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U.S. Shorebird
Conservation Plan

National Shorebird Research Needs

A Proposal for a National Research Program and Example High Priority Research Topics

A Technical Report of the Research and Monitoring Working Group of the
U.S. Shorebird Conservation Plan

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Introduction

Populations of many of North America's 52 shorebird species are in steep decline. In order to reverse these declines, and to assure stable, self-sustaining populations, fundamental knowledge of shorebird biology is essential. However, vast gaps exist in our knowledge of North America's shorebirds. For example, for only a few of the rarest species is there a scientifically valid estimate of population size. In addition, the factors limiting the populations of most species are unknown. Maintenance of stable and self-sustaining shorebird populations is the central goal of the National Shorebird Research Program (NSRP) proposed here. Shorebird conservation efforts cannot succeed in the absence of sound knowledge on various aspects of shorebird biology.

As information on shorebird biology unfolds, it is difficult to predict what topics will emerge as key issues for conservation. For example, population declines may turn out to have sources in breeding areas, along migration routes, or on the wintering grounds, or even a combination. Issues such as acid rain, pollution, global warming, or habitat loss might be involved, or other issues not presently recognized may be key. Alternatively, with improved information, we may discover that some declines that originally appeared to be alarming are actually the results of natural population fluctuations.

In order to provide the up-to-date, scientifically rigorous information essential for shorebird conservation, the U. S. Shorebird Conservation Plan recommends the institution of the NSRP. This program will support essential conservation based research on shorebirds through establishment of a competitive grants program administered by the Biological Resources Division of the United States Geological Survey, acting upon the recommendation of a panel of experts. The program should include annual funding of $2 million for national research priorities, and $1.75 million for regional research priorities.

Program Administration

The NSRP will be administered at USGS Patuxent Wildlife Research Center. It may be necessary to utilize some proportion of new research funding to hire support staff. The program administrator, a USGS employee, will work with the Shorebird Planning Council to identify panel members, each with the highest scientific credentials and possessing skills representative of various research areas, e.g. breeding and non-breeding biology, coastal and inland areas. The makeup of the panel will include a Chair named by USGS and eight additional shorebird experts named by the Shorebird Planning Council. The panel and the program administrator will develop proposal guidelines and operating procedures, following as closely as possible the guidelines used by the National Science Foundation.

The function of the panel is to assure that funds are spent in a manner most likely to enhance the goal of assuring stable and self-sustaining shorebird populations. Proposals submitted to the NSRP will have the obligation of convincing the evaluation panel that they will contribute knowledge important to the restoration or maintenance of stable shorebird populations. The panel will have the obligation of ranking proposals on the basis of their likelihood to enhance shorebird conservation through restoration or maintenance of stable populations. The panel will have the national shorebird conservation priorities as a guide in prioritizing proposed research. Partnerships among federal, state, non-governmental organizations, and academic scientists will be encouraged where this is logical for achieving the goal of stable and self-sustaining shorebird populations.

While the goal of this program is population based, this in no way infers that high priority research could not be funded at other levels, such as mechanistic research dealing with the behavior or physiology of shorebirds, their prey and predators; community, ecosystem or landscape level ecology, etc. But, in the end, the goal is to maintain stable and self-sustaining populations. Therefore, mechanistic, community, ecosystem, or landscape proposals all have the obligation of demonstrating their relevance to conservation of shorebird populations.

In addition to the 2M requested for the NSRP, 1.75 M has been requested to support regional research. Just as the national shorebird community has established national conservation priorities, regional groups are ranking conservation priorities of species within regions. Sometimes these are concordant with national priorities, sometimes they are different. Regional support should be sought for research primarily of importance relative to regional conservation priorities, or for monitoring or management research primarily of regional application.

Example Priority Research Topics

A. Essential research designed to facilitate stable and self-sustaining shorebird populations, especially those of high national conservation priority (ranks 5,4).

Persons proposing this research accept the responsibility of elucidating how it will help lead to stable and self-sustaining shorebird populations. Research aimed primarily at species/subspecies of low national conservation ranking but high regional ranking should seek funding through local/regional programs. Categories below overlap broadly since avian life history necessarily involves multiple factors at the same moment in time or space. Proposals for development of new techniques broadly applicable to the topics below are encouraged.

1. Identification of population limiting factors
What limits the size of shorebird populations, especially for species of concern? Understanding the answer is basic to developing sound conservation strategies.

a. Factors influencing productivity/breeding success
b. Factors influencing both juvenile and adult mortality (including predation, environmental toxicants)
c. Disturbance as a factor affecting "a" and "b" above, as well as predation risk.

2. Distribution and abundance
Understanding patterns of shorebird distribution and abundance, and factors controlling them. Research to improve monitoring activities would fit in this area, but activities specifically aimed at monitoring population trends are addressed under priority monitoring programs.

3. Space use and dispersal (including movements within and among years)
Exploration of factors affecting space use and dispersal decisions, including the relationship of key habitat features such as foraging benefit, predator risk, and information acquisition to relative use of space.

4. Migration systems
Increasing our understanding of the dynamics of migration patterns, including how populations move among sites, and why.

5. Turnover rates and stopover ecology
Understanding the timing of landscape level habitat use, which is critical for monitoring studies, and understanding factors affecting turnover rates.

6. Energetics and foraging ecology
Analysis of dietary requirements, elucidation of dietary preferences, nutritional requirements, and metabolic needs.

7. Differentiation of sub-species and species
Identifying geographic population subdivision, determining conservation issues below the species level, and identification of the role of subspecies in the overall population dynamics of a species.

B. Management research with application across regions.

Research proposals in this area must establish broad applicability to enhancing shorebird populations across multiple regions, and includes technique development where applicable to managing shorebirds.

1. Controlling population limiting factors.
Research designed to develop techniques for reducing specific population limiting factors, e.g., techniques for reducing nest predation, reducing risks from toxicants, and improving or providing habitat.

1. Effects of global climate change.
Modeling potential impacts of and development of management protocols to mitigate effects of global climate change.

2. Predator control.
Development of techniques to deter predators, e.g., including aversive conditioning to reduce losses from both avian and mammalian predators.

3. Disturbance.
Disturbance effects on foraging and breeding, including measuring disturbance impact and/or studying ways of reducing disturbance.

4. Increasing productivity.
Techniques for increasing productivity, including, captive breeding reintroduction and associated techniques.

C. Monitoring research and development of protocols for tracking population trends.

Research proposals in this area should identify how the projects can lead to improved monitoring of species of national conservation concern and/or development of techniques widely applicable across species. Identification of sites used, habitats used, and variation across time and space is primarily a monitoring activity and should be supported with monitoring funds. However, development of new techniques for analysis of monitoring data is highly appropriate for funding from this program, including:

1. Population trends.
Development of models to predict population trends;

2. Population fluctuations.
Exploration of population fluctuations, and their impact on estimates of numbers using sites; and

3. Research on the validity of sampling techniques.

D. Other Priority Research Topics.

The topics outlined above are meant to be illustrative, not all inclusive. Any research proposal judged by the Panel as likely to provide knowledge of high value for enhancing stable and self-sustaining shorebird populations is suitable for this program. One specific additional topic identified by the working group as high priority is a detailed literature review of existing life history information by species, noting important gaps in knowledge on the following topics:

A. Distribution and abundance, including temporal and spatial variation
B. Energetics, diet and foraging behavior
C. Shorebird migration systems: origins, routes and destinations of specific populations
D. Genetic variation within and between populations
E. Population dynamics, including:
    1. natality including factors affecting variation
    2. hatching/fledging, including factors affecting variation

    3. recruitment, including factors affecting variation
    4. longevity/survival, including factors affecting variation
    5. dispersal

Appendix 1. Descriptions of Selected Research Topics

This appendix provides 5 examples of research topics of current interest to development and implementation of National Shorebird Research Priorities. These are intended to be illustrations of topics where compiled information would benefit national shorebird conservation planning.

1) Critical Life History Information

The maintenance of viable shorebird populations requires a long term balance between recruitment and mortality. For species that have already declined significantly from historic populations, restoration requires that recruitment exceed mortality. Assessment of whether or not these goals are being attained, and development of plans to increase populations, requires baseline data on such factors as distribution and abundance, natural variation in population sizes and distribution patterns, and detailed knowledge of population limiting factors. Therefore, the first priority for shorebird research is completion of a species by species review of life history data including distribution and abundance, and aspects of population dynamics such as age at first breeding, hatching and fledging success, survival to reproductive age, longevity, causes of mortality, geographic and annual variation of populations, and interconnectedness of populations. This project is described in section A. below, followed by recommendations for collection of missing information on high priority species.

A. Analysis of existing information on life histories and populations.

A considerable amount of research has been conducted on many species of shorebirds to describe their basic life history characteristics. However, there has never been a comprehensive analysis of the areas where information critical to conservation is missing, even for many high priority species. This section describes the elements that should be addressed in a project designed to collect existing life history information, and to locate and prioritize the most critical information needed to effectively manage particular species:

1. Distribution and abundance, including temporal and spatial variation
2. Energetics, diet, and foraging behavior
3. Interconnectedness of breeding, post-breeding, migrating, and wintering populations
4. Genetic variation within and between populations
5. Population dynamics, including:
    a) Natality, including factors affecting variation
    b) Hatching/fledging including factors affecting variation
    c) Recruitment, including factors affecting variation
    d) Longevity/survival, including factors affecting variation
    e) Dispersal

B. Collection of missing life history information for high priority species.

Filling in missing information for high priority species should be a primary research focus, especially for species with high conservation priority rankings.

2) Basic Research with Significant Conservation Implications

A. Shorebird distribution and abundance, including temporal and spatial variation (Laura Payne)

Classification of distribution, density, and habitat specificity. The success of conservation and management programs depends to a large extent on how much prior information we have on the distribution and abundance of each species. To identify important gaps in our knowledge of distribution and abundance, shorebirds should be classified according to distribution, density, and habitat specificity, and also including a measure of the level of confidence in the classification of each species. In some cases it may be useful to make separate matrices for breeding season, migration, and/or winter season.

Population Density	*Extensive range, broad specificity*	*Extensive range, narrow specificity*	*Restricted range, broad specificity*	*Restricted range, narrow specificity*	*Unknown*
Dense					
Sparse					
Unknown					

(Based on Rabinowitz 1981)

Species with sparse population density, extensive range, and broad habitat specificity may be threatened by gradual loss of habitat (such as conversion of wetlands to agriculture) in the interior U.S., while species with a dense population, restricted range, and narrow habitat specificity may be threatened by oil spills or beachfront development in the coastal U.S. This project will help prioritize future conservation efforts by classifying species. Which species (or guilds, or types of species) are well covered, and which are not? In which cases are species-based approaches necessary, given that most efforts to date are site-based?

Landscape scale distribution. Most of our knowledge of shorebird migration has come from specific geographic locations, without the benefit of an overriding landscape-scale perspective. Consequently, our assumptions about how shorebirds use the landscape are influenced by the scale at which we observe and census them. Research should be undertaken to determine the scale at which shorebirds use the landscape, including their local movements during breeding, migration (see Farmer and Parent 1997), and wintering.

Anthropogenic effects on shorebird distribution. Several mechanisms have been proposed to explain (changes in) distribution and abundance patterns of shorebirds. Further research should investigate anthropogenic influences, whether through direct disturbance (see Pfister et al. 1992), habitat alteration, or change in landscape/community structure.

Responses to changing habitat characteristics. Some species show consistent, year to year use of the same 'traditional' sites (especially in coastal areas). How flexible are these species to habitat loss or long term changes? Does restored habitat attract these shorebirds as effectively as it might their opportunistic, inland congeners?

B. Space Use and Dispersal (Sue Haig and Lew Oring).

Traditional shorebird conservation efforts have focussed on identifying and protecting migratory stop-over sites where massive numbers of birds pass through an area for a short period of time. In North America, this tradition has continued as much of shorebird breeding takes place in arctic regions where, until recently, habitat was thought to be unharmed; and winter sites are only recently being recognized. However, as more studies are conducted that examine how shorebirds use their habitats within and among different phases of the annual cycle as well as across years, we are learning the critical importance of having this information prior to designing conservation strategies for species, sites, or regions (Table 1).

For example, in the western Great Basin, individual American Avocets move among multiple sites that can span hundreds of kilometers in distance during the 2-4 months they spend post-breeding/pre-migration. Conversely, Killdeer in the region will generally stay within 1-3 km of their former nests sites for most of the year, however, they use their immediate area far more than Avocets. Thus, to design a regional conservation strategy that includes even just two of the nine breeding shorebirds in the area, we need to consider extensive areas around wetlands as well as a mosaic of wetlands that offer alternatives for Avocets.

Table 1. Examples of studies of space use and movements in North American shorebirds.

Spatial consideration	Examples
Movements among sites prior to breeding to inspect possible nest locations	Oring & Lank 1984; Reed & Oring 1992; Plissner et al.c
Movements during the breeding season in response to re-nesting after early nest failure.	Haig & Oring 1988a; Reed & Oring1993; Stenzel et al. 1994; Paton 1995; Robinson & Oring 1997.
Territory switching within a breeding season.	Haig & Oring 1988a; Colwell & Oring 1989; Oring et al. 1994; Paton 1995.
Use of foraging areas away from nest sites.	Plissner et al. c.
Use of special brood-rearing habitat away from the nest site.	Knopf & Rupert 1996
Post-breeding movements of young and/or adults to staging areas or other sites providing species-, age-, or sex-specific resources.	Plissner et al.a,b,
Movements within migration and winter sites.	Connors et al. 1981; Myers 1981,1988; Skagen & Knopf 1993, 1994; Boettcher et al.1994;Warnock et al. 1995; Iverson et al. 1996; Warnock & Takekawa 1996; Farmer & Parent 1997; Skagen 1997; Warnock & Bishop 1998; Bishop & Warnock 1998.
Interannual breeding site fidelity	Oring & Lank 1984, Gratto et al. 1985, Colwell et al. 1986, Haig & Oring 1988b, Stenzel et al. 1994. Paton & Edwards 1996.

Similarly, the links between more distant sites used over various phases of the annual cycle are important to identify. For example, Western Sandpipers use of series of North American stopover sites and breeding areas that range from Baja to western Alaska. Yet Western Sandpipers that winter in San Francisco Bay have home ranges that average 22 km. Thus, single-species efforts must take a multi-dimensional view that links distant sites.

Finally, annual patterns of site use, regardless of the phase of the annual cycle, can provide perspective on habitat quality and stability. For example, each year sites such as the Great Salt Lake, Mono Lake, and Lake Abert provide post-breeding/pre-migration habitat for hundreds of thousands of shorebirds. Thus, it was important to recognize these sites and their inter-linkages for species such as American Avocets, Wilson's Phalaropes, and Red-necked Phalaropes. Conversely, during the breeding season, species such as Piping Plovers, Buff-breasted Sandpipers, and various phalaropes have widely-varying site fidelity that can range from returning to local areas to moving hundreds of kilometers away. Thus, they must be provided options for breeding when conditions change in their highly dynamic environments.

Therefore, our conservation planning efforts from local to global must consider and incorporate the vast diversity of space use among shorebirds throughout the annual cycle. Included in these studies should be efforts not only to describe patterns of space use but to address hypotheses that will explain factors that contribute to space use decisions, what limits space use, and what can be done to insure proper conservation of the suite of sites needed for viable populations. Use of color-marked birds, radio-telemetry, satellite telemetry, population-specific molecular markers, and geographic information systems will provide the tools necessary to address these issues.

C. Shorebird migration systems: origins, routes, and destinations of specific populations (Guy Morrison)

Knowledge of what may be termed the migration system of a shorebird species, involving an understanding of its breeding origins, migration routes and wintering destinations, is a basic requirement for conservation. Knowledge of how populations move between sites and which sites are linked is important in ensuring that all the areas needed by the birds to complete their annual travels are adequately protected.

While the broad outline of the migration systems used by many species may be understood, detailed knowledge exists for remarkably few species, and even for those, is often incomplete. Shorebirds exhibit a variety of migration systems and strategies. Table 1 shows a general categorization of shorebirds according to whether they are principally coastal or inland migrants (in North America, note many species occur in both types of habitat, though usually one predominates), according to migration distance (long, intermediate, short) and flyway/coast occurrence. Note that coastal migrants are generally gregarious, occurring in large flocks during migration and wintering periods, while inland migrants tend to include solitary or more dispersed species.

General Approach: While it is desirable to have a clear knowledge of migration links for all species, a more practical approach may be to focus on a number of "flagship" species that move between many of the key areas situated in the various flyways. This approach has proved effective in elucidating links between sites for a number of species, including Red Knot, Sanderling, Semipalmated Sandpiper and Western Sandpiper. A number of potential flagship species are indicated in bold in Table 2.

Methods. Traditional methods of investigating migration patterns have involved banding and color-marking shorebirds, and these continue to be effective, if time consuming and labor intensive, for many species. New techniques need to be used and developed. Radio tracking has proved very instructive in showing long-distance movements of Western Sandpipers along the Pacific Flyway and is being developed for Red Knots along the Western Atlantic Flyway. Satellite telemetry has almost reached the point where it can be used for shorebirds, though available units are still potentially rather heavy to place on long-distance migrants: development of smaller units and/or lighter power sources will revolutionize the study of shorebird migration and should be pursued. A variety of "molecular" methods are available by which populations and sub-populations may potentially be identified, including DNA techniques and methods involving analysis of stable isotopes. Combination of these methods will provide insight into movements of populations, sub-populations, sexes etc.

Recommendation. A number of flagship species which use major sites in all geographical regions and flyways should be chosen for study, and an integrated program involving traditional and new techniques developed to elucidate movement patterns of all segments of the population in relation to ecological requirements at all stages of the annual cycle.

Table 2. Migration systems of shorebirds, showing principal flyway/coast(s) used and migration distance for species that occur principally in coastal or inland habitats. Species that tend to be dispersed, or occur either solitarily or in small flocks are in italics. Some suggested "flaghip" species representative of different categories are indicated in bold.

Coastal

	Both	Pacific	Central-Pacific	Central	Central-Atlantic	Atlantic
Long	**SAND** RNPH REPH	**PGPL** SHSA WATA SURF			**HUGO** RUTU	**REKN**
Intermediate	BBPL SEPL LESA **DUNL** SBDO WHIM	**WESA** LBDO				**SESA**
Short	**WILL**	BLOY BLTU ROSA			AMOY	**PUSA**

Inland

	Both	Pacific	Central-Pacific	Central	Central-Atlantic	Atlantic
Long				BASA **WIPH** PESA	AGPL ESCU **WRSA**	
Intermediate	*GRYE* *LEYE* *SPSA*			*SOSA*	*UPSA*	
Short	*KILL* **BNST** *COSN*		*SNPL* AMAV *LBCU* **MAGO**	*MOUP*	*WIPL* ***PIPL*** *AMWO*	

D. Differentiation of sub-species and populations (Rick Lanctot)

Monitoring shorebird population trends, distribution, and abundance is one of the top priorities of the Shorebird Plan. Essential to this goal is the ability to identify geographically distinct subspecies and/or populations. This section describes the merits of identifying geographic population subdivision (or phylogeography), lists previous efforts to identify populations within shorebird species, and lists future research priorities.

Understanding geographic population subdivision is imperative given the varied geographic distributions, life histories, and migratory pathways of most shorebirds. Indeed, species (and perhaps populations within species) may differ in their breeding and natal philopatry, winter fidelity, migratory pathways, and location in which they winter. The extent to which these factors contribute to genetic differentiation of populations within species varies, and is relatively unknown for most shorebirds. Phylogeographic structuring can have dramatic effects on how species should be managed however. For example, high breeding site fidelity and/or natal philopatry may result in genetically unique populations which would require particular areas within a species range be conserved to protect that portion of the breeding population. Similarly, highly defined migratory pathways may require protection of particular staging areas to ensure the species is able to complete their annual flight.

Historically, ornithologists have relied on observational methods, such as mark and recapture techniques or morphological comparisons, to investigate contemporary gene flow or population distinctness within shorebird species. These methods have provided valuable information in a few cases, but have been generally difficult to conduct, unreliable (i.e., few birds have been resighted), and/or expensive. The advent of satellite transmitters has the potential to provide valuable information on migratory movements, although current transmitter models are too heavy for all but the largest of shorebirds. A variety of molecular techniques have also been employed to estimate historic (and possibly contemporary) gene flow among populations (Table 3). Most of these studies, utilizing protein, mitochondrial DNA and minisatellite DNA markers, have found low levels of population subdivision within shorebirds. Haig et al. (1997), using random amplified polymorphic DNA (RAPD) markers, found that population subdivision varied greatly within breeding populations of nine migratory species sampled throughout North America. Their results provided strong evidence for phylogeographical structure, with population differentiation correlated with interspecific variation in philopatry and geographic separation of breeding populations. Recent molecular advances involve the use of the polymerase chain reaction and microsatellite markers, although no data have been published on North American shorebirds to date. A new avenue for identifying the geographic origins of migratory bird species (and hence the degree of mixing of breeding populations on migratory or wintering sites) involves the use of stable isotopes (Chamberlain, et al. 1997). Isotopes accumulated in the feathers of birds on their breeding groups have the potential of acting as markers, much as colored tarsal bands can identify the location a bird was captured. Undoubtedly, a combination of the above methods should be used to accurately identify the level at which species can be subdivided into definable management units.

Given the limiting finances available to conduct phylogeographic studies, it seems reasonable that future research be limited to species 1) that are threatened or endangered in particular portions of their breeding or wintering range, 2) whose members are distributed in geographically distinct locations and whose relatedness is unknown, and 3) who have morphologically similar congeners whose taxonomic status is questionable. Such efforts may prove valuable in defining subspecies or populations within species, and consequently determining whether segments of any one species should be managed separately and perhaps preferentially from other segments.

Table 3. Molecular techniques employed to estimate population structure in shorebirds.

Genetic Marker	Species Tested	Conclusions	References
Protein electrophoresis	*Calidris canutus, C. maritima, C. minutilla, C. fuscicollis, C. alpina, C. mauri, Catoptrophorus semipalmatus, Limnodromus griseus*	Most species had low levels of within-species genetic variation, and resembled large panmictic populations.	Baker and Strauch 1988
	Charadrius melodus	Little population differentiation.	Haig and Oring 1988
Random amplified polymorphic DNA (RAPD)	*Limnodromus scolopaceus, L. griseus, Limosa haemastica, Phalaropus lobatus, Charadrius semipalmatus, Calidris alpina, C. melanotos, C. pusilla, C. mauri*	Phylogeographic structured varied among species and correlated with variation in philopatry and geographical separation of breeding populations.	Haig et al. 1997
	Scolopax rusticola	Support migration patterns based on banding data.	Burlando et al. 1996
Mitochondrial DNA	*Arenaria interpres, Calidris alpina*	*A. interpres* populations are unstructured, whereas *C. alpina* show genetic structure.	Wenink et al. 1994
	Calidris alpina	Five major phylogeographic groups identified.	Wenink et al. 1996
Minisatellite DNA	*Actitis macularia*	Little differentiation between two populations in center of range.	Reed et al. 1996
Microsatellite DNA	*Haematopus ostralegus*	No population structure.	Treuren et al. Submitted
Stable Isotopes	No shorebirds to date.	No information available.	Chamberlain et al. 1997

E. Turnover rates and stopover ecology (Nils Warnock and Mary Anne Bishop)

Understanding the stopover ecology of shorebirds is a critical component of understanding the complete life cycle of these birds. Conservation of migratory stopover sites relies not only on knowing how and when different areas of their migration landscape are used, but also on knowing what influences the use of and time spent at different areas of that landscape (Warnock and Bishop 1998). Most monitoring efforts require some understanding of turnover rates of shorebirds at different sites, since without these data interpretive power of count data and accurate estimation of maximum population sizes using sites and regions are weakened (Warnock et al 1998). Recent work in the Great Plains of North America has emphasized the importance of understanding length of stay of shorebirds by demonstrating that although small, scattered wetlands may support small numbers of shorebirds at a single time, when combining use of small wetlands over a region and factoring in rapid turnover, large numbers of shorebirds are actually using the flyway (Skagen and Knopf 1994, Farmer and Parent 1997, Skagen 1997). Until recently length of stay of shorebirds has largely been estimated through resightings of marked birds, but advances in the miniaturization of radiotransmitters have resulted in more accurate estimates of length of stay at banding and stopover sites (Skagen and Knopf 1994, Iverson et al. 1996, Warnock and Bishop 1998). Calculations of length of stay of shorebirds other than *Calidris* sandpipers at migratory stopover sites are largely lacking and urgently needed.

Length of stay of some North American Sandpipers

Table 4 lists published length of stay information for some sandpipers.

Factors affecting length of stay (from Warnock and Bishop 1998). Numerous studies have examined the relationship between indexes of body condition of migrant shorebirds to length of stay at stopover sites (e.g. Skagen and Knopf 1994, Lyons and Haig 1995, Iverson et al. 1996). Warnock and Bishop (1998) found

Table 4. Published length of stays of some sandpipers in North America. Range of mean length of stay estimates given in days. LESA = Least Sandpiper, SESA = Semipalmated Sandpiper, WESA = Western Sandpiper, WRSA = White-rumped Sandpiper

Species	Length of Stay	Season	Area	Citation
LESA	5 - 20	Fall	North Carolina	Post and Browne 1976
LESA	5	Fall	British Columbia	Butler and Kaiser 1995
SESA	15 - 24	Fall	North Dakota and Bay of Fundy	Lank 1983
SESA	10 – 14	Fall	Maine	Dunn et al. 1988
SESA	2 – 4	Fall	Ontario	Page and Middleton 1972
SESA	15	Fall	Bay of Fundy	Hicklin 1987
SESA	3 – 13	Spring	Great Plains	Skagen and Knopf 1994
SESA	2 - 8	Spring	South Carolina	Lyons and Haig 1995
WESA	1 - 3	Fall	British Columbia	Butler et al. 1987
WESA	1 - 3*	Spring	Pacific Flyway	Warnock and Bishop 1998
WESA	1 - 4	Spring	Pacific Flyway	Iverson et al. 1996
WRSA	7 – 9	Spring	Great Plains	Skagen and Knopf 1994

*Does not include length of stay at site where bird was banded no relationship between length of stay and body condition of birds at their banding sites. However, they detected a small but significant trend for body condition at the banding site of male Western Sandpipers to be correlated with length of stay at the Copper River Delta. Adult, male Western Sandpipers tend to arrive slightly earlier at the breeding grounds than females, just as snow begins to melt (Holmes 1971). Earliest arrivals to sub-Arctic and Arctic breeding grounds encounter greater uncertainties in weather (Green et al. 1977) and food availability (Holmes 1972), forces that will select for birds in better body condition.

However, body condition of migrating shorebirds at time of capture generally explains little of the variation in the length of stay of birds at stopovers (Skagen and Knopf 1994, Lyons and Haig 1995, Iverson et al. 1996, Warnock and Bishop 1998), and other factors need be considered. Wind conditions could mask effects of body condition on length of stay at stopover sites (Holmgren et al. 1993), and may be an important influence on length of stay for some species of shorebirds (Butler et al. 1997). Skagen and Knopf (1994) failed to detect effects of wind on the departures of migrating Semipalmated Sandpipers (*C. pusilla*), but in one year they found White-rumped Sandpipers departing more often on northerly winds. Western Sandpipers appear to be unable to make the migration movement from San Francisco to Alaska given the time they do it in (Iverson et al. 1996) and their body conditions without assistance from wind (Butler et al. 1997).

Other factors likely influence length of stay of shorebirds at stopover sites. Two such factors are arrival date and sex. Semipalmated Sandpipers (Dunn et al. 1988, Lyons and Haig 1995), Little Stints (*C. minuta,* Keijl et al. 1992), and White-rumped Sandpipers (in one of two years, Skagen and Knopf 1994), have shorter length of stays as the migration progresses. Male Semipalmated Sandpipers have shorter length of stay in spring than females (Skagen and Knopf 1994, Lyons and Haig 1995). Warnock and Bishop (1998) failed to detect differences in length of stay of Western Sandpipers at banding sites based on date or sex. However, at one stopover site, the Copper River Delta, the last major stopover site before the breeding grounds, the later in date a male arrived, the shorter he stayed. No pattern was detected for females. In Spain, male Curlew Sandpipers had longer lengths of stay than females (Figuerola and Bertolero 1998).

Shorebirds migrating towards breeding grounds in the sub-Arctic and Arctic face time constraints, and males probably face tighter constraints than females the closer they get to the breeding grounds, as has been suggested for Western Sandpipers (Warnock and Bishop 1998). Early arrivals may fledge more young than late arrivals as is seen with female, polyandrous Spotted Sandpipers (*Actitis macularia,* Oring and Lank 1986). Females also face time constraints. Eggs laid too early in the season face freezing (Green et al. 1977), while for chicks hatching too late in the short breeding season there is an increased probability of food shortages (Holmes 1972) and, in some years, greater predation (Oring and Lank 1986, Jönsson 1991). However, energetic costs for females may be equally or more important than time considerations because egg production is energetically expensive (MacLean 1969, Blem 1990).

A potential influence on length of stay is prey depletion at stopover sites. At some sites, it has been shown that shorebirds impact invertebrate populations over the migration period (Schneider and Harrington 1981, Wilson 1989). Prey depletion at stopover sites by Western Sandpipers is not thought to affect length of stay (Warnock and Bishop 1998). Migration season (Fall vs. Spring) may influence the length of stay of some shorebirds, but this remains to be properly tested.

3) Identification of Population Limitations (Cheri Gratto-Trevor)

To effectively manage, enhance or maintain shorebird populations we need to understand their population dynamics: factors affecting their productivity and survival. Some similarities exist among species (e.g. most North American shorebirds lay clutches of 4 eggs on the ground), but many other aspects differ according to mating system, taxonomic group, species size, latitudinal distribution, coastal versus interior habitat, annual variation in climate and predator regimes, and so on (Pitelka et al. 1974, Evans and Pienkowski 1984, Whitfield 1985, Helmers and Gratto-Trevor 1996). We need to know whether populations of shorebirds in decline are most affected by changes in productivity or survival (and immigration/emigration), where the greatest effects occur, and why. Some of this information exists for some species in some areas, but much is lacking (e.g. Table 5).

A. Factors influencing productivity and breeding success

For many shorebird species, estimates of year to year variation in hatching rates exist (e.g. Table 5). Fewer studies provide information on fledging rates, or numbers hatched or fledged per adult female (including annual variation in mate acquisition and non breeding). Almost no shorebird studies have determined survival from hatch to age of first breeding. Average age of first breeding itself (including sex and annual differences) is unknown for many species. Rates of natal philopatry and dispersal are virtually unknown (Evans and Pienkowski 1984, Thompson et al. 1994). Due to this lack of information, it is difficult to produce useful models to examine the potential effects of changes in productivity, breeding biology, and survival on population trends. Reasons for year to year variation in productivity have been examined in some species, and some general conclusions can be drawn about the effects of disturbance, weather, changes in predator regimes, etc. in some habitats (e.g. Evans and Pienkowski 1984). The importance of microtine cycles (with shorebird eggs and chicks as alternative prey in low microtine years) has been demonstrated in some parts of the arctic (Summers and Underhill 1987, Sutherland 1988), but whether such factors are important in other regions such as the prairies is unknown. A few studies have discussed potential effects of climate change on shorebird populations (Lester and Myers 1991, Gratto-Trevor 1997), but more information is necessary.

Table 5. Population demography information for selected shorebird species: those with Birds of North America accounts. Average nest success=% nests with > 1 hatched/total nests, range from different studies, in parentheses=%eggs hatched/total eggs. Average fledging success=fledged chicks/chicks hatched, range from different studies. Annual adult survival estimate from computer program. This is not intended to include all studies where multiple datasets exist on the same factor.

Species	Average	Ave. nest	Ave. fledging	Ave.	Survival to	Annual adult	Annual adult	Reference
	mass (g)	success	success	1st breeding	1st summer	return rate	survival est.	
LESA	23	57-90+%	40%	1		52%		Miller 1983, Cooper 1994
SESA	28	50%	50%	2-3		47%	59%	Gratto-Trevor 1992, Sandercock and Gratto-Trevor 1997
SNPL	41	53%	40%	1		75%	58-88%	Page et al. 1995
SPSA	46	(51%)	83%	1?		63%?		Oring et al. 1997
SOSA	48							Moskoff 1995
WRSA	50							Parmelee 1992
PIPL	54	34%	~82%	1		66%	66%	Haig 1992, Haig and Oring 1988
DUNL	58	30%	36%	2	33%	72%	74%	Warnock and Gill 1996, Warnock et al. 1999
STSA	58	53-92%	<50%			73%		Klima and Jehl 1998
WIPH	60	33%		1		19%		Colwell and Jehl 1994
BBSA	63	40%	28%			12%		Lanctot and Laredo 1994
PESA	81	62-71%				6%		Holmes and Pitelka 1998
MOPL	95	26-65%	25-35%?					Knopf 1996
AMWO	135	58%	90%?	1	59%	40%	60%	Keppie and Whiting 1994
AMGP	152	50-70%		1		76%		Johnson and Connors 1996
GRYE	153							Elphick and Tibbitts 1998
SURF	202							Senner and McCaffery 1997
BBPL	220	58-65%		2?	63%	89%		Paulson 1995
AMAV	312	40%	38%	2	58% (to 2S)	83-86%		Robinson et al. 1997
ESCU	375							Gill et al. 1998
WHIM	404	48%	32%	3				Skeel and Mallory 1996
BLOY	555	54-62%	32-82%	5		90%		Andres and Falxa 1995
AMOY	602	72%	34-80%	3-4		85%		Nol and Humphrey 1994

B. Factors influencing juvenile and adult mortality

We have some estimates of survival rates, mostly for adults, primarily based on return rates that confound philopatry and survival (e.g. Table 5). A computer model of population trends in Semipalmated Sandpipers was very sensitive to even slight changes in adult survival (and emigration/immigration) compared to large changes in productivity (Hitchcock and Gratto-Trevor 1997). If this is true for one of the smallest shorebirds it seems likely to be so for most other shorebird species, especially those with considerable year to year variability in productivity and/or delayed age of first breeding. If even slight changes in adult survival (and immigration/emigration) rates have such a large effect on population trend, we need better estimates of adult survival (e.g. using modern computer programs such as Surge or Mark - although even those cannot correct for birds that permanently emigrate, e.g Warnock et al. 1999) and movements among breeding populations for most shorebird species (Haig ?). We need to know where mortality is occurring in the life cycle, in what locations and why - whether declines have occurred due to anthropogenic changes in habitat (e.g. power lines, predator regimes, disturbance, etc.). Particularly for endangered species, population trends should be modeled, to determine if increases in productivity possible through management can conceivably offset even slight declines in adult survival. It is possible that management efforts would be better directed towards improving adult survival than improving productivity.

4) Habitat Use, Quality, & Dynamics (Brian Harrington)

A. Habitat Distribution and Abundance

There are approximately 70 species of shorebirds found in North America, roughly 50 of which occur regularly. Each species has its own food and habitat requirements, and for most species, the requirements are different between breeding, migration, and wintering seasons. In some situations (varying with species, season and geographic season) species may be quite labile in selection of food and/or habitat, whereas in other cases they may be highly specialized. Outlining habitat research requirements for shorebirds is an awesome challenge, demanding that a process be identified that can be applied across species to find out priority information needs. Habitat research priorities for the USSCP aim to identify food and habitat information needs with respect to their influences on population stability and conservation planning.

1. Means of identifying and assessing the quality of shorebird habitat

a) <u>Breeding Habitat</u>

A systematic research program is needed to identify amounts and availability of breeding habitat of North American shorebirds with a view to understanding whether amounts of habitat are limiting population size. In the US SCP, priority is given to research for developing mapping by using satellite or other aerial imagery. For each selected species breeding habitat preferences needs to be identified and characterized for signatures detectable with remote imagery. Amounts of habitat within the breeding range of the species can then be evaluated. Ground-based sub-sampling with a goal of quantifying breeding densities, habitat amounts and locations can document effectiveness of the methods. Priority should be given to species that use habitats thought to be highly limited and/or in decline, for example Alaskan breeding habitat of Bristle-thighed Curlews, short-grass prairie, alkalai basins, prairie pothole, or coastal beaches.

Conditions of breeding habitat also can change from year-to-year, depending for example, on rainfall amounts or (in Alaska and Arctic Canada) spring snow conditions (Nol *et al.,* 1997). Some shorebirds species, for example Pectoral Sandpiper, will shift breeding locations as habitat (and other ?) conditions vary (Parmelee *et al.*, 1968), whereas other species do not (Lappo, 1996). Relationships between annual habitat conditions and annual breeding productivity of shorebird species are poorly known. Annual shorebird breeding habitat conditions (e.g. temperature and snow cover in Alaska, temperature and rainfall in the Lower 48 states) should be monitored to establish how habitat conditions relate to annual breeding production.

b) <u>Non-breeding Habitat</u>

Most shorebirds that breed in the U.S. migrate to wintering areas in the Caribbean, Central and South America, in Oceania, or in the southern United States. In many cases the nonbreeding period is almost a continuum of movement, with southward migration requiring 1-4 months, a 2-4 month wintering period, and a 1-3 month northward migration period (Morrison, 1984). Many kinds of shorebirds depend upon migration stopover habitats in the United States, yet relatively small portions of their populations may breed or spend winter in the U.S.

Migration seasons. Although there is little documenting research, it is generally held that shorebirds are more limited by availability of suitable habitat during migration than by availability of particular prey types. For example, based on assessments of Skagen & Oman (1996), it is clear that many kinds of shorebirds are quite variable in prey selection during migration, taking advantage of foraging opportunities as they develop at the right time and place. Frequently good migration foraging opportunities are associated with changed habitat conditions, for example lowering water levels in nonmarine wetlands that make mud-dwelling invertebrate animals accessible to shorebirds (Safran *et al.*, 1997). Other situations are more predictable, for example a seasonal bloom of marine invertebrate animals at tidal coastal locations (Schneider & Harrington, 1981).

The way in which shorebirds use migration stopover areas may also vary. In some situations individuals may visit a stopover site only briefly before quickly moving to another location ('short-hop' migrants , e.g. American Avocets (Robinson & Oring, 1996). Other species visit stopover sites for many days in order to lay on fat, muscle and other body tissues needed for long-distance flights that may span hundreds or thousands of miles without stops ('long-hop' migrants, e.g. White-rumped Sandpipers (Harrington et. al., 1991).

A variety of studies show that food resources at migration staging areas can be depleted by shorebirds (e.g. Schneider & Harrington, 1981); other studies have not found prey depletion (Duffy *et al.* 1981). Those situations where food depletion has been documented indicate that migration habitat may be limiting to shorebird numbers. Moreover, circumstantial information suggests that shorebirds unable to gain sufficient fat at staging sites have higher mortality rates than those that do (Pfister et al 1998). Notwithstanding this logic, it also is possible that large fractions of a species population may use a single staging site simply because it is a location with rich food resources accessible at a strategic time. This does not preclude the possibility that there is extensive alternative habitat available. In other situations there is little pre-migration fattening as daily turnover rates of birds are high (i.e. visitation periods by individual birds are too short to enable pre-migration fattening, Butler *et al.,* 1987).

Research is needed on relationships between shorebirds' use of migration staging sites, prey depletion, and population biology to identify whether populations are affected by loss of migration stopover habitat. This requires information on the migration strategies that different species employ (migration duration, numbers of stopovers used) and understandings of whether conditions at migration stopover areas have important effects on populations. A good starting point will be to compare dispersion patterns between shorebird species, identifying those whose populations are most concentrated at small numbers of migration and/or wintering areas. This should be followed with studies of resource use and prey depletion patterns of the most highly concentrated species to explore whether they are habitat-limited (studies also can simultaneously examine other factors such as disease and predation).

Some shorebirds may employ more than one kind of migration strategy, depending upon stage of migration and/or prevailing habitat conditions (e.g. White-rumped Sandpiper, Harrington et al. 1991). Little is known of whether/how shorebirds may change strategies. The question is particularly important with respect to species migrating through regions where habitat and food resources are unpredictable (Skagen & Knopf, 1994). For example, pothole prairie or playa lake habitat conditions can vary enormously depending upon rainfall cycles; during some years water levels are high in practically all wetlands, whereas only relatively small numbers of wetlands are available during dry periods. There is little information to suggest whether such variable landscape conditions affect shorebird populations, both with respect to breeding species or species in migration. Costs of doing this research are estimated at $2.5 million per year over a two decade period.

Winter seasons. There also is very little known of how winter habitat conditions affect shorebird populations. Baker and Baker (1972), in their classic studies, propose that shorebird populations may be more limited by wintering habitat conditions than by breeding habitat conditions.

Most of the shorebird species breeding in North America winter principally south of the United States. Species that winter principally in North America –and mostly in the U.S.-- include Piping Plover, Snowy Plover, Mountain Plover, Killdeer, Black and American Oystercatcher, Black Turnstone, Purple and Rock Sandpipers, Dunlin, and Common Snipe. A number of additional species have portions of their populations wintering in the U.S., with most individuals wintering south of the U.S.

Habitat research needed for predominately U.S.-wintering species. Little is known of what makes good winter habitat for most of the species listed above, possibly excepting ongoing research with Piping and Mountain plovers. The balance of the listed species are all wintering in coastal habitats, some (e.g. American Oystercatcher and Rock and Purple Sandpiper) in relatively restricted zones where loss of key habitat could potentially reduce population size by a serious degree. Research needed should focus on developing a basic understanding of the feeding and roosting habitat requirements.

U.S.-breeding shorebirds that winter predominately outside of the United States include Wilson's and Snowy Plover , Black-necked Stilt, American Avocet, Willet, Spotted Sandpiper, Upland Sandpiper, Long-billed Curlew, Marbled Godwit, Surfbird**, Western Sandpiper*, Long-billed Dowitcher*, and Wilson's Phalarope. Several of these species concentrate in relatively small wintering regions, and appear vulnerable to loss of strategic wintering habitat. Research is needed in western Mexico –especially in Sinaloa, Nayarit and

Baja California del Sur-- on habitat requirements of Black-necked Stilt, American Avocets, Willets, Long-billed Curlews, Marbled Godwits, dowitchers and Western Sandpipers (Morrison *et al.* 1993). Upland Sandpipers winter principally in Argentina, but evidently are quite dispersed (Hayes *et al.*, 1990). [Large numbers of Willets also winter in on the Atlantic coast of South America between Guyana and eastern Brazil; it is unclear whether these are mostly Eastern and/or Western Willets, but it is most likely that they are the Eastern race. Little is known of their winter ecology.] Wilson's Phalarope winter principally in Chile and Argentina, and evidently are concentrated in a relatively small number of lakes and wetlands (Laredo, 1996). Research is needed to clarify their wintering dispersion and habitat requirements for all of the above species and groups.

2. Means of cooperation with other initiatives to track the distribution of wetland and waterbird habitats

Tracking the availability of wetland habitats is a monumental task that will require cooperation among many diverse organizations, including all of the bird conservation initiatives, federal land management agencies, and the National Wetlands Inventory.

Remote sensing of habitat. A research project should be undertaken to determine utility of developing and implementing a large-scale program (such as the use of satellite imagery -- see Morrison 1997) for determining or assessing distribution and abundance, and for in addition to quantifying suitable habitat. Ideally, these methods could allow for coarse-scale monitoring as well.

B. Migration Stopover Sites

1. Identification of characteristics of migratory stopover sites that correlate with high use by shorebirds

Ideally the above review of habitat research needs would have been focused on key habitats, and not on species. However, because so little work has been completed on habitat requirements for most kinds of shorebirds, it is premature to pick 'focal habitats' for special attention. An exception exists with questions about migration stopover area habitat, where enough research has been completed to begin asking the right questions. Some of the key issues about migration stopover habitats were introduced in the earlier sections, so here we introduce additional habitat questions that should be answered in future research.

What makes a good migration stopover area? We know that many kinds of shorebirds concentrate to an extraordinary degree at traditionally used migration staging sites. We still do not know whether there are certain attributes of these sites that make them a singular or strategic resource, which if lost, would have serious impacts to shorebird populations. A controversial example is the Delaware Bay staging area used in spring by substantial fractions of continental Ruddy Turnstone, Red Knot, Semipalmated Sandpiper, and Sanderling populations. No information has been collected to explore whether alternative staging sites exist for these species should Delaware Bay conditions change (as is beginning to appear very likely).

Another example exists with Semipalmated Sandpipers during southward migration. Studies in the 1970's and the 1980's (Morrison & Harrington, 1979) found high numbers for locations in New England. Today relatively few use these same areas, evidently having shifted to using invertebrate-rich shorelines near the head of the Bay of Fundy. Did the New England locations become less useful due to invertebrate population change, and/or did the Bay of Fundy sites somehow become more attractive?

2. Specific environmental risks associated with changes in habitat characteristics

Individual sites versus wetland complexes. Much of the conservation planning for shorebirds has focused on individual wetlands that play key roles as shorebird staging or wintering locations. In some key instances, however, shorebirds are not focusing on a single site as a staging area, but rather are using a complex of sites, shifting between them as conditions change within or between years. A good example is the prairie pothole region, where annual rainfall conditions make a big difference in what wetlands will provide suitable shorebird habitats. Research is needed to better understand how shorebirds use habitats such as potholes under different conditions.

Physical characteristics. The characteristics of migration stopover areas also affect habitat availability and habitat use in ways that are not well understood. For example, the penetrability of substrates evidently has an important effect on shorebird foraging, but is poorly understood. Other important physical factors include shoreline development and the physiognomic shape of a bay or estuary and effects on amounts and quality of intertidal habitat, on sediment grain size, and on food chain relationships. Physical characteristics also will affect lengths of time that habitats are available to foraging shorebirds. Research is needed to better understand how intertidal acreage, shoreline development, degree of tidal flux, and other physical characteristics of bays and estuaries affect shorebird habitat needs during migration as well as winter seasons.

In nonmarine wetlands there are whole complexes of research issues revolving around shorebird habitat requirements and management activities that should be researched. Little is known of optimal strategies possible with different management scenarios, or of risks that may exist with respect to disease, obnoxious vegetation growth, or trade-offs with benefits to other biota. These issues are further discussed elsewhere.

There also is growing evidence, but little research, to suggest that the presence and relative location of suitable resting areas may be an important habitat attribute of shorebird stopover sites. Research is needed to better understand this.

Vegetative surroundings (for example forest) of otherwise suitable wetlands, bays and estuaries affect their suitability to shorebirds, evidently because shorebirds avoid conditions where stealth approaches by raptors are easily accomplished (Cresswell & Whitfield, 1994). Research is needed to understand details of these habitat relationships.

Finally, it seems inherently obvious that the density of available food will affect habitat suitability for shorebirds at migration stopovers, but there has been little research to understand where thresholds lie.

5) Management Research

Management for species rated as conservation priorities should be a national priority where the research involves carefully controlled experiments and has broad applicability, i.e. it is not primarily of value at single sites unless that site is of overwhelming importance to a large number of individuals or high priority species.

A. Assessment of population limiting factors

This heading includes research to determine the relative effects of population limiting factors, e.g. studying predator behavior, contaminant ecology, or invertebrate ecology, which may contribute more to removing limitations to shorebirds than studying shorebird species. This area of research is very broad, so no detailed examples are provided. However, the working group determined that research to assess and manage population limiting factors should be among the highest priorities for shorebird research.

B. Research to design techniques for reducing specific population limiting factors

Research designed to reduce population limiting factors (not simply use factors), e.g. reduction of predation, reduction of contaminant exposure, increase in prey availability.

1. Management techniques to protect nesting shorebirds (Todd Mabee)

Nest predation is a pervasive problem for breeding shorebirds throughout North America. The loss or alteration of breeding habitat due to urbanization and agricultural development has been compounded by the influx of predator communities associated with these altered landscapes. The changes in the composition or abundance of predators in these communities may be responsible for decreased recruitment of many shorebird populations (Helmers and Gratto-Trevor 1996). For example, high predation rates in coastal habitats have been attributed to increased predator populations due to alternate food sources (e.g. landfills) near human population centers (Howe 1982, Haig 1992).

Several methods have been used to reduce nest predation, primarily by excluding predators from nests or nesting areas rather than removing predators (i.e. predator control). One common technique used to reduce nest predation is to place predator exclosures consisting of wire mesh around nests. Predator exclosures of various sizes and shapes have been used to protect threatened or endangered species such as Piping Plover (*Charadrius melodus*) nests on the Atlantic Coast, Great Lakes, and in the Midwest U.S. (Rimmer and Deblinger 1990, Powell and Cuthbert 1992, Melvin et al. 1992, Mabee 1996, C. Kruse, unpubl. data.) and Snowy Plover (*C. alexandrinus*) nests in California and Oregon (Page et al. 1995, M. Stern, unpubl. data), Colorado (Mabee 1996) and in Europe (Tucker and Heath 1994). At these locations, predator exclosures were designed to protect nests from the primary nest predators including red foxes (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), gulls (*Larus* spp.), and crows (*Corvus* spp.). Predator exclosures have also been used to protect nests of common species such as Killdeer (*C. vociferus*) (Nol and Brooks 1982) and Pectoral Sandpipers (*Calidris melanotos*) (Estelle et al. 1996) for research purposes. Lastly, electric fences have been used to reduce mammalian predation on Piping Plover nests and chicks (Mayer and Ryan 1991).

Although most studies suggest that barrier techniques (i.e. predator exclosures, electric fencing) increase nest success (Table 6, Deblinger et al. 1992; but see Nol and Brooks 1982, Mabee 1996), they are generally not designed to quantify the degree of effectiveness. Future research on barrier techniques is necessary, and could be strengthened by 1) identifying which predators are causing nest failure at each breeding location (to ensure an appropriate barrier design) and 2) using an appropriate experimental design to quantify the difference in nesting success between protected and unprotected nests or nesting areas. Then managers can decide if barrier techniques increase nest success sufficiently to warrant the expenditure of limited time and resources, or if alternative options (e.g. eliminating cattle or human disturbances from nesting areas) may yield better results.

TABLE 6. Observed nest success (%, n) and barrier efficacy of Piping Plover, Snowy Plover, Killdeer, and Pectoral Sandpiper nests protected (P) and unprotected (U) by individual predator exclosures or electric fencing.

		Nest success			
Species	Barrier	(P)	(U)	Barrier efficacy	Author
Piping Plover					
	exclosure	92 (26)	25 (24)	effective against medium-sized mammals & birds	Rimmer & Deblinger 1990
	exclosure	90 (29)	17 (24)	effective against medium-sized mammals & birds	Melvin et al. 1992
	exclosure	60 (5)	75 (4)	ineffective against rodents & snakes	Mabee 1996
	fence	---	---	effective against some mammalian predators	Mayer & Ryan 1991
Snowy Plover					
	exclosure	69 (13)	57 (14)	ineffective against rodents & snakes	Mabee 1996
	exclosure	57 (14)	54 (13)	ineffective against rodents & snakes	Mabee 1996
Killdeer					
	exclosure	33 (12)	29 (17)	effective for gulls, not mammals	Nol & Brooks 1982
	exclosure	14 (7)	33 (9)	ineffective against rodents & snakes	Mabee 1996
Pectoral Sandpiper					
	exclosure	77 (13)	3 (39)	effective against arctic foxes	Estelle et al. 1996

2. Evaluating created wetland habitats for migrating shorebirds (David Mizrahi)

The quantity and quality of natural intertidal and freshwater habitats are declining (Tiner 1984, Dahl 1990) and consequently, shorebird species dependent on these habitats are in jeopardy (Senner and Howe 1984). Significant population declines have been reported in Piping Plovers (Haig and Plissner 1993), Sanderlings (Howe et al. 1989, Clarke et al. 1993), Semipalmated Sandpipers (Clark et al 1993, Morrison et al. 1994), Least Sandpipers (Morrison et al. 1994), Short-billed Dowitchers (Howe et al. 1989, Morrison et al. 1994), and Whimbrel (Howe et al. 1989). Shorebird populations are at particular risk from habitat declines along traditional migration routes, when thousands of individuals of several species can congregate at relatively few suitable sites. Staging areas such as Copper River Delta in southeastern Alaska, Grays Harbor in Washington, Delaware Bay along the Atlantic coast, Mono Lake in eastern California, and Cheyenne Bottoms in central Kansas, are unique because of their capacity to support hundreds of thousands of shorebirds during migration (Senner and Howe 1984, Harrington and Perry 1995). Alternative sites of comparable quality may be scarce (Myers et al. 1987).

A variety of human-made or modified wetlands may provide supplemental habitats for migrating and wintering shorebirds, and ameliorate the loss of natural wetlands (Davidson and Evans 1986). Wetlands constructed for mosquito control (Erwin et al. 1994, Brush et al. 1986), managed as waterfowl habitat (Weber and Haig 1996, Boettcher et al. 1995), or created by alterations in agricultural (Colwell 1998, Elphick and Oring 1998, Twedt et al. 1998,) and industrial practices (Warnock and Takekawa 1995, Velasquez 1992, Duffield 1986), can support large numbers of shorebirds at various times during the annual cycle. Several studies report that under certain conditions, shorebird use of human-made habitats can be significantly greater than use of adjacent natural wetlands (e.g., Elphick and Oring 1998, Weber and Haig 1996, Warnock and Takekawa 1995, Burger et al. 1982). However, Brush et al. (1986) suggest that shorebird use of wetlands created for open marsh water management (OMWM) in Massachusetts was not significantly different than natural pool habitats.

Although it is clear from these studies that shorebird use of human-made or modified wetlands is widespread, patterns of use are species-specific, and dependent on factors, such as water depth, (Elphick and Oring 1998, Weber and Haig 1996), salinity (Velasquez 1992), and tides (Warnock and Takekawa 1995). The effects of these factors on the use of altered wetlands by shorebirds seem to be related to access and availability of food resources. However, we know little about the types of food shorebirds eat in modified wetlands (but see Weber and Haig 1997, Rehfisch 1994, Velasquez 1992). Additionally, few data have been published that address the relative abundance and quality of food resources in modified wetlands compared with adjacent natural ones (but see Weber and Haig 1996), or how different factors (e.g., water level regimes, salinity) affect prey abundance. Large numbers of birds might be attracted to areas with suboptimal food resources because optimal habitats are unavailable or monopolized by competitively superior individuals (e.g., adults versus juveniles). In this way, modified wetlands may act as habitat sinks.

Do alternative wetland habitats provide the quantity and quality of food necessary for shorebirds to successfully complete their annual cycle? To answer this question we must (1) determine the array and abundance of food resources available in different types of altered wetlands, (2) compare these food resources with resources available in natural wetlands, (3) understand how factors such as water level and salinity affect food abundance and distribution, (4) understand the link between diet composition and energetic condition, especially during migration, and (5) determine if there is differential use of man-made or modified wetlands by different age groups or sexes. This information is essential to determining the future role of managed and modified wetlands as alternative habitat for shorebirds.

Table 1. Studies that the document relative use of natural and various human-made wetlands by shorebirds, or results of experiments that test the effects of habitat manipulation on invertebrate biomass and shorebird use.

Author(s)	Type of man-made Wetland	Results
Burger et al. (1982)	Impoundments, mosquito control ditches	Impoundments and ditches supported higher numbers of shorebirds than adjacent natural marshes. However, species typically breeding in salt marshes (Clapper Rail, Sharp-tailed Sparrow) were more common in natural marshes.
Brush et al. (1986)	Open Marsh Water Management (OMWM)	Although shorebirds numbers increased initially after construction of ponds (spoil deposition), they eventually decreased to prealteration levels.
Davidson and Evans (1986)	Unspecified	Shorebirds used peripheral human-modified wetlands to extend feeding time beyond time available in natural wetlands, and for protection from winds. Site choice and use (e.g., foraging, roosting) was species-specific and varied seasonally.
Duffield (1986)	Urban stormwater treatment wetland complex	Shorebirds preferred stormwater control marsh over natural marshes in wetland complex. Percentage of open water, emergent vegetation and water depth accounted for differences in marsh use.
Velasquez (1992)	Commercial saltpans	Quality of artificial wetlands dependent on benthic macrofauna abundance and availability. Availability determined by salinity and water level, respectively. Shorebirds numbers increased as water levels were lowered. Variation attributed to changes in prey composition. Species-specific differences in site use also related to the effect of salinity on prey composition.
Erwin et al. (1994)	Open Marsh Water Management (OMWM)	Shorebirds preferred natural tidal ponds in summer but OMWM ponds in autumn. Change in use patterns not attributable to changes in species composition. Preference of OMWM ponds greatest at low and high tides compared with mid-tides and dependent on pond size (large > small).
Rehfisch (1994)	Impoundments constructed for waterbird use	Invertebrate prey biomass dominated by Chironomidae. Major determinants of chironomid biomass were water depth,

		organic content of sediments, and prey biomass. Shorebirds consumed only a small portion of prey biomass because water depth made prey inaccessible.
Warnock and Takekawa (1995)	Artificial salt pond complex	Habitat preferences in radio-tagged Western Sandpipers were complex and dependent on spatial scale, season, and tidal cycle.
Weber and Haig (1996)	Waterfowl impoundments	Overwintering shorebird frequencies higher in tidal wetlands than in impoundments. During migration this relationship was reversed. Invertebrate density during the migration period was greater in impoundments than in natural tidal wetlands.
Elphick and Oring (1998)	Flooded rice fields	Flooded rice fields had significantly higher shorebird densities than unflooded fields. Different straw manipulations used to improve stubble decomposition had little affect on densities. Water depth was an important predictor of species occurrence.

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