km^2) lakes, due to factors including eutrophication, habitat destruction, aquaculture cultivation and climate change (Short *et al.* 2016; Zhang *et al.* 2017). Such widespread changes in aquatic plant abundance will have implications for swans, as food loss in wetlands can influence swan abundance at key sites (Fox *et al.* 2011; González & Fariña 2013) and their distributions within a landscape (Liu *et al.* 2018). Loss of aquatic plants can also have impacts on individual swans, including a reduction in body mass; for example, Norambuena & Bozinovic (2009) found that the mean body mass of Black-necked Swans at the Cayumapu River in Chile was 25% lower than that of control birds after the loss of the main aquatic plant (Brazilian Waterweed *Egeria densa*) following a pollution incident. Petersen *et al.* (2008) reported a decline in Bewick's Swans' use of a coastal stopover site in Denmark following the loss of aquatic vegetation due to changes in water regime management; Bewick's Swan use of this site was found to be positively correlated with aquatic vegetation cover. Hence, where aquatic plants abundance is restored following conservation interventions, decline in swan abundance may be reversed (Noordhuis *et al.* 2002). Similarly, Balsby *et al.* (2017) documented that the recovery of Common Eelgrass *Zostera marina* at a coastal inlet in Denmark was followed by the return of swans and other waterbirds to the site. Given the continued loss of wetlands and aquatic food resources, key sites used by swans throughout annual cycle must be identified and protected from further degradation or loss.

Despite the multitude of threats faced by swans, there are also causes for optimism. Globally, most swan species have good conservation status, although data are lacking for some populations and in particular for the South American species (Rees *et al.* 2019). Both the successes of the Trumpeter Swan recovery programmes in North America (Shea *et al.* 2002; Handrigan *et al.* 2016), and the recovery of the UK Mute Swan population from lead poisoning (Wood *et al.* 2019a), show the value of effective conservation interventions. Furthermore, the actions that have been undertaken to understand and alleviate the decrease in the Northwest European Bewick's Swans show the resolve of the swan research community to tackle the issue of species declines. Swans are viewed widely by the public as charismatic animals, which can help the conservation of swans and their habitats. As an example, a severe pollution incident in southern Chile in 2004 that caused the degradation of a protected wetland and the deaths of many Black-necked Swans provoked a widespread public outcry that led to the strengthening of Chile's environmental protection laws in 2009 (Sepúlveda & Villarroel 2012; Sepúlveda-Luque 2018).

Because swans show measurable responses to changes in their environment, including changes in individual body condition, distribution and numbers (*e.g.* Artacho *et al.* 2007; Norambuena & Bozinovic 2009; Jia *et al.* 2018; Newth *et al.* 2016) they could prove valuable indicator species in assessments of environmental perturbations. In particular, at sites where swans are already captured regularly (*i.e.* as part of long-term studies of swan demography or movement), the additional use of swans for bioassessment could add value to existing research programmes and facilitate novel collaborations between research groups in different fields. While this area of research remains at a very early stage, a growing number of studies have begun to investigate the bioaccumulation in swans of contaminants, in particular trace metals, from aquatic plants and the wider environment (Grúz *et al.* 2015; Wang *et al.* 2017). As an example, Wang *et al.* (2017) reported strong correlations between trace metal concentrations in eelgrass tissues and swan tissues. The use of faeces or feathers in such bioassessments (*e.g.* Grúz *et al.* 2015) could be particularly useful as these remove the need to capture the birds and undertake invasive sampling. Similarly, swans have the potential to be valuable sentinel species for disease monitoring; since swans are so large and conspicuous, they are often the first species detected in disease die-offs (Hars *et al.* 2008). Whether swans are the best species to use in such assessments remains to be determined, yet we believe that these early results are promising and warrant further investigation. The further development of this research area could benefit the conservation of the swans, other biota and their habitats.

Other topics and techniques

In addition to the five major areas covered above, there are many additional ones that offer exciting opportunities to advance our knowledge of swans. Whilst not well represented at the 6th ISS, recent published articles have shown that there is growing interest in understanding the genetic diversity within swan populations (*e.g.* Oyler-McCance *et al.* 2007; Butkauskas *et al.* 2012; Kolodinska-Brantestam *et al.* 2015; Delpassand *et al.* 2019). Comparisons of the patterns of genetic variation at different microsatellite loci across different flocks has allowed the genetic consequences of Trumpeter Swan restoration efforts to be assessed (Ransler *et al.* 2011). Furthermore, new genetic analyses offer powerful tools for improving our understanding of the recent evolutionary history of swan species (*e.g.* Rawlence *et al.* 2017). Recent evidence has also found evidence of a genetic basis for some behavioural differences between individual swans (van Dongen *et al.* 2015), which can complement traditional observation-based studies of swan behaviour.

Advances in remote sensing technology, including aerial photograph resolution, hyperspectral imagery, radar, and Light Detection and Ranging (LiDAR), offer many potential applications for swan research (Guo *et al.* 2017). For example, Delgado & Marín (2013) used a remote sensing approach to assess changes in the wetland habitat area of the Black-necked Swan in southern Chile. Similarly, contemporary advances in both computing power and ecological theory have facilitated the development of simulation models, such as individual-based models, which have proven to be useful tools for predicting how swans will respond to environmental change or altered habitat management (Nolet & Mooij 2002; Wood *et al.* 2014; Nolet *et al.* 2016). Such models are possible, in part, due to the rich literature on the foraging ecology and resource use of swans that has developed in recent decades (*e.g.* Nolet & Drent 1998; Nolet *et al.* 2001; Wood *et al.* 2012; Nolet & Gyimesi 2013; Clausen *et al.* 2018). A challenge for organisers of future swan symposia will be how to attract researchers using new and emerging approaches to attend and present their work at the meeting.

The future for swan research

It is clear from the synthesis presented here that there has been great progress made in our understanding of swans in the almost half a century since the 1st ISS in 1971. However, there are clear geographic biases in swan research that do not stem from different research needs. In particular, the southern hemisphere species continue to receive less attention than their northern hemisphere counterparts, despite facing many of the same pressures. The need to improve our understanding of South American swans and their habitats, including the development of an effective monitoring programme, has been highlighted in the recommendations of previous swan symposia (*e.g.* Moser 1991; Rees *et al.* 2002b) and we reiterate those recommendations here. The monitoring programmes established for many of the northern hemisphere swan populations (*e.g.* Laubek *et al.* 2019) could serve as templates to inform the establishment of new monitoring schemes in South America and elsewhere. Even amongst some of the northern hemisphere swans, research effort has been markedly unequal amongst different species and populations; for example, amongst Bewick's, Mute and Whooper Swans in Eurasia, study effort has been biased towards the western parts of the ranges relative to the east. Moreover, for Bewick's Swans, the relatively large number of studies in the wintering range are not supported by similar levels of study across the breeding grounds. Therefore, a key challenge for the swan research community is how we can promote more research on understudied species and populations, in particular in the southern hemisphere.

Existing monitoring efforts show that, at least where trends are known, most of the world's swan populations appear to be stable or increasing (Rees *et al.* 2019), which in light of the ongoing biodiversity crisis is a testament to the hard work of the swan research community and its partners. Yet, being large birds, swans tend to have smaller absolute population sizes in comparison with smaller-bodied birds such as ducks and geese, with even swan populations considered "abundant" typically numbering in the tens or low-hundreds of thousands. Swans also reproduce at relatively low rates which, whilst buffering against multiple years of poor breeding success, does ultimately limit their rate of population increase even under favourable environmental conditions (Bart *et al.* 1991; Koons *et al.* 2014). These lower population sizes and "slow" life history traits may make swans more vulnerable to extinction or extirpation where survival is impacted, compared with more abundant, rapidly reproducing, smaller-bodied birds, because swan populations always begin their decline closer to zero (*i.e.* extinction), and their relatively low annual breeding success does not offset poor survival. Population declines therefore may continue even during years of relatively good breeding success. For these reasons, analyses of species across a wide range of animal taxa have concluded that species with slow life histories have higher risks of extinction (*e.g.* Purvis *et al.* 2000; Cardillo 2003), so continued monitoring is critical for providing advance warning of any declines in numbers and preparation of appropriate conservation interventions.

Broadening the swan research community to include new approaches and foster greater collaborative links with stakeholders will likely continue to benefit research and conservation. In particular, recent studies have begun to demonstrate that incorporating research elements from social science disciplines can help to improve our understanding of interactions between people and swans, and aid the design of conservation interventions to alleviate problems such as illegal hunting (Newth *et al.* 2019). Greater engagement between researchers and stakeholders, including the public, could bring numerous benefits including greater public support for research and conservation efforts, as well as increased capacity of monitoring programmes through citizen science. The Wildfowl & Wetlands Trust's *Flight of the Swans* expedition (Rees *et al.* 2017), which raised awareness of the decline of the northwest European Bewick's Swan population, and the community outreach activities of the Trumpeter Swan Society (Smith 2017), both provide excellent examples of such engagement that future projects could learn from.

It is clear that, given the challenges facing swan researchers in the 21st century, international cooperation will continue to be vital. Swans are highly mobile animals and many populations undertake migrations spanning thousands of kilometres, and crucially do not recognise human geographic and political borders. It is for these migratory species that effective networks of collaborators will be most critical, for example, in identifying and protecting chains of important sites across a flyway. Such international collaborations will be particularly important in coordinating future monitoring and conservation activities. The IUCN-SSC/Wetlands International Swan Specialist Group (SSG) is a global network of over 300 swan specialists from 38 countries who undertake monitoring, research, conservation and management of swan populations. In this role the SSG will continue to support international collaborations and communication among the global community of swan researchers. The new SSG website (http://www.swansg.org) was launched in 2018 and aims to provide a platform to highlight new projects and findings, as well as facilitate effective communication between all those with an interest in the study of swans worldwide. In future the website could also act as an open-access repository for critical data, to facilitate the sharing of these data among the global swan research community. Wider social media and data-sharing platforms will also continue to support these aims. Similarly, news and updates on research activities are provided in the annual SSG newsletter *Swan News*, which has now been published each year since 2015 after a gap of 11 years prior to this. Regional swan study groups will also help to support and coordinate local collaborations and information sharing, as will species-specific groups such as the Trumpeter Swan Society. However, all of these groups, including the SSG, will only succeed if individuals are willing to support and contribute to them.

Throughout this article we have highlighted the substantial challenges that swan researchers will face, together with the wide range of fundamental and applied topics that would benefit from additional research effort. There is therefore no doubt that swan researchers will continue to benefit from regular symposia to share information and develop collaborations. As such, we recommend holding International Swan Symposia every 4–5 years.

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Photograph: Mute Swan in flight, by Steve Nicholls/WWT.

