Sanderling | **Bécasseau sanderling** (*Calidris alba*) (Arnold Meijer / Blue Robin)

12. Demographic monitoring along the East-Atlantic Flyway: a case study on Sanderlings using international citizen science

Jeroen Reneerkens

Summary

The size of waterbird populations continuously change. Counts of waterbirds describe these changes. If long-term and/or steep declines are detected, this should signal the need for conservation measures. However, conservation actions will only be effective if they tackle or mitigate threats that negatively impact population growth at the scale of the flyway. Identifying where and when in the annual cycle of a flyway population declines are caused could be a first step towards identifying which ecological factor is responsible for the decline and how this could be reversed. This entails demographic monitoring, i.e. the investigation of spatial and temporal variation in survival and reproduction. This is exemplified with a case study in which observations of individually colour-marked Sanderlings *Calidris alba* along the coasts of Europe and Africa were used to estimate temporal and spatial variation in the probabilities of annual adult survival and the age of first reproduction. Combined with estimates of clutch survival from the Greenlandic breeding grounds, it could be shown that the growth of the Sanderling flyway-population is currently limited by annual variation in clutch survival and adult survival in W Africa. Despite its potential to effectively target conservation action, demographic monitoring is not the standard practice and we are often in the dark about the causes of population change. Increased and continued long-term and flyway-wide efforts to monitor survival and reproduction of waterbird populations could considerably improve this situation.

Résumé

La taille des populations d'oiseaux d'eau change continuellement. Les comptages d'oiseaux d'eau décrivent ces changements. Si des déclins à long terme et/ou importants sont détectés, cela devrait signaler la nécessité de prendre des mesures de conservation. Toutefois, les mesures de conservation ne seront efficaces que si elles s'attaquent aux menaces qui ont un impact négatif sur la croissance des populations à l'échelle de la voie de migration ou si elles les atténuent. Identifier où et quand, dans le cycle annuel d'une voie de migration, les déclins de population sont causés pourrait être un premier pas vers l'identification du facteur écologique responsable du déclin et de la manière dont il pourrait être inversé. Cela implique un suivi démographique, c'est-à-dire l'étude des variations spatiales et temporelles de la survie et de la reproduction. Ceci est illustré par une étude de cas dans laquelle des observations de Bécasseaux sanderlings Calidris alba *marqués individuellement par une couleur le long des côtes d'Europe et d'Afrique ont été utilisées pour estimer la variation temporelle et spatiale des probabilités de survie annuelle des adultes et l'âge de la première reproduction. En combinaison avec les estimations de la survie des pontes dans les zones de reproduction du Groenland, il a été démontré que la croissance de la population de bécasseaux sanderling est actuellement limitée par la variation annuelle de la survie des pontes et des adultes en Afrique de l'Ouest. Malgré son potentiel pour cibler efficacement les actions de conservation, le suivi démographique n'est pas la pratique standard et nous sommes souvent dans l'ignorance des causes des changements de population. Des efforts accrus et continus à long terme et à l'échelle de la voie de migration pour suivre la survie et la reproduction des populations d'oiseaux d'eau pourraient considérablement améliorer cette situation.*

12.1 Introduction

The coordination and standardised implementation of international counts of waterbirds is a logistical challenge. Fortunately, along the East Atlantic Flyway (EAF) this coordination and implementation is well taken care of. The results of the most recent counts are presented in this report. Knowledge of the numbers and trends of bird populations is valuable to keep track of how these populations are faring, whether the numbers are stable, increasing or decreasing. However, only the realisation that populations change and the rate at which they do, does not inform us about the cause(s) of these changes. This is a problem, because only if these causes are known it becomes possible to counteract or mitigate them. In other words, a diagnosis of the ecological and demographic mechanisms of population changes is essential for an effective management strategy (Robinson *et al.* 2005). If the international counts indicate that the population size of a waterbird species is declining along the EAF, what could be done to halt this decline? To answer that question, we first need to identify the cause of the decline. Pinpointing where and when in

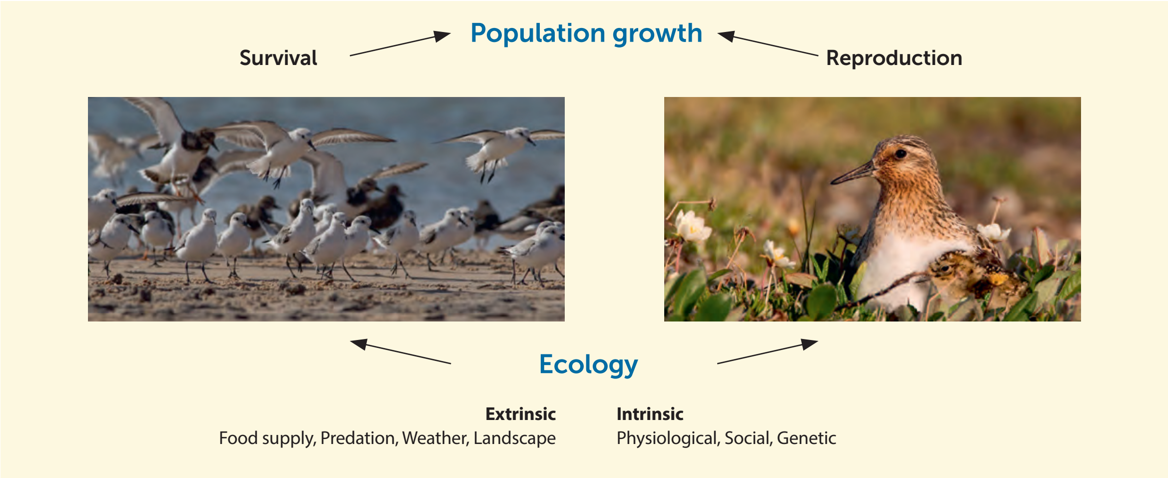

Figure 12.1. Flyway population change is mostly determined by the combined effect of the survival of individuals and the number of young they produce. Both survival and reproduction are influenced by extrinsic and intrinsic factors, of which a few examples are given.

the annual cycle these declines are being caused is a useful first step towards identifying the underlying ecological causes. To identify these, we need a basic understanding of three aspects:

(1) Knowledge of the biogeography; where and when does (a population of) a species breed and winter, and which staging sites are used during migration?
(2) Basic ecological understanding of the species, such as knowledge of their diet in different seasons and sites along the flyway, the quantity and quality of the available food and which anthropogenic pressures the birds suffer from (e.g., land reclamation, fisheries, climate change, hunting).
(3) An insight into the demographic factors affecting the population. This concerns details about the spatial and temporal variation in survival and reproduction of the population.

We generally have a good understanding of the biogeography of most waterbird species along the EAF (Scott & Rose 1996, Engelmoer & Roselaar 1998, Delany *et al.* 2009), although current developments in the technology of lightweight tracking devices and molecular techniques are rapidly leading to new insights (e.g. Bridge *et al.* 2011, Bom *et al.* 2021). The world is continuously changing, and bird populations are affected by, and respond to, such changes in their environment. Thus, the understanding of the ecology and distribution of waterbird species needs to be continuously updated.

To understand the changes in population sizes, we need to understand what demographic components are related to these changes. Long-term changes in survival or productivity may be evident before changes in population numbers occur and signal conservation need (Piersma & Lindström 2004). Unfortunately, it is not standard practice to estimate survival and/or reproductive success in waterbird populations. Hence, conservation actions are often not based on a demographic evaluation. Consequently, significant gaps remain in our understanding of bird population trends, as exemplified in this report.

There are three main demographic components that determine population trajectories: *births*, *deaths*, and *movements* (immigration and emigration). Although redistribution between flyways may (partially) explain changes in flyway populations (Rakhimberdiev *et al.* 2011, see also Chapter 2)thousands of northward migrating ruffs (Philomachus pugnax, flyway populations are usually considered 'closed' and thus mostly affected by the combination of reproduction ('births') and survival (the counterpart of 'deaths') (Fig. 12.1). Reproduction and survival may vary between years and seasons, migration trajectories and locations, and between individuals. A combination or interaction of these factors is also possible. In Eurasian Spoonbills *Platalea leucorodia* for example, particularly older males with longer migration distances breed later and consequently produce fewer chicks that survive until adulthood (Lok *et al.* 2017). Temporal and spatial variation in demographic components can be caused by intrinsic or extrinsic factors. Examples of intrinsic factors are an individual's sex, age, social status, physiological condition or genetic make-up. Examples of extrinsic factors are predation, food supply, disease, weather conditions and habitat (Fig. 12.1). Extrinsic factors are usually of interest to conservationists because they can most easily be managed.

Population changes are most effectively diagnosed by demographic studies that can identify whether survival or reproduction are limiting the population growth and moreover, when in the annual cycle and thus where along the flyway this occurs. This will generate hypotheses about the ecological factors that can be tested locally and preferably should lead to measurable conservation actions. The alternative – often followed – approach is to test at a local scale which ecological factors affect (components of) survival and/or reproduction. However, this approach may not always result in the desired impact on the flyway population growth since local effects may be buffered or counteracted by other ecological factors elsewhere along a flyway.

It is of great importance that governments, nature conservation organisations and other funding agencies invest in demographic knowledge and studies to ensure effective conservation. However, it is not an easy task to identify the factors that regulate changes in population sizes (Weiser *et al.* 2020). This is especially true for species with vast geographic distributions. Here, I will describe a citizen science project on Sanderlings *Calidris alba*, showing that with international collaboration it is possible to diagnose what regulates a population, even when its distribution spans the entire EAF. First, I will briefly describe what is currently known about the biogeography and ecology of Sanderlings in the EAF, followed by a description of what it takes to set up and maintain a large international colour-ringing project, and finish with showing how analyses based on observations of colour-ringed Sanderlings have identified limiting factors in their population growth.

12.2 Sanderlings along the East Atlantic Flyway: biogeography and ecology

Sanderlings are one of the few shorebird species using the EAF that breed entirely in the High Arctic. The breeding area of Sanderlings using the EAF spans from NE Canada to east and N Greenland and the Taimyr peninsula in N Russia (Reneerkens *et al.* 2008, Scott 2009, Lappo *et al.* 2012). The species has also been reported to breed on Jan Mayen and Svalbard, although in (very) low numbers. During the non-breeding period, Sanderlings inhabit sandy beaches and mudflats along the entire Atlantic coasts of Europe and Africa, and to a lesser extent the Mediterranean coast.

It is unclear whether birds from the Siberian breeding population co-occur with the Greenlandic and Canadian breeding population along the E Atlantic coast during the non-breeding season (Reneerkens *et al.* 2009, Conklin *et al.* 2016). Sanderlings occurring along the Atlantic coast of Africa south of the equator have been assumed – without evidence – to be of Siberian breeding origin (Scott 2009, van Roomen *et al.* 2018). Moreover, the Canadian and Greenlandic breeding population has been suggested not to migrate further south than Ghana and Benin. Therefore, Sanderlings that spend the non-breeding season from Cameroon south to South Africa were previously not included in the estimates of the size of the East-Atlantic population (van Roomen *et al.* 2015). Recently though, the importance of southern Africa (i.e. Walvis bay in Namibia) for the Greenlandic breeding population has been identified (Loonstra *et al.* 2016, Reneerkens *et al.* 2020) and this finding has been implemented in this report (see Annex 1). Greenlandic and Siberian Sanderlings cannot yet be distinguished using genetic markers (Conklin *et al.* 2016). Since the density of observers and ringing activity is very low in Siberia, the easiest approach to determine whether Siberian-breeding Sanderlings make use of the EAF would be to track a representative sample of individuals using solar geolocators.

Remarkably, the EAF population of Sanderlings has been increasing for four decades (van Roomen *et al.* 2015). The number of Europe-wintering birds has been increasing at a faster rate than those that spend the non-breeding period in Africa (see Chapter 2 and Annex 1 in this report). Only in the last few years this increase in population size has come to a halt, and even turned into a decrease (this report). Despite Sanderlings being common along the entire EAF, the mechanisms that have resulted in the population growth, nor the recent stabilisation, are unknown.

There are indications that the growing population in itself may have limited the population growth rate ('density-dependence') (Ntiamoa-Baidu *et al.* 2014). Anthropogenic threats to Sanderlings concern habitat destruction, climate change (Reneerkens *et al.* 2016, Schmidt *et al.* 2019, Reneerkens 2020), human disturbance (Burger & Gochfeld 1991), pollution (Bianchini & Morrissey 2018) and hunting. It is yet unknown to which extent any of these threats has affected Sanderlings' population growth. To learn whether certain anthropogenic threats affect population size and via which mechanism, flyway-wide schemes of individually marked birds can be very helpful (Box 12.1).

12.3 Starting an international colour-ringing project

Estimates of survival are best obtained by using observations of individually marked animals (Box 12.1), but such observations can be applied for many other purposes too. Based on my experiences with the international Sanderling project described here, I will indicate what it takes to establish, maintain, and coordinate a large scheme of colour-ringed birds that occur along the entire length of the EAF.

When initiating demographic monitoring studies by using individual colour-marked birds, it is important to consider the purpose of the study, to ensure that there are sufficient resources to make it sustainable, and that the set-up will produce reliable results. These are matters of bird behaviour, logistics and personnel. The potential power of a colour-ringing project is very large, but the efforts to coordinate, maintain and finance such a scheme are often overlooked. The (licensed) catching and colour-marking of many birds is useless if there is no system in place to collect and store the observations and without the statistical skills to eventually analyse the data. It is important to carefully consider when and how many individuals need to be caught and colour-marked and especially how to assure a

Box 12.1: Estimating survival probabilities

Survival is a demographic parameter that has been shown to have one of the greatest potential impacts on population growth (Crone 2001). Conservation actions will often have the best potential to effectively influence rates of population change when they influence survival rates (Sandercock 2006). However, the timing and cause of mortality of individual free-living animals is often unknown and survival rates of populations can only be estimated from long-term data. Another complication is that in most bird populations, the age classes with often different survival rates to which individuals belong cannot be distinguished based on their appearance.

The most common method to estimate survival rates is the analysis of live observations of individually marked birds within a population, which can be analysed using mark-recapture analyses (Sandercock 2003). Observations can be either physical (re) captures, resightings of colour-marked birds or a combination of both. The concept is rather straightforward; when you individually mark a sample of birds, you monitor how many and which of them are present in the future and thus have survived. The more individuals return to the site of marking, the more have survived. However, the probability of re-encountering a bird not only depends on its survival until the next period, but also on its site fidelity. Individuals that permanently emigrate to other sites are still alive but will not be re-encountered. Furthermore, individuals that are site faithful should be available to be detected by observers. Even if they are present, there still is a probability that they will not be detected. Mark-recapture analyses are able to disentangle the probability of 'true survival' - the variable of interest to ecologists and conservationists - from site fidelity, site propensity and detection probability (Sandercock 2006). Usually, models include sex, time, and age-class but ecological variables, such a predator densities or weather, can also be included as covariates.

Jeroen Reneerkens

A necessity to study (changes in) demographic variables within populations over the vast area of a flyway, is to make use of a network of citizen scientists. International colour-ringing projects with individually recognisable birds can be used to estimate various demographic variables. Along the EAF, there are numerous such projects (http://www.c-birding.org/), but only few of those are used to measure demographic variables that can inform nature conservationists and policy makers.

balanced resighting effort of those individuals. Capture-mark-recapture analyses (Box 12.1) assume that marked individuals are representative of the population of interest. In addition, it assumes that each marked individual has the same probability of being resighted, and that birds distribute themselves randomly within populations. In practice, these assumptions will rarely be met, but advanced statistical techniques can fortunately deal with these issues.

Observations of individually colour-ringed birds can be used in numerous ways. They may help to unravel migration patterns and study the timing of migration or length of stay at certain staging sites. However, where and when birds are observed does not only depend on their migration trajectories, but to a large extent on whether observers are active in those areas. For example, it is unlikely to learn about the breeding location of arctic-breeding waterbirds given the very low density of observers on the arctic tundra. For such questions, the use of tracking devices may be more suited. Also, estimating the total size of a passage population accounting for turn-over at staging sites based on observations of colour-ringed individuals (e.g. Loonstra *et al.* 2016), requires that there are observers present at these sites during the (expected) total stay of all individuals.

An important consideration in starting colour-marking schemes to estimate (annual) survival rates is that they require long time series. A first estimate of apparent annual survival can only be made after three years, yielding two estimates of annual survival. Moreover, if the species of interest has a large non-breeding range, temporal variation in annual survival at one study site could be biased and may not capture existing spatial variation in annual survival. Thus, besides the duration of these studies, it also requires field work at a representative selection of sites along the flyway.

Given the longevity of many bird species, durable material for colour-rings that minimises the risk of loss or discolouration of the rings is needed. Both ring loss and discolouration would violate an important assumption in mark-recapture analyses that each marked individual has

Box 12.2: Estimating reproduction

Free-ranging populations remain stable if during a lifetime each pair of animals replaces themselves with two young that will start reproducing themselves, provided that the life span and age of first reproduction is similar for each generation. Clearly, we will not understand what causes population change if we do not measure both survival (Box 12.1) and reproduction simultaneously. Estimating individual lifetime reproductive success of wild animals is complicated: most individuals cannot be followed from birth to death, nor can their offspring. Fortunately, there are useful alternative metrics available that can be used in population models. Reproduction consists of several components:

- **(I)** the probability to occupy a territory and find a partner;
- **(II)** the number of eggs laid;
- **(III)** the probability of eggs to hatch;
- **(IV)** the probability of chicks to survive from hatching to fledging and;
- **(V)** survival until first reproduction.

The boundary between what is considered part of reproduction and of survival is sometimes a bit vague and may vary between sources. While (V) above is often included in 'fecundity' in population models, it is usually described as (juvenile or fist year) 'survival' and estimated in the same way as adult survival. How it is treated may depend on how and when in the annual cycle reproductive output is quantified, e.g. as the number of fledged young or from an age ratio among birds reaching a wintering ground. The distinction between reproduction and survival does not really matter as long as all components of the life cycle are covered in population models, without overlap. The latter can be an issue when reproduction is quantified as the number of young fledged, but first-year survival is estimated from data of young ringed at an earlier stage in the pre-fledging period.

Ideally, we would have reliable estimates of all the probabilities associated with reproduction, but that is usually not possible. Many studies focus on daily clutch survival or daily chick survival, albeit both components have complications too, because most clutches cannot be followed from the day they have been laid until either failure or hatching (Weiser 2021). Similary, most chicks cannot be followed from hatch until death or fledging. There are however useful field methods and statistical methods to get reliable estimates of both clutch and chick survival (e.g. Dinsmore *et al*. 2002, Ruthrauff & McCaffery 2005). These metrics can be useful indicators of which ecological factors have a local impact on reproductive success.

To identify whether annual reproductive success at the population level is limiting, the number of juvenile birds that recruit into the non-breeding population can be estimated. This measure of productivity includes components of mortality prior to fledging and from the first southward migration. However, the critical recruitment parameter from a demographic point of view is that of birds recruiting into the breeding population (Robinson *et al*. 2005). In geese, families migrate and stay together until spring, and family sizes and the proportion of juveniles in the population can easily be determined using field observations (e.g. Nolet *et al*. 2013). In shorebirds, the number of recruits into the non-breeding population can be determined by counting the number of juveniles and adults during field observations or in catches (e.g. Blomqvist *et al*. 2002, Lemke *et al*. 2012).

an equal probability of being observed. International colour-mark studies entail individual recognition of many different birds. Thus, the number of unique combinations of rings that can be used with a given number of colours or inscriptions on rings for a given duration of the study is an important consideration. The choice of ring colours and/or inscriptions and positions on the birds' legs needs to be coordinated with other ongoing colour-ringing schemes that are active in the same flyway. Clearly, individually marked birds from different research projects should be distinguishable from each other. For shorebirds along the EAF, the International Wader Study Group (www.waderstudygroup.org) takes up this coordination. Collaboration among projects may be a good way to maintain a large international network of ringers and observers. The success of an international colour-ringing project depends particularly on the communication with observers. Observers often need to make considerable effort to learn where they should report their observations. Therefore, it is only fair if they receive a polite and speedy response about the whereabouts of the individual bird(s) they reported. Even when the observation was incomplete and the individual cannot be recognised, observers appreciate it when they learn that their effort to read the rings and to report the observation is valued. It can guide and motivate them to continue to look out for and report their observations of colour-ringed birds.

12.4 Tropical-wintering Sanderlings perform poorest

Since 2003, Sanderlings have been colour-ringed at numerous locations along the EAF. Starting in Mauritania in 2003,

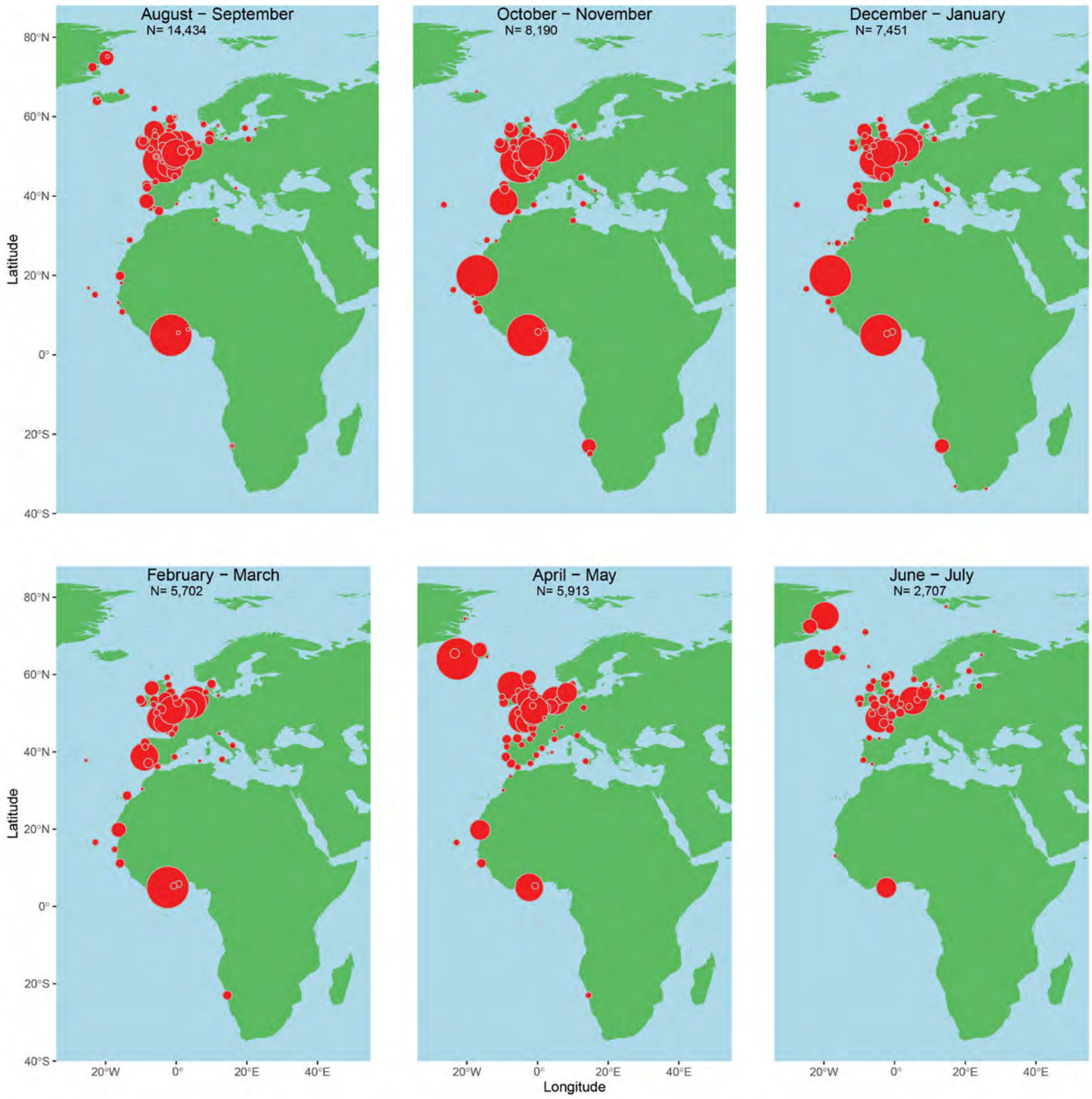

Figure 12.2. Locations along the EAF where individually colour-ringed Sanderlings were observed per two-month period in 2003-2021. Larger red dots represent more observations. For graphical clarity, locations within 200 km of each other were pooled. The sample sizes in the graph refer to the total number of unique observations. In total 100,670 observations were reported of 6,592 individual Sanderlings, allowing a detailed tracking of individuals throughout their lifetime, and analyses of e.g., migration phenology and survival probabilities.

the work was extended from 2007 onwards to Ghana, Portugal and England, as well as staging sites (Iceland and Dutch Wadden Sea) and the breeding area in Greenland. Between 2003 and September 2021, a total of 6,592 Sanderlings have been individually colour-ringed, which thus far resulted in 100,760 observations, allowing us to follow individuals from year to year and between seasons (Fig. 12.2). We have used these observations to estimate three important (demographic) variables: (1) annual adult survival, (2) the probability of northward migration of juvenile Sanderlings and (3) the timing of northward migration through Iceland, the last staging area before the flight to the breeding area in Greenland and Canada. The details of the methodology can be found in (Reneerkens *et al.* 2020).

One of the key findings of our study was that annual adult survival depended on winter location. Sanderlings spending the non-breeding season in W Africa (Mauritania and Ghana) had a lower annual survival probability than Sanderlings from three European wintering sites and Namibia (Fig. 12.3a). Also, the probability of juveniles to migrate northwards compared to that of birds older than one year was considerably lower in Ghana and Mauritania than in Portugal and England, where adult and juveniles were equally likely to migrate northwards (Fig 12.3b). Sanderlings from Mauritania and Ghana also migrated northward through Iceland on average 5-15 days later than birds wintering either further north or south (Fig. 12.3c). This suggests that the growth of the EAF population of Sanderling is currently limited by the conditions in W Africa (Reneerkens *et al.* 2020).

We suggest that relatively poor conditions in W Africa for fuelling up for northward migration may explain this pattern, perhaps due to a depleted food availability prior to the breeding season, when a higher food intake is needed to fuel the migratory flight (Reneerkens *et al.* 2020). A lower annual adult survival will result in a shorter lifespan and thus in fewer years of reproduction. Similarly, the tendency of first-year Sanderlings to spend the summer in W Africa also means that these Sanderling skip their first potential breeding season. The later spring migration through Iceland – the last possible staging site for the northbound birds – is likely to correlate with a late arrival in the breeding grounds. Reproductive success may be influenced by a seasonal decline in reproductive performance (Weiser *et al.* 2018), but this seems unlikely to also apply for Sanderlings arriving late in Greenland, because early clutches have a larger risk to fail due to depredation (Reneerkens *et al.* 2016).

On the basis of three published demographic parameters (Fig. 12.3, Reneerkens *et al.* 2020), in combination with published estimates of seasonal variation in clutch survival (Reneerkens *et al.* 2016) it could be shown that the growth of the Sanderling flyway-population is currently limited by annual variation in clutch survival and adult survival in W Africa (Sandercock 2020). A flyway-wide annual monitoring scheme of juveniles recruiting into the non-breeding population (Box 12.2), together with estimates of seasonal survival and annual survival estimates of first-year and older Sanderlings along the flyway (Box 12.1 & 12.2) will lead to an even better understanding of what drives changes of the flyway population size. Detailed studies of the ecological factors that are expected to cause the variation in the demographic parameters that have the largest impact on the population trajectory (Benton & Grant 1999, Caswell 2001) may then inform conservationists (Fig. 12.1). An increased and continued long-term and flyway-wide effort to monitor survival and reproduction of waterbird populations is essential to diagnose threats and the effects of conservation efforts.

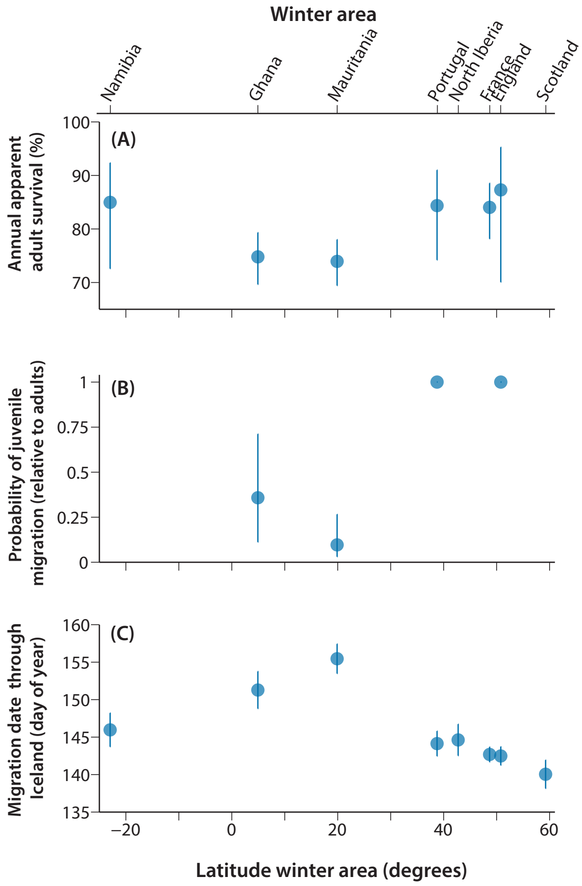

Figure 12. 3. Annual adult survival probabilities of Sanderlings wintering in six areas within the EAF (A), probability that juvenile Sanderlings from four winter areas migrated northwards in the summer following their first winter, relative to that in adults (B), and timing of northward migration through Iceland of Sanderlings wintering in eight wintering areas (C). Day of year 140 represents 20 May. Latitudes are those from the main study sites within winter areas. Dots are averages, and error bars indicate 95% confidence intervals. (From Reneerkens *et al.* 2020.)

Acknowledgements

Clearly, a long-term international research project like described here can only be successful if it is carried by many people. First, I want to thank the more than 2,500 enthusiastic and dedicated observers who reported colour-ring observations and age counts of Sanderlings. This work would not have existed without them or without the pleasant and fruitful collaboration with many colleagues and co-workers in the field, in the lab and behind computers. Theunis Piersma and Yaa Ntiamoa-Baidu have played key roles from the start. The work was financially supported through two grants from the Netherlands Polar Programme of the Netherlands Organisation for Scientific Research (NWO) and from the Metawad project awarded by Waddenfonds to Jeroen Reneerkens and Theunis Piersma, the Prins Bernhard Cultuurfondsprijs to Theunis Piersma and INTERACT grants for Transnational Access from the European Community's Seventh Framework Programme. Sjoerd Duijns, Marc van Roomen en Hans Schekkerman provided useful comments on an earlier draft of the text.

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Arnold Meijer / Blue Robin

Sanderling | **Bécasseau sanderling** (*Calidris alba*)