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EFFECTS OF HABITAT LOSS ON SHOREBIRDS DURING THE NON-BREEDING SEASON: CURRENT KNOWLEDGE AND SUGGESTIONS FOR ACTION

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Resumen. – Efecto de la pérdida de hábitat en las aves playeras durante la época no-reproductiva: conocimiento actual y sugerencias sobre cómo proceder. – Muchas de las aves playeras son especies migratorias Neárticas-Neotropicales que migran de sus áreas norteñas de reproducción a áreas de invernada en Centro y Sudamérica. Las aves playeras difieren de otros grupos de aves migratorios por sus vuelos extremadamente largos y demandantes, ser altamente gregarias, tender a concentrarse en pocos sitios, ser muy longevas y con bajo éxito reproductivo. Datos durante la migración indican que hay disminuciones en las poblaciones de aves playeras que se reproducen en Norteamérica y se piensa que la pérdida de hábitat es un factor importante. La considerable degradación y la pérdida de hábitat debidas a actividades antropogénicas han influenciado los humedales a lo largo de la distribución no-reproductiva de las aves playeras. Si se quiere predecir las consecuencias de la pérdida de hábitat para las poblaciones de aves playeras, además de cuantificar los cambios en el área de hábitat disponible, también es importante entender el papel de las funciones denso-dependientes a consecuencia de que las poblaciones se concentran, como ha sido demostrado para poblaciones de aves playeras en Europa. En contraste, poco se conoce sobre la ecología poblacional o conductual de este grupo de aves al sur de los Estados Unidos de América. Se presenta una revisión breve del estado de conocimiento del efecto de la pérdida de hábitat en las aves playeras durante la época no-reproductiva en el Neotrópico, ilustrado con varios ejemplos, para exponer las muchas preguntas todavía sin contestar. Es fundamental obtener un mejor conocimiento de los factores limitantes en las poblaciones en esta región debido a que las aves playeras son influenciadas por modificaciones del hábitat a través de su distribución durante la época no-reproductiva. La importancia relativa de las funciones denso-dependientes durante la época reproductiva vs no-reproductiva aún debe ser evaluada para la mayoría de las especies.

Abstract. – Many shorebirds are Nearctic-Neotropical migrants that move from their northern breeding grounds to wintering areas in Central and South America. Shorebirds differ from many other groups of avian migrants by their extremely long and demanding flights, gregariousness, restriction to limited numbers of sites, long lifespans, and low recruitment. Migration monitoring data suggest that population declines are occurring in shorebirds that breed in North America, and non-breeding habitat loss is thought to be a contributing factor. Considerable habitat loss and degradation from anthropogenic activities have influenced wetlands across the shorebird non-breeding range. If we wish to predict the consequences of habitat loss for shorebird populations, we must not only quantify changes in available habitat area, but also understand the role of density-dependence as populations pack into or expand from areas, as demonstrated for European shorebird population parameters. In contrast, little is known about the population or behavioral ecology of the wintering shorebirds south of the United States. We briefly review of the state of knowledge of the effects of habitat loss on shorebirds during the non-breeding season in the Neotropics, illustrated with several examples, to highlight the many unanswered questions. It is crucial to gain better understanding of population limiting factors in this region because shorebird populations are influenced by habitat alterations across the non-breeding range. The relative importance of non-breeding vs breeding season density-dependence remains to be assessed for most species. *Accepted 15 December 2007.*

Key words: Habitat loss, migratory shorebirds, Neotropics, non-breeding season, research needs.

INTRODUCTION

Migratory shorebirds, as a group, are of particular conservation concern, owing to their long migrations, low reproductive rate, and dependence on a wide variety of wetland habitats for which extensive losses have occurred (Myers *et al.* 1987, Bildstein *et al.* 1991). Shorebirds worldwide have suffered alarming recent declines. Forty-eight per cent of 200 populations with known trends are in decline, whereas only 16% are increasing (International Wader Study Group 2003). Migration monitoring suggests that declines are also occurring in shorebirds that breed in North America (Howe *et al.* 1989, Morrison *et al.* 2001, Bart *et al.* 2007). There is little information to explain proximate cause(s) of these population declines (Thomas *et al.* 2007), but habitat loss is one likely factor (Zöckler *et al.* 2003). The principal habitats used by most kinds of shorebird during migration and winter seasons are coastal and interior wetlands. Therefore, these declines are of particular conservation concern because the reliance of shorebirds on wetland ecosystems suggests that they may be important indicators of wetland health on a global scale (CHASM 2004).

Although not well enumerated, there is no doubt that the cumulative loss of wetlands worldwide has been enormous during the last two centuries. In the United States, for example, it is estimated that more than 50% of the wetlands that existed in the 1700s' are now gone (Harrington 2003). In the Western Hemisphere little effort has been made outside Canada and United States to document wetland loss on a systematic basis. Further, little is known about the population or behavioral ecology of migratory shorebirds south of the United States, and the effect of habitat loss on population sizes. Population dynamics of migratory shorebirds can be influenced by events that occur during the non-breeding, migration and breeding periods, and population regulation can occur by a combination of mechanisms operating in one or more of these seasons (Piersma & Baker 2000). In this paper, we present a brief overview of the state of knowledge of the effects of habitat loss on migratory shorebirds during the non-breeding season in the Neotropics, illustrated with several examples, to highlight the many unanswered questions.

HABITAT LOSS – A BEHAVIORAL AND POPULATION ECOLOGICAL FRAMEWORK

Many human activities, such as agricultural intensification, industrial development, landclaim, resource harvesting, and salt production, affect or destroy the habitats used by shorebird populations. Their coastal habitats may also be particularly vulnerable to sea level rise caused by climate change. Human disturbance is equivalent to habitat loss or degradation because shorebirds may avoid or underuse areas (Gill & Sutherland 2000). As consequences of habitat loss or human disturbance, food abundance, habitat or time available for feeding may decrease. To understand the effect of habitat loss on migratory shorebirds, we need to think about habitat quality and individual variability. Habitats used by shorebirds vary in quality as a function of food abundance, predation danger and competition. Individuals typically vary considerably in how they exploit food resources, and in their susceptibility to predation and interference competition (Durell 2000, Ydenberg *et al.* 2002). Habitat quality depends on both benefits and costs, and the best habitat choice for any individual thus involves condition- or state-dependent tradeoffs that balance metabolic requirements, safety priorities, and social status or dominance. Such individual variations have important implications for the effect the population consequences of habitat loss or change. If habitat loss or change occurs, some segments of the population will be affected more than others, particularly first-year birds (Goss-Custard & Sutherland 1997, Goss-Custard 2003).

For resident populations, the simplest starting assumption is that populations will decrease in proportion to amounts of habitat lost or degraded. However, to predict the population consequences of habitat loss, we also need to understand the role of density-dependence (Goss-Custard & Sutherland 1997, Goss-Custard 2003). In our case, how will populations be affected if more shorebirds attempt to occupy less space during the non-breeding season? It is likely that body condition and rates of survival of shorebirds will decline due to changes in competition for food and/or intensity of predation at fewer sites. Whether shorebirds starve or emigrate may not be of immediate concern for a particular site, but could have an important effect on that site in the long term (Goss-Custard 2003). Local population size would be expected to decline by an amount that depends on the availability of alternative non-breeding sites, and also of density-dependent interactions on the breeding grounds (see below). Migratory species require a more complex conceptual framework for predicting the consequences of habitat loss (Goss-Custard *et al.* 1995, Sutherland 1998). Because density-dependent processes operate with different relationships at different times of year, this habitat loss framework indicates that it is important to consider the relationship between total population size and per capita population change on both the breeding and wintering grounds. In short, the impact of habitat loss is more severe for the season or region in which density-dependence is stronger. To predict the consequences of habitat loss on population size, therefore, the strength of the density-dependence in both breeding and wintering areas needs to be known (Gunnarsson *et al.* 2005). In theory, the magnitudes of density-dependent process at migration stopover sites would also be involved (Skagen 2006). Finally, population dynamics of migratory species are probably more even complex than previously thought because of carry-over effects – events in one season that produce residual effects on individual's breeding performance and survivorship the following season (Norris 2005).

CURRENT KNOWLEDGE FROM THE NEOTROPICS

Little is known about the population or behavioral ecology of nearly all of the migratory shorebirds in the Neotropics. In particular, the effects of habitat loss on migratory shorebirds have received little attention, in contrast to the numerous detailed studies on European species that winter at northern temperate latitudes (e.g., Goss-Custard *et al.* 1995, Goss-Custard & Sutherland 1997, Durell *et al.* 2005, West & Caldow 2006).

For most Neotropical migratory shorebirds, in contrast, the information available during the non-breeding season is meager and dispersed. As a starting point, however, for the most at-risk shorebird species, most non-breeding sites and areas of substantial importance have been identified (WHSRN 2007). Although there is an assessment of how much habitat has been lost in some countries (e.g., Fuente de León & Carrera 2005), there is no analysis of its effects on shorebird populations beyond a local scale. While annual adult survivorship has been estimated for some species (Sandercock 2003), there is no partitioning of these values into breeding season, migration season, and non-breeding season mortality rates (cf. Sillett & Holmes 2002), which would identify stages with the highest daily risk of mortality. There is information for some species on differential habitat distribution by sex, age, and size, either latitudinally (Myers 1981, Nebel *et al.* 2002, O'Hara *et al.* 2006, Nebel 2006) or among habitats on a local scale (Fernández & Lank 2006), and we know of intraspecific differences in energetic costs and life-history strategies with respect to migration distances (Myers *et al.* 1985, Castro *et al.* 1992, O'Hara *et al.* 2005), but the population implications of these patterns have not been worked out. There are several published studies on the feeding and intertidal food resources of migratory shorebird species from sites in Brazil (Kober & Bairlein 2006a, 2006b), Argentina (e.g., González *et al.* 1996, Ieno *et al.* 2004, Bala 2006), Chile (Velasquéz & Navarro 1993), Panama (Schneider 1985), and Peru (Duffy *et al.* 1981), but few assessments of the importance of raptor populations on non-breeding behavior or demography (Myers 1980, Myers *et al.* 1985, Nebel & Ydenberg 2005).

FUTURE DIRECTIONS

Based on our current knowledge of how habitat loss will affect migratory shorebirds in the Neotropics, the main deficiencies and recommendations for future research can be summarized as follows.

Mapping and habitat classification. Information on land-cover patterns at a range of spatial scales has important applications in conservation. Land-cover and land-use data are necessary for environmental monitoring, change detection, designation of important areas as well as development of multiple zoning schemes (Kerr & Ostrovsky 2003). For migratory shorebirds, these data can be applied to investigate the links between biological processes, such as survival and dispersal of individuals, and physical patterns, such as landscape structure. To be applied efficiently, land-cover and land-use data need to be available in GIS at a scale relevant to shorebirds (Zharikov *et al.* 2005).

Feeding and danger ecology. We need to understand the effects of food and predation as limiting factors for shorebird populations. Establishing these relationships would explain the processes determining local habitat use and population numbers of shorebirds and, ultimately, provide the capacity to predict the effects of habitat change on these populations (Goss-Custard & Durell 1990, Piersma & Baker 2000). Ideally, a detailed research program investigating predator-prey interactions needs to include the numeric and functional responses of the shorebirds to fluctuations in their food supply, temporal patterns in shorebird diet, and distribution in the feeding sites, competitive interactions among foraging individuals, age- and sex-related differences in feeding behavior, and how foraging decisions are influenced by changes in predation danger. We would want to describe changes in these characteristics with population density.

Demographic modeling. Monitoring and modeling demographic rates is key to both understanding the factors that have affected shorebird populations and as a first step towards predicting the effect of habitat change upon them during the non-breeding season. Adult survival is a critical variable in determining population dynamics of migratory shorebirds (Hitchcock & Gratto-Trevor 1997), and this magnifies the importance of the quality of the limited non-breeding habitat in the winter and migration sites on which birds rely (Piersma & Baker 2000). Banding (marking) programs are essential to estimate survivorship, and the color banding of individuals also allows more detailed observation of behavior including habitat use and foraging ecology. Also, we must understand the functional links between the seasonal habitats of migratory shorebirds (Webster *et al* 2002). Coupled with banding shorebirds, the use of stable isotopes and genetic information may provide a powerful tool for estimating population-specific demographic parameters and increase our understanding of their migration systems.

Behavior-based modeling. Recently, individual-based models have been developed in an attempt to predict how migratory bird populations will be affected by environmental change, such as habitat loss, disturbance, and climate change (Pettifor *et al.* 2005, West & Caldow 2006). These models follow the behavioral responses of individual animals to changes in the environment and predict variables such as population mortality rates from the fates of all individuals. Birds in these models use optimal decision rules to determine their behavior, thus model birds should respond to environmental changes in the same way as real ones would. The most important advantage of this approach is provides a means of predicting how animal populations will be influenced by environmental changes outside the ranges of those we have already observed. Although individual-based models are often complex and take a long time to develop, they have already proved useful in a range of issues and locations in Europe (e.g., Durell *et al.* 2005, Pettifor *et al.* 2005, West & Caldow 2006).

Finally, to safeguard migratory shorebird populations, we have to protect the interconnected chains of wetlands they rely on from further deterioration and disappearance (Myers *et al.* 1987, Piersma & Baker 2000). Invariably, to develop a thorough understanding of the functioning of a wetland ecosystem in which shorebirds represent a key component, requires a huge investment in time and effort. It is clear that more attention needs to be paid to individual variation in competitive abilities and to competitive process, since these determine the form of density-dependent demographic functions (Goss-Custard 2003). Knowledge of density-dependence within the non-breeding season alone, however, is insufficient to predict the consequences of non-breeding habitat loss on migratory shorebird populations. The relative importance of non-breeding versus breeding season density-dependence remains to be assessed for most shorebird species. Although we are focused on Nearctic-Neotropical shorebirds, the consequences of habitat loss could be similar to other shorebird species. Thus, this approach would be useful for non-migratory or Neotropical species, comparing for example seasonal differences in density-dependent functions. Finally, in order to assess the future impact of habitat loss and human disturbance during the non-breeding season, we need to be able to predict how body condition and survival of migratory shorebirds will be affected as conditions change. This information is vital to manage shorebird populations and their habitats in order to maintain or increase the size of their populations.

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REFERENCES

Bala, L. O. 2006. Humedales de la Península Valdés y aves playeras migratorias. Una síntesis de procesos biológicos y ecológicos con fines conservacionistas. CENPAT, Puerto Madryn, Argentina.

Bart, J., S. Brown, B. Harrington, & R. I. G. Morrison. 2007. Survey trends of North American shorebirds: population declines or shifting distributions? J. Avian Biol. 38: 73–82.

Bildstein, B. L., G. T. Bancroft, P. J. Dugan, D. H. Gordon, R. M. Erwin, E. Nol, E., L. X. Payne, & S. E. Senner. 1991. Approaches to the conservation of coastal wetlands in the western Hemisphere. Wilson Bull. 103: 218–254.

Castro, G., J. P. Myers, & R. E. Ricklefs. 1992. Ecology and energetics of Sanderlings migrating to four latitudes. Ecology 73: 833–844.

Committee for Holarctic Shorebird Monitoring (CHASM). 2004. Monitoring Arctic-nesting shorebirds: an international vision for the future. Wader Study Group Bull. 103: 2–5.

Duffy, D. C., N. Atkins, & D. C. Schneider. 1981. Do shorebirds compete on their wintering grounds? Auk 98: 215–229.

Durell, S. E. A. Le V. dit. 2000. Individual feeding specialisation in shorebirds: population consequences and conservation implications. Biol. Rev. 75: 503–513.

Durell, S. E. A. Le V. dit, R. A. Stillman, P. Triplet, C. Aulert, D. O. dit Bio, A. Bouchet, S. Duhamel, S. Mayot, & J. D. Goss-Custard. 2005. Modelling the efficacy of proposed mitigation areas for shorebirds: a case study on the Seine estuary, France. Biol. Conserv. 123: 67–77.

Fernández, G., & D. B. Lank. 2006. Sex, age, and body size distributions of Western Sandpipers during the nonbreeding season with respect to local habitat. Condor 108: 547–557.

Fuente de León, G., & E. Carrera. 2005. Cambio de uso del suelo en la zona costera del estado de Sinaloa. Ducks Unlimited de México A.C., Monterrey, Nuevo León, México.

González, P. M., T. Piersma, & Y. Verkuil. 1996. Food, feeding, and refuelling of Red Knots during northward migration at San Antonio Oeste, Rio Negro, Argentina. J. Field Ornithol. 67: 575–591.

Gill, J. A., & W. J. Sutherland. 2000. Predicting the consequences of human disturbance from behavioural decisions. Pp. 51–64 *in* Morris, L. M., & W. J. Sutherland (eds.). Behaviour and conservation. Cambridge Univ. Press, Cambridge, UK.

Goss-Custard, J. D. 2003. Fitness, demographic rates and managing the coast for wader populations. Wader Study Group Bull. 100: 183–191.

Goss-Custard, J. D., & S. E. A. Le V. dit Durell. 1990. Bird behaviour and environmental planning: approaches in the study of wader populations. Ibis 132: 273–289.

Goss-Custard, J. D., & W. J. Sutherland. 1997. Individual behaviour, populations and conservation. Pp. 373–395 *in* Krebs, J. R., & N. B. Davies (eds.). Behavioural ecology: an evolutionary approach. Blackwell Science, Inc., Oxford, UK.

Goss-Custard, J. D., R. T. Clarke, S. E. A. Le V. dit Durell, R. W. G. Caldow, & B. J. Ens. 1995. Population consequences of winter habitat loss in a migratory shorebird. I. Estimating model parameters. J. Appl. Ecol. 32: 337–351.

Gunnarsson, T. G., J. A. Gill, A. Petersen, G. F. Appleton, & W. J. Sutherland. 2005. A double buffer effect in a migratory shorebird population. J. Anim. Ecol. 74: 965–971.

Harrington, B. A. 2003. Shorebird management during the non-breeding season – an overview of need, opportunities, and management concepts. Wader Study Group Bull. 100: 59–66.

Hitchcock, C. L., & C. Gratto-Trevor. 1997. Diagnosing a shorebird local population decline with a stage-structured population model. Ecology 78: 522–534.

Howe, M. A., P. A. Geissler, & B. A. Harrington. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biol. Conserv. 49: 185–199.

Ieno, E., D. Alemany, D. E. Blanco, & R. Bastida. 2004. Prey selection by Red Knot feeding on mud snails at Punta Rasa (Argentina) during migration. Waterbirds 27: 493–498.

International Wader Study Group. 2003. Waders are declining worldwide. Conclusions from the 2003 International Wader Study Group Conference, Cádiz, Spain. Wader Study Group Bull. 101/102: 8–12.

Kerr, J. T., & M. Ostrovsky. 2003. From space to species: ecological applications for remote sensing. Trends Ecol. Evol. 18: 292–300.

Kober, K., & F. Bairlein. 2006a. Shorebirds of the Bragantinian Peninsula I. Prey availability and shorebird consumption at a tropical site in northern Brazil. Ornitol. Neotrop. 17: 531–548.

Kober, K., & F. Bairlein. 2006b. Shorebirds of the Bragantinian Peninsula II. Diet and foraging strategies of shorebirds at a tropical site in northern Brazil. Ornitol. Neotrop. 17: 549–562.

Morrison, R. I. G., Y. Aubry, R. W. Butler,G. W. Beyersbergen, G. M. Donaldson, C. L. Gratto-Trevor, P. W. Hicklin, V. H. Johnston, & R. K. Ross. 2001. Declines in North American shorebird populations. Wader Study Group Bull. 94: 34–38.

Myers, J. P. 1980. Territoriality and flocking by Buff-breasted Sandpipers: variation in non-breeding dispersion. Condor 82: 241–250.

Myers, J. P. 1981. A test of three hypotheses for latitudinal segregation of the sexes in wintering birds. Can. J. Zool. 59: 1527–1534.

Myers, J. P., J. L. Maron, & M. Sallaberry. 1985. Going to extremes: why do Sanderlings migrate to the Neotropics? Ornithol. Monogr. 36: 520–535.

Myers, J. P., R. I. G. Morrison, P. Z. Antas, B. A. Harrington, T. E. Lovejoy, M. Sallaberry, S. E. Senner, & A. Tarak. 1987. Conservation strategy for migratory species. Am. Sci. 75: 19–25.

Nebel, S. 2006. Latitudinal clines in sex ratio, bill, and wing length in Least Sandpipers. J. Field Ornithol. 77: 39–45.

Nebel, S., & R. C. Ydenberg. 2005. Differential predator escape performance contributes to a latitudinal sex ratio cline in a migratory shorebird. Behav. Ecol. Sociobiol. 59: 44–50.

Nebel, S., D. B. Lank, P. D. O'Hara, G. Fernández, B. Haase, F. Delgado, F. A. Estela, L. J. Evans Ogden, B. Harrington, B. E. Kus, J. Lyons, B. Ortego, J. Y. Takekawa, N. Warnock, & S. E. Warnock. 2002. Western Sandpiper (*Calidris mauri*) during the nonbreeding season: spatial segregation on a hemispheric scale. Auk 119: 922–928.

Norris, D. R. 2005. Carry-over effects and habitat quality in migratory populations. Oikos 109: 178–186.

O'Hara, P. D., G. Fernández, F. Becerril, H. de la Cueva, & D. B. Lank. 2005. Life history varies with migratory distance in Western Sandpipers *Calidris mauri*. J. Avian Biol. 36: 191–202.

O'Hara, P. D., G. Fernández, B. Haase, H. de la Cueva, & D. B. Lank. 2006. Differential migration in Western Sandpipers with respect to body size and wing length. Condor 108: 225–232.

Pettifor, R. A., R. W. G. Caldow, J. M. Rowcliffe, J. D. Goss-Custard, J. M. Black, K. H. Hodder, A. I. Houston, A. Lang, & J. Webb. 2000. Spatially explicit, individually-based, behavioural models of the annual cycle of two migratory goose populations. J. Appl. Ecol. 37(Suppl. 1): 103–135.

Piersma, T., & A. J. Baker. 2000. Life history characteristics and the conservation of migratory shorebirds. Pp. 105–124 *in* Morris, L. M., & W. J. Sutherland (eds.). Behaviour and conservation. Cambridge Univ. Press, Cambridge, UK.

Sandercock, B. K. 2003. Estimation of survival rates for wader populations: a review of mark-recapture methods. Wader Study Group Bull. 100: 163–174.

Schneider, D. 1985. Migratory shorebirds: resource depletion in the tropics? Ornithol. Monogr. 36: 546–558.

Sillett T. S., & R. T. Holmes. 2002. Variation in survivorship of a migratory songbird throughout its annual cycle. J. Anim. Ecol. 71: 296–308.

Skagen S. K. 2006. Migration stopovers and the conservation of arctic-breeding calidridine sandpipers. Auk 123: 313–322.

Sutherland, W. J. 1998. The effect of local change in habitat quality on populations of migratory species. J. Appl. Ecol. 35: 418–421.

Thomas, G. H., R. B. Lanctot, & T. Székely. 2006.

Can intrinsic factors explain population declines in North American breeding shorebirds? A comparative analysis. Anim. Conserv. 9: 252–258.

Velásquez, C. R., & R. A. Navarro. 1993. The influence of water depth and sediment type on the foraging behavior of Whimbrels. J. Field Ornithol. 64: 149–157.

Webster, M. S., P. P. Marra, S. M. Haig, S. Bensch, & R. T. Holmes. 2002. Links between worlds: unraveling migratory connectivity. Trends Ecol. Evol. 17: 76–82.

West, A. D., & R. W. G. Caldow. 2006. The development and use of individual-based models to predict the effects of habitat loss and disturbance on waders and waterfowl. Ibis 148: 158–168.

Western Hemisphere Shorebird Reserve Network (WHSRN). 2007. Species conservation plans. On line at: http://www.whsrn.org/shorebirds/conservation_plans.html. Accessed May 2007).

Ydenberg, R. C., R.W. Butler, D. B. Lank, C. G. Guglielmo, M. Lemon, & N. Wolf. 2002. Tradeoffs, condition dependence and stopover site selection by migrating sandpipers. J. Avian Biol. 33: 47–55.

Zharikov, Y., G. A. Skilleter, N. L. Loneragan, T. Taranto, & B. E. Cameron. 2005. Mapping and characterising subtropical estuarine landscapes using aerial photography and GIS for potential application in wildlife conservation and management. Biol. Conserv. 125: 87–100.

Zöckler, C., S. Delany, & W. Hagemeijer. 2003. Wader populations are declining – how will we elucidate the reasons? Wader Study Group Bull. 100: 202–211.