STATUS OF THE SPECIES – red knot (*Calidris canutus rufa*)

Legal Status - *threatened*

The U.S. Fish and Wildlife Service (Service) listed the *rufa* subspecies of red knot (*Calidris canutus rufa*) as threatened under the Endangered Species Act of 1973, as amended (Act) (87 Stat. 884; 16 U.S.C. 1531 *et seq.*) in the Federal Register on December 11, 2014 (Service 2014a). The reason for listing was due to loss of both breeding and nonbreeding habitat; likely effects related to disruption of natural predator cycles on the breeding grounds; reduced prey availability throughout the nonbreeding range; and increasing frequency and severity of asynchronies (mismatches) in the timing of the birds' annual migratory cycle relative to favorable food and weather conditions. Critical habitat has not been proposed or designated for the red knot at this time.

Species Description

Appearance/Morphology

The red knot is a medium-sized shorebird about 9 to 11 inches (in) (23 to 28 centimeters [cm]) in length. The red knot is easily recognized during the breeding season by its distinctive rufous (red) plumage (feathers). The face, prominent stripe above the eye, breast, and upper belly are a rich rufous-red to a brick or salmon red, sometimes with a few scattered light feathers mixed in. The feathers of the lower belly and under the tail are whitish with dark flecks. Upperparts are dark brown with white and rufous feather edges; outer primary feathers are dark brown to black (Davis 1983; Harrington 2001). Females are similar in color to males, though the rufous colors are typically less intense, with more buff or light gray on the dorsal (back) parts (Niles *et al.* 2008). Red knots have a proportionately small head, small eyes, short neck, and a black bill that tapers from a stout base to a relatively fine tip. The bill length is not much longer than head length. Legs are short and typically dark gray to black, but sometimes greenish in juveniles or older birds in nonbreeding plumage (Harrington 2001). Nonbreeding plumage is dusky gray above and whitish below. Juveniles resemble nonbreeding adults, but the feathers of the scapulars (shoulders) and wing coverts (small feathers covering base of larger feathers) are edged with white and have narrow, dark bands, giving the upperparts a scalloped appearance (Davis 1983).

Taxonomy

There are six recognized subspecies of red knots (*C. canutus*), and the Service accepts the characterization of *C.c. rufa* as a subspecies because each recognized subspecies is believed to occupy separate breeding areas, in addition to having distinctive morphological traits (*i.e.*, body size and plumage characteristics), migration routes, and annual cycles.

Life History

Breeding birds

Based on estimated survival rates for a stable population, few red knots live for more than about 7 years (Niles *et al.* 2008). Age of first breeding is uncertain, but for most birds it is probably at least 2 years (Harrington 2001). Red knots generally nest in the Canadian Arctic in dry, slightly elevated tundra locations, often on windswept slopes with little vegetation. Breeding territories are located inland, but near Arctic coasts, and foraging areas are located near nest sites in freshwater wetlands (Harrington 2001; Niles *et al.* 2008). Breeding occurs in June (Niles *et al.* 2008), and flocks of red knots sometimes arrive at breeding latitudes before snow-free habitat is available. Upon arrival or as soon as favorable conditions exist, male and female red knots occupy breeding habitat, and territorial displays begin (Harrington 2001). In red knots, pair bonds form soon after arrival on the breeding grounds and remain intact until shortly after the eggs hatch (Niles *et al.* 2008). Female red knots lay only one clutch (group of eggs) per season, and, as far as is known, do not lay a replacement clutch if the first is lost (Service 2014b). The usual clutch size is four eggs, though three-egg clutches have been recorded (Service 2014b. The incubation period lasts approximately 22 days from the last egg laid to the last egg hatched, and both sexes participate equally in egg incubation. Young are precocial, leaving the nest within 24 hours of hatching and forage for themselves (Niles *et al.* 2008; Service 2014b). No information is available regarding chick survival rates (Niles *et al.* 2008). Females are thought to leave the breeding grounds and start moving south soon after the chicks hatch in mid-July. Thereafter, parental care is provided solely by the males, but after about 25 days (around August 10) they also abandon the newly fledged juveniles and move south (Service 2014b). Not long after, they are followed by the juveniles (Niles *et al.* 2008).

Breeding success of High Arctic shorebirds such as red knots varies dramatically among years in a somewhat cyclical manner. Two main factors seem to be responsible for this annual variation: weather that affects nesting conditions and food availability, and predation rates which fluctuate annually. Production of shorebird young is sensitive to adverse weather during the breeding season. Red knot chicks grow poorly during cold weather due to higher rates of energy expenditure, shorter foraging periods, and reduced prey availability (Schekkerman *et al.* 2003; Piersma and Lindström 2004). Growth rate of red knot chicks is very high compared to similarly sized shorebirds nesting in more temperate climates and is strongly correlated with weather-induced and seasonal variation in availability of invertebrate prey (Schekkerman *et al.* 2003). Second, successful shorebird reproduction occurs almost exclusively during peak lemming (*Dicrostonyx torquatus* and *Lemmus sibericus*) years when snowmelt is early (Summers and Underhill 1987; Blomqvist *et al.* 2002; Piersma and Lindström 2004; Service 2014b). Arctic fox (*Alopex lagopus*) and snowy owl (*Nyctea scandiaca*) feed largely on lemmings, which are easily caught when their abundance is high. However, in years when lemming numbers are low, the predators turn to alternative prey, such as shorebird eggs, chicks, and adults. Lemming

abundance is often cyclical, and the variation in shorebird production closely follows variations in lemming abundance due to their affected predation rates.

Nonbreeding birds

Little information is available about nonbreeding red knots. Unknown numbers of nonbreeding red knots remain south of the breeding grounds during the breeding season, and many, but not all, of these red knots are 1-year-old (*i.e.,* immature) birds (Niles *et al.* 2008). Nonbreeding red knots, usually individuals or small groups, have been reported during June along the U.S. Atlantic and Gulf coasts, with smaller numbers around the Great Lakes and Northern Plains in both the U.S. and Canada (eBird.org 2012). There is also little information on where juvenile red knots spend their winter months (Service and Conserve Wildlife Foundation of New Jersey 2012), and there may be at least partial segregation of juvenile and adult red knots on the wintering grounds. All juveniles of the Tierra del Fuego wintering region are thought to remain in the Southern Hemisphere during their first year of life, possibly moving to northern South America, but their distribution is largely unknown (Niles *et al.* 2008). Because there is a lack of specific information on juvenile red knots, the Service uses the best available data from adult red knots to draw conclusions about juvenile foraging and habitat use.

Migration

The red knot migrates annually between its breeding grounds in the Canadian Arctic and several wintering regions, including the Southeast U.S., the Northeast Gulf of Mexico, northern Brazil, and Tierra del Fuego at the southern tip of South America. Departure from the breeding grounds begins in mid-July and continues through August. Red knots tend to migrate in single-species flocks with departures typically occurring in the few hours before twilight on sunny days. Based on the duration and distance of migratory flight segments estimated from geolocator results, red knots are inferred to migrate during both day and night (Normandeau Associates, Inc. 2011). The size of departing flocks tends to be large (greater than 50 birds) (Niles *et al.* 2008), and females are thought to leave first followed by males and then juveniles (Harrington 2001; Niles *et al.* 2008).

Red knots make one of the longest distance migrations known in the animal kingdom, traveling up to 19,000 miles (mi) annually, and may undertake long flights that span thousands of miles without stopping. As red knots prepare to depart on long migratory flights, they undergo several physiological changes. Before takeoff, the birds accumulate and store large amounts of fat to fuel migration and undergo substantial changes in metabolic rates. In addition, leg muscles, gizzard (a muscular organ used for grinding food), stomach, intestines, and liver all decrease in size, while pectoral (chest) muscles and heart increase in size. Due to these physiological changes, red knots arriving from lengthy migrations are not able to feed maximally until their digestive systems regenerate, a process that may take several days. Because stopovers are time-constrained, red knots require stopovers rich in easily digested food to achieve adequate weight gain (Piersma *et al.* 1999; van Gils *et al.* 2005a, 2005b; Niles *et al.* 2008; Service 2014b) to fuel

the next leg of their migratory flight and, upon arrival in the Arctic, to fuel the body transformation to breeding condition (Morrison 2006; Service 2014b). At each stopover, the adults gradually replace their red breeding plumage with white and gray, but generally they do not molt their flight or tail feathers until they reach their wintering areas (Morrison and Harrington 1992; Niles *et al.* 2008).

During both the northbound (spring) and southbound (fall) migrations, red knots use key staging and stopover areas to rest and feed. Major spring stopover areas along the Atlantic coast include Río Gallegos, Península Valdés, and San Antonio Oeste (Patagonia, Argentina); Lagoa do Peixe (eastern Brazil, State of Rio Grande do Sul); Maranhão (northern Brazil); the Virginia barrier islands (U.S.); and Delaware Bay (Delaware and New Jersey, U.S.) (González 2005; Niles *et al.* 2008; Cohen *et al.* 2009; Service 2014b). Important fall stopover sites include southwest Hudson Bay (including the Nelson River delta), James Bay, the north shore of the St. Lawrence River, the Mingan Archipelago, and the Bay of Fundy in Canada; the coasts of Massachusetts and New Jersey and the mouth of the Altamaha River in Georgia, U.S.; the Caribbean (especially Puerto Rico and the Lesser Antilles); and the northern coast of South America from Brazil to Guyana (Spaans 1978; Morrison and Harrington 1992; Antas and Nascimento 1996; Niles *et al.* 2008; Schneider and Winn 2010; Niles *et al.* 2010; Niles 2012a; Newstead 2013). However, large and small groups of red knots, sometimes numbering in the thousands, may occur in suitable habitats all along the Atlantic and Gulf coasts from Argentina to Canada during migration (Niles *et al.* 2008).

Red knots are restricted to the ocean coasts during winter, and occur primarily along the coasts during migration. However, small numbers of red knots are reported annually during spring and fall migration across the interior U.S. (*i.e.*, greater than 25 mi from the Gulf or Atlantic Coasts). Such reported sightings are concentrated along the Great Lakes, but multiple reports have been made from nearly every interior State (eBird.org 2012). For example, Texas red knots follow an inland flyway to and from the breeding grounds, using spring and fall stopovers along western Hudson Bay in Canada and in the northern Great Plains (Skagen *et al.* 1999; Newstead 2013). Some red knots wintering in the southeastern U.S. and the Caribbean migrate north along the U.S. Atlantic coast before flying over land to central Canada from the mid-Atlantic, while others migrate over land directly to the Arctic from the southeastern U.S. coast (Niles *et al.* 2012b). These eastern red knots typically make a short stop at James Bay in Canada, but may also stop briefly along the Great Lakes, perhaps in response to weather conditions (Morrison and Harrington 1992; Niles *et al.* 2008). Thus, red knots from different wintering areas appear to employ different migration strategies, including differences in timing, routes, and stopover areas. However, full segregation of migration strategies, routes, or stopover areas does not occur among red knots from different wintering areas.

Wintering

Red knots occupy all known wintering areas from December to February, but may be present in some wintering areas as early as September or as late as May. In the Southern Hemisphere, these months correspond to the austral summer (*i.e.*, summer in the Southern Hemisphere). Wintering areas for the red knot include the Atlantic coasts of Argentina and Chile (particularly the island of Tierra del Fuego that spans both countries), the north coast of Brazil (particularly in the State of Maranhão), the Northwest Gulf of Mexico from the Mexican State of Tamaulipas through Texas (particularly at Laguna Madre) to Louisiana, and the Southeast U.S. from Florida (particularly the central Gulf coast) to North Carolina (Niles *et al.* 2008; Newstead 2013). Smaller numbers of red knots winter in the Caribbean, and along the central Gulf coast (Alabama, Mississippi), the mid-Atlantic, and the Northeast U.S. Red knots are also known to winter in Central America and northwest South America, but it is not yet clear if those birds are the *rufa* subspecies. Little information exists on where juvenile red knots spend the winter months (Service and Conserve Wildlife Foundation of New Jersey 2012), and there may be at least partial segregation of juvenile and adult red knots on the wintering grounds.

Examples of red knots changing wintering regions do exist, but are few. Generally red knots are thought to return to the same wintering region each year. Re-sightings of marked birds indicate few or no inter-annual movements of red knots between the Brazil and Tierra del Fuego wintering areas, or between the Southeast and Tierra del Fuego wintering areas (Baker *et al.* 2005; Harrington 2005).

Foraging

The red knot is a specialized molluscivore, eating hard-shelled mollusks, sometimes supplemented with easily accessed softer invertebrate prey, such as shrimp- and crab-like organisms, marine worms, and horseshoe crab (*Limulus polyphemus*) eggs (Harrington 2001; Piersma and van Gils 2011; Service 2014b). Mollusk prey are swallowed whole and crushed in the gizzard (Piersma and van Gils 2011; Service 2014b). From studies of other subspecies, Zwarts and Blomert (1992) concluded that the red knot cannot ingest prey with a circumference greater than 1.2 in (30 millimeters). Foraging activity is largely dictated by tidal conditions, as the red knot rarely wades in water more than 0.8 to 1.2 in (2 to 3 cm) deep (Harrington 2001). Due to bill morphology, the red knot is limited to foraging on only shallow-buried prey, within the top 0.8 to 1.2 in (2 to 3 cm) of sediment (Zwarts and Blomert 1992; Gerasimov 2009).

On the breeding grounds, the red knot's diet consists mostly of terrestrial invertebrates such as insects (Harrington 2001). In non-breeding habitats, the primary prey of the red knot include blue mussel (*Mytilus edulis*) spat (juveniles); *Donax* and *Darina* clams; snails (*Littorina spp.*), and other mollusks, with polycheate worms, insect larvae, and crustaceans also eaten in some locations. A prominent departure from typical prey items occurs each spring when red knots

feed on the eggs of horseshoe crabs, particularly during the key migration stopover within the Delaware Bay of New Jersey and Delaware. Delaware Bay serves as the principal spring migration staging area for the red knot because of the availability of horseshoe crab eggs (Morrison and Harrington 1992; Harrington 1996; Harrington 2001; Clark *et al.* 2009; Service 2014b), which provide a superabundant source of easily digestible food.
Red knots and other shorebirds that are long-distance migrants, must take advantage of seasonally abundant food resources at intermediate stopovers to build up fat reserves for the next nonstop, long distance flight (Clark *et al.* 1993). Although foraging red knots can be found widely distributed in small numbers within suitable habitats during the migration period, birds tend to concentrate in those areas where abundant food resources are consistently available from year to year.

Habitat

Migration and wintering habitat

Long-distance migrant shorebirds are highly dependent on the continued existence of quality habitat at a few key staging areas. These areas serve as stepping stones between wintering and breeding areas. Habitats used by red knots in migration and wintering areas are generally coastal marine and estuarine habitats with large areas of exposed intertidal sediments. In many wintering and stopover areas, quality high-tide roosting habitat (*i.e.*, close to feeding areas, protected from predators, with sufficient space during the highest tides, free from excessive human disturbance) is limited. The supra-tidal (above the high tide) sandy habitats of inlets provide important areas for roosting, especially at higher tides when intertidal habitats are inundated (Harrington 2008). In some localized areas, red knots will use artificial habitats that mimic natural conditions, such as nourished beaches, dredged spoil sites, elevated road causeways, or impoundments; however, there is limited information regarding the frequency, regularity, timing, or significance of red knots' use of such artificial habitats.

In South American wintering areas, red knots are found in intertidal marine habitats, especially near coastal inlets, estuaries, and bays. Habitats include sandy beaches, mudflats, mangroves, saltwater and brackish lagoons, and "restinga" formations (an intertidal shelf of densely packed dirt blown by strong, offshore winds) (Harrington 2001; Niles *et al.* 2008). Red knots were recently observed using rice fields in French Guiana (Niles 2012) and in Trinidad (eBird.org 2012). In Suriname in the early 1970s, small numbers of red knots were observed on firm and tough clay banks emerging from the eroding coastline and in shallow lagoons, but knots were never found on soft tidal flats (Spaans 1978). Those observations suggest a deviation from the red knot's typical nonbreeding habitats.

In North America, red knots are commonly found along sandy, gravel, or cobble beaches, tidal mudflats, salt marshes, shallow coastal impoundments and lagoons, and peat banks (Harrington 2001; Truitt *et al.* 2001; Niles *et al.* 2008; Cohen *et al.* 2009; Cohen *et al.* 2010). In

Massachusetts, red knots use sandy beaches and tidal mudflats during fall migration. In New York and the coast of New Jersey, red knots use sandy beaches during spring and fall migration (Niles *et al.* 2008). In Delaware Bay, red knots are found primarily on beaches of sand or peat at the mouths of tidal creeks, along the edge of tidal marshes dominated by salt marsh cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*S. patens*), and in salt pannes (shallow, high salinity, mud-bottomed depressions on the marsh surface) and shallow coastal ponds or embayments (Burger *et al.* 1979; Meyer *et al.* 1999; Karpanty *et al.* 2006; Niles *et al.* 2008; Cohen *et al.* 2009). In the southeastern U.S., red knots forage along sandy beaches during spring and fall migration from Maryland through Florida. During migration, knots also use tidal mudflats in Maryland and along North Carolina's barrier islands. In addition to the sandy beaches, red knots forage along peat banks for mussel spat in Virginia and along small pockets of peat banks where the beach is eroding in Georgia (Niles *et al.* 2008). In Florida, red knots also use mangrove and brackish lagoons. Along the Texas coast, red knots forage on beaches, oyster reefs, and exposed bay bottoms and roost on high sand flats, reefs, and other sites protected from high tides. Red knots also show some fidelity to particular migration staging areas between years (Harrington 2001; Duerr *et al.* 2011).

Distribution

The red knot's range spans 40 states, 24 countries, and their administrative territories or regions extending from their breeding grounds in the Canadian Arctic to migration stopover areas along the Atlantic and Gulf coasts of North America, to wintering grounds throughout the southeastern U.S., the Gulf coast, and South America (reaching as far south as Tierra del Fuego at the southern tip of South America). In Delaware Bay and Tierra del Fuego, the era of modern surveys for the red knot and other shorebird species began in the early 1980s. Systematic red knot surveys of other areas began later, and for many portions of the red knot's range, available survey data are patchy. Prior to the 1980s, numerous natural history accounts are available, but provide mainly qualitative or localized population estimates. Nonetheless, a consistent narrative emerges across many historical accounts that red knots were extremely abundant in the early 1800s, decreased sharply starting in the mid-1800s, and may have begun to recover by the mid-1900s. Most writers agree the cause of that historical decline was intensive sport and market hunting. It is unclear whether the red knot population fully recovered its historical numbers (Harrington 2001) following the period of unregulated hunting.

The current geographic distribution of the red knot has not changed relative to that recorded in historical writings with the notable exception of Delaware Bay (discussed in detail below). Several early writers reported that red knots breed in the Arctic and winter along the U.S. Gulf coast and in South America including Brazil and Tierra del Fuego (Audubon 1844; Mackay 1893; Shriner 1897; Eaton 1910; Forbush 1912; Ridgway 1919; Bent 1927; Hellmayr and Conover 1948; Lowery 1974). Bent (1927) included Jamaica and Barbados as part of the possible wintering range of red knots, and described knots as "rarely" wintering in parts of

Louisiana and Florida. Hellmayr and Conover (1948) noted the use of the West Indies (Jamaica, Barbados, and Trinidad) during migration. Several writers described the red knot as occurring primarily along the coasts with relatively few sightings inland, but interior migration routes through the central U.S. were also known (Audubon 1844; Eaton 1910; Forbush 1912; Ridgway 1919; Bent 1927; Hellmayr and Conover 1948; Lowery 1974). As with the geographic distribution, a number of historical accounts suggest that the timing of the red knot's spring and fall migrations along the Atlantic coast was generally the same in the past as it is today (Wilson 1829; Giraud 1844; Roosevelt 1866; Stearns and Coues 1883; Mackay 1893; Dixon 1895 in Barnes and Truitt 1997; Shriner 1897; Forbush 1912; Bent 1927; Stone 1937; Urner and Storer 1949; Myers and Myers 1979).

Although the large-scale geographic distribution of migration stopover habitats does not seem to have changed, some authors have noted regional changes in the patterns of red knot stopover habitat usage along the U.S. Atlantic coast. For example, based on a review of early literature, Cohen *et al.* (2008) suggest that red knots had a more extensive spring stopover range a century ago than now, with thousands of birds noted in Massachusetts, New York, New Jersey, and Virginia during the spring. Harrington *et al.* (2010a) found changes in the regional patterns of stopover habitat usage in Massachusetts, as well as a shift in the wintering destination of birds stopping in Massachusetts during fall migration.

Delaware Bay

Delaware Bay was not recognized as a major shorebird stopover area until the early 1980s, despite detailed shorebird studies (*e.g.*, Stone 1937; Urner and Storer 1949) in the South Jersey region (Clark *et al.* 1993; Clark in Farrell and Martin 1997; Botton *et al.* in Shuster *et al.* 2003; Clark *et al.* 2009). There were some early anecdotal reports involving horseshoe crabs, as summarized by Botton *et al.* (in Shuster *et al.* 2003). Wilson (1829) noted ruddy turnstones in the bay fed "almost wholly on the eggs, or spawn, of the great king crab," but no similar accounts were made of red knots. Forbush (1912) noted red knots "are fond of the spawn of the horsefoot crab, which, often in company with the Turnstone, they dig out of the sand…" Stone (1937) observed ruddy turnstones and black-bellied plovers regularly feeding on dead horseshoe crabs in Delaware Bay. Stone (1937) also mentions flights of ruddy turnstones across the Cape May Peninsula in the spring, as happens today when they go to roost at night along the Atlantic coastal marshes (Botton *et al.* in Shuster *et al.* 2003). Interestingly, no mention of horseshoe crab eggs as food is found in Stone's (1937) accounts of any shorebird in the Cape May area, or in the decade-long study by Urner and Storer (1949) and Botton *et al.* in Shuster *et al.* (2003). During his early studies of horseshoe crabs in 1951, Shuster observed many shorebirds feeding along Delaware Bay beaches, including red knots. However, another 30 years elapsed before scientists began to study the shorebird/horseshoe crab relationship in detail, and documented the very large numbers of shorebirds using the bay as a stopover (Botton *et al.* in Shuster *et al.* 2003). Lack of earlier scientific documentation cannot be attributed to remoteness. Delaware

Bay is located within a few hours' drive of millions of people, and university marine laboratories were established many years ago on both shores of the bay (Botton *et al.* in Shuster *et al.* 2003).

It is unclear if the large magnitude of the shorebird-horseshoe crab phenomenon was simply missed by science until 1981, or if the distribution of the red knot and other shorebird species changed over the period of the historical record. For much of the 20th century, this phenomenon in Delaware Bay may have been much reduced (relative to 1980s levels), and therefore, easier to miss, due to the occurrence of low points in the abundance of both shorebirds (caused by hunting) and horseshoe crabs (caused by intensive harvest) (Clark in Farrell and Martin 1997; Botton *et al.* in Shuster *et al.* 2003). Alternatively, it may be that the red knot did not make extensive use of Delaware Bay prior to its population decline a century ago. Under this scenario, red knots came to rely on Delaware Bay because their populations were recovering at the same time that Atlantic-side stopover habitats in the region were becoming developed and the shorelines stabilized (Cohen *et al.* 2008). We have no means to determine how long shorebirds have been reliant on horseshoe crab eggs in Delaware Bay (Botton *et al.* in Shuster *et al.* 2003) prior to the early 1980s.

Population Dynamics

Localized and regional red knot surveys have been conducted across the subspecies' range with widely differing levels of geographic, temporal, and methodological consistency. Population surveys are available in the November 2014 Rufa Red Knot Background Information and Threats Assessment (Supplemental Document), located at www.regulations.gov under Docket Number FWS-R5-ES-2013-0097. Some general characterizations of the available data are noted as follows:

1. No population information exists for the breeding range because, in breeding habitats, red knots are thinly distributed across a huge and remote area of the Arctic. Despite some localized survey efforts, (*e.g.,* Niles *et al.* 2008; Bart and Johnston 2012), there are no regional or comprehensive estimates of breeding abundance, density, or productivity (Niles *et al.* 2008).
2. Few regular surveys are conducted in the fall because southbound red knots tend to be less concentrated than during winter or spring.
3. Some survey data are available for most wintering and spring stopover areas. For some areas, long-term data sets have been compiled using consistent survey methodology. Because there can be considerable annual fluctuations in red knot counts, longer-term trends are more meaningful. At several key sites, the best available data show that numbers of red knots declined and remain low relative to counts from the 1980s, although the rate of decline appears to have leveled off since the late 2000s.
4. Inferring long-term population trends from various national or regional datasets derived from volunteer shorebird surveys and other sources, Morrison *et al.* (2006) and Andres (2009) concluded that red knot numbers declined, probably sharply, in recent decades.

Wintering areas

Counts in wintering areas are particularly useful in estimating red knot populations and trends because the birds generally remain within a given wintering area for a longer period of time compared to the areas used during migration. This eliminates errors associated with turnover or double-counting that can occur during migration counts.

North American Atlantic coast

Small numbers of wintering red knots have been reported from Maryland, U.S., to Nova Scotia, Canada (BandedBirds.org 2012; Burger *et al.* 2012; eBird.org 2012), but no systematic winter surveys have been conducted in these northern areas. In surveys of five sites within North Carolina's Outer Banks in 1992 and 1993, Dinsmore *et al.* (1998) found over 500 red knots per year.

Southeastern U.S. and Caribbean

Extensive data for Florida are available from the International Shorebird Survey and other sources. However, geographic coverage has been inconsistent, ranging from 1 to 29 sites per year from 1974 to 2004. Statewide annual totals ranged from 5 knots (1 site in 1976) to 7,764 knots (7 sites in 1979). The greatest geographic coverage occurred in 1993 (4,265 knots at 25 sites) and 1994 (5,018 knots at 29 sites) (Niles *et al.* 2008). Harrington *et al.* (1988) reported that the mean count of birds wintering in Florida was 6,300 birds (± 3,400, one standard deviation) based on four aerial surveys conducted from October to January in 1980 to 1982. These surveys covered the Florida Gulf coast from Dunedin to Sanibel-Captiva, sometimes going as far south as Cape Sable. Based on those surveys and other work, the Southeast wintering group was estimated at roughly 10,000 birds in the 1970s and 1980s (Harrington 2005).

Sprandel *et al.* (1997) identified the top 60 sites for wintering shorebirds in Florida and surveyed those areas in 1994. Red knots were found at 27 sites, mainly on the central Gulf coast. Adding the average number of birds counted at each site, these authors estimated a statewide total of 1,452 red knots across 3 sites in the Florida Panhandle, 18 sites in southwest Florida, 4 sites in the Everglades, and 2 sites in Northeast Florida (Sprandel *et al.* 1997). During frequent surveys of nine sites along approximately 55 mi of the central Florida Panhandle, Smith (2010) found a mean of about 84 wintering red knots in the winter of 2007. Smith (2010) covered roughly 25 percent of the Panhandle region as delineated by Sprandel *et al.* (1997), with the survey sites clustered on the eastern end of that region.

Niles (2009) conducted winter aerial and ground counts along Florida's Gulf coast from 2006 to 2010, covering essentially the same area in which Harrington *et al.* (1988) had reported an average of 6,300 red knots (± 3,400) in the winters of 1980 to 1982. As the more recent aerial

counts were lower, red knot numbers may have decreased in western Florida, perhaps due to birds shifting elsewhere within the larger Southeast wintering region (Harrington 2005). However, a comparison of the geographic coverage of Sprandel *et al.* (1997) with Niles (2009) suggests red knot numbers did not change much from 1994 to 2010.

Based on re-sightings of birds banded in South Carolina and Georgia from 1999 to 2002, the Southeast wintering population was estimated at 11,700 ± 1,000 (one standard error) red knots. Although there appears to have been a gradual shift by some of the southeastern knots from the Florida Gulf coast to the Atlantic coasts of Georgia and South Carolina, population estimates for the Southeast region in the 2000s were at about the same level as during the 1980s (Harrington 2005). Based on recent modeling using re-sightings of marked birds staging in Georgia in fall, as well as other evidence, the Southeast wintering group may number as high as 20,000, but field survey data are not available to corroborate this estimate.

Two recent winter estimates are available for the central Gulf of Mexico. During the International Piping Plover Census in 2006 and 2011, 250 to 500 knots were counted from Alabama to Louisiana. From work related to the Deepwater Horizon oil spill, an estimated 900 red knots were reported from the Florida Panhandle to Mississippi. Older surveys recorded similar numbers from the central Gulf coast, with peak counts of 752 red knots in Alabama (1971) and 40 knots in Mississippi (1979) (Morrison and Harrington 1992). Numbers of red knots wintering in the Caribbean are essentially unknown, but in the course of piping plover surveys in February 2011 in the Bahamas, 70 red knots were observed on the Joulters Cays just north of Andros Island, and 7 red knots were observed on the Berry Islands. In December 2012 (*i.e.*, winter 2013), 52 red knots were observed in the Green Turtle Cay flats in Abaco, Bahamas. Roughly 50 red knots occur annually on Green Turtle Cay (eBird.org 2012).

Northwest Gulf of Mexico

Except for localized areas, there have been no long-term systematic surveys of red knots in Texas or Louisiana, and no information is available about the number of red knots that winter in northeastern Mexico. From survey work in the 1970s, Morrison and Harrington (1992) reported peak winter counts of 120 red knots in Louisiana and 1,440 in Texas, although numbers in Texas between December and February were typically in the range of 100 to 300 birds. Records compiled by Skagen *et al.* (1999) give peak counts of 2,838 and 2,500 red knots along the coasts of Texas and Louisiana, respectively, between January and June over the period 1980 to 1996, but these figures could include spring migrants. Morrison *et al.* (2006) estimated only about 300 red knots wintering along the Texas coast, based on surveys in January 2003 (Niles *et al.* 2008). Higher counts of roughly 700 to 2,500 red knots have recently been made on Padre Island, Texas, during October, which could include wintering birds (Niles 2009; Newstead 2013).

Foster *et al.* (2009) found a mean daily abundance of 61.8 red knots on Mustang Island, Texas, based on surveys every other day from 1979 to 2007. Similar winter counts were reported by Dey *et al.* (2011a) for Mustang Island from 2005 to 2011. From 1979 to 2007, mean abundance of red knots on Mustang Island decreased 54 percent, but this may have been a localized response to increasing human disturbance, coastal development, and changing beach management practices (Foster *et al.* 2009; Newstead 2013).

There are no current estimates for the size of the Northwest Gulf of Mexico wintering group as a whole (Mexico to Louisiana). The best available current estimates for portions of this wintering region are about 2,000 in Texas (Niles 2012) or approximately 3,000 in Texas and Louisiana, with about half in each State and movement between them.

Spring stopover areas

Records of migrating red knots have been collected at many sites along the Atlantic coast. Not all migration areas are well surveyed, and considerable turnover of individuals occurs as birds migrate through an area. Consequently, using counts of migrating red knots as a basis for population estimates may lead to inaccuracies due to errors associated with turnover or double-counting. However, long-term counts made at a specific location are good indicators of usage trends for that area and, considered together, may reflect trends in the overall population of the red knot.

Virginia

Aerial surveys of the entire chain of barrier island beaches in Virginia have been conducted since 1995 using consistent methods and observers. Although the number of surveys has varied from one to six per year, the aerial survey effort has consistently covered the peak period during the last week of May. Since 2007, Karpenty *et al.* (2012) have estimated total red knots based on ground counts at 100 to 150 randomly selected points throughout Virginia's barrier island beaches including peat banks, with each location visited from one to three times per stopover season. Although the recent ground surveys show an upward trend, the aerial counts have been relatively steady since the mid-1990s. Because of differences in methodology and timing, the two data sets are not comparable.

Delaware Bay

Aerial surveys have been conducted in Delaware Bay since 1981. Methods and observers were consistent from 1986 to 2008. The methodology during this period involved weekly counts; thus, it was possible the absolute peak number of birds was missed in some years. However, since most shorebirds remain in Delaware Bay at least a week, it is likely the true peak was captured in most years (Clark *et al.* 1993). The surveys covered consistent areas of New Jersey and Delaware from the first week of May to the second week of June. All flights were conducted 3 to 4 hours after high tide, a period when birds are usually feeding on the beaches (Clark *et al.* 2009).

Methodologies and observers changed several times from 2009 to 2012. Flights are now flown only during the end of May. In addition, aerial counts for 2010 and 2011 were adjusted with ground counts from Mispillion Harbor, Delaware, to more accurately reflect large concentrations of birds at this key site (Dey *et al.* 2011a). Further, problems in 2009 and 2012 prevented accurate aerial counts, and ground counts have been substituted. Caution should be used in comparing ground and aerial counts (Laursen *et al.* 2008); differences between the two methods may account for markedly higher counts in 2009 and 2012. Although aerial counts had typically been higher than ground counts prior to 2009, this was likely because many areas that could be surveyed by air were inaccessible on the ground. Since 2009, ground survey crews have attempted to minimize the access problem by using boats in remote areas.

As with other stopover areas, it is impossible to separate population-wide trends from trends in usage of a particular spring site. Because birds pass in and out of a stopover area, the peak count for a particular year is lower than the total passage population. Thus, differences in the number of birds in Delaware Bay may reflect stopover patterns rather than (or in addition to) trends in the overall red knot population (Clark *et al.* 1993). Using re-sightings of marked birds, several attempts have been made to estimate the total passage population of Delaware Bay through mathematical modeling. However, the pattern and timing of these declines in Delaware Bay relative to Tierra del Fuego and other stopovers is suggestive of a decrease in the overall population. Comparing four different time periods, average red knot counts in Delaware Bay declined by approximately 70 percent from 1981 to 2012.

Other areas along the U.S. Atlantic Coast

Beginning in 2006, coordinated red knot surveys have been conducted from Florida to Delaware Bay during two consecutive days from May 20 to 24. This period is thought to represent the peak of the red knot migration. There has been variability in methods, observers and areas covered. From 2006 to 2010, there was no change in counts that could not be attributed to varying geographic survey coverage (Dey *et al.* 2011a); thus, we do not consider any apparent trends in these data before 2010. Because red knot numbers peak earlier in the Southeast than in the mid-Atlantic, the late-May coast-wide survey data likely reflect the movement of some birds north along the coast, and may miss other birds that depart for Canada from the Southeast along an interior (overland) route prior to the survey window. Thus, greater numbers of red knots may utilize southeastern stopovers than suggested by the data.

Fall stopover areas

Fall peak counts from International Shorebird Survey sites along the U.S. Atlantic coast ranged from 6,000 to 9,000 red knots during the mid- to late-1970s (Morrison and Harrington 1992). In a review of numbers and distribution of red knots on the Massachusetts coast during southward

migration, Harrington *et al.* (2010a) found overall red knot numbers increased from the late 1940s to the early 1970s, especially on the mainland (western Cape Cod Bay), with a smaller increase on outer Cape Cod. After 1975, counts declined significantly on the mainland, but increased significantly on outer Cape Cod (Harrington *et al.* 2010b). Evidence suggests both the mainland and the Cape Cod areas were historically used by red knots having Argentina-Chile destinations, but recently the Cape Cod locations have increasingly been used by red knots with wintering destinations in the Southeast U.S., thus, balancing out the declining numbers of red knots with Argentina-Chile wintering destinations (Harrington *et al.* 2010b). By 2008, peak counts of Argentina-Chile red knots in Massachusetts had fallen to about 1,000 birds, while birds from the Southeast group increased to about 800 (Harrington *et al.* 2010a).

No regular counts are currently conducted in Massachusetts, but flocks of over 100 knots are routinely reported from Monomoy National Wildlife Refuge (eBird.org 2012). About 1,500 red knots were present in Avalon on the coast of New Jersey in the fall of 2011 (Service 2011a). Also, on the coast of New Jersey, hundreds of red knots are regularly reported from North Brigantine and Stone Harbor, sometimes in flocks of over 500 (eBird.org 2012). Islands at the mouth of the Altamaha River, Georgia, support the only known late summer and fall staging site on the east coast of the U.S., attracting as many as 12,000 knots at one time (Schneider and Winn 2010).

Summary

After a careful review of available survey data from areas regularly used by substantial numbers of red knots in spring, fall, and winter, the Service has determined:

1. For some areas, available data are insufficient to substantiate any conclusions regarding population trends over time;
2. For other areas, there are apparent trends, but they are associated with relatively low confidence; and
3. For a few key areas, the consistency of geographic coverage, methodologies, and surveyors lead us to greater confidence in apparent trends. Those population data are summarized as follows:
    a. Northwest Gulf of Mexico wintering region: There are insufficient data for trend analysis;
    b. Southeast wintering region: There is an apparent decline on Florida's Gulf coast when comparing aerial surveys from 1980 to 1982, with similar surveys (using different surveyors) of approximately the same area from 2006 to 2010, which are associated with lower confidence because birds may have simply shifted elsewhere within this large wintering region. The two region-wide survey efforts to date (from the 2006 and 2011 piping plover surveys) are associated with lower confidence inherent in the methodology (red knots are not the focus of this survey), but do tend to support the perception that knots shift from state to state within this region among years. A long-term data set from Georgia, showing wide inter-annual fluctuations,

also supports this perception. Data from the Caribbean are insufficient to infer any trends. Comparing ground surveys of Florida's Gulf coast in 1994 to aerial surveys of about this same area from 2006 to 2010, red knot counts were roughly the same over this time period;

c. Virginia barrier islands spring stopover area: There is no apparent trend based on aerial surveys since 1995, which is associated with high confidence. A newer data set based on ground surveys suggests an increase since 2007;
d. Delaware Bay spring stopover area: There is a highly variable data set showing possible declines in the 1990s, and more consistent and substantial declines through the mid-2000s, which are associated with high confidence during the core years of 1986 to 2008. Numbers may have stabilized from 2009 to 2012, but we have lower confidence in trends over this later period due to multiple shifts in methodology and surveyors;
e. Atlantic coast spring window survey: There is an apparent increase from 2010 to 2012, but it is associated with lower confidence because, despite improvements, methodology and geographic coverage are still stabilizing and because only 3 years of (relatively consistent) data are available; and
f. Fall stopover areas: There are insufficient data for trend analysis in most areas. Since the 1970s, there were probable declines in some parts of eastern Canada and changes in red knot usage of Massachusetts (mainland versus Cape Cod, proportion of birds bound for Southeast versus Argentina-Chile wintering destinations).

Threats

In this section, we provide an analysis of threats to red knots and their habitat in their migration and wintering range, with some specific references to their breeding range. Because we lack information on threats to red knots for many countries outside the U.S. (with a few exceptions), this analysis is mainly focused on threats to red knots within the continental U.S. portion of their migration and wintering range, unless otherwise noted.

Climate change

Our analyses under the Act include consideration of observed or likely environmental effects related to ongoing and projected changes in climate. As defined by the Intergovernmental Panel on Climate Change (IPCC), "climate" refers to average weather, typically measured in terms of the mean and variability of temperature, precipitation, or other relevant properties over time; thus "climate change" refers to a change in such a measure which persists for an extended period, typically decades or longer, due to natural conditions (*e.g.*, solar cycles) or human-caused changes in the composition of the atmosphere or in land use (IPCC 2013, p. 1450). Detailed explanations of global climate change and examples of various observed and projected changes and associated effects and risks at the global level are provided in reports issued by the IPCC (2014 and citations therein). Information for the U.S. at national and regional levels is

summarized in the National Climate Assessment (Melillo *et al.* 2014 entire and citations therein; see Melillo *et al.* 2014, pp.28-45 for an overview). Because observed and projected changes in climate at regional and local levels vary from global average conditions, rather than using global scale projections, we use "downscaled" projections when they are available and have been developed through appropriate scientific procedures, because such projections provide higher resolution information that is more relevant to spatial scales used for analyses of a given species and the conditions influencing it. (See Melillo *et al.* 2014, Appendix 3, pp. 760-763 for a discussion of climate modeling, including downscaling). In our analysis, we use our expert judgment to weigh the best scientific and commercial data available in our consideration of relevant aspects of climate change and related effects.

The natural history of Arctic-breeding shorebirds makes this group of species particularly vulnerable to global climate change (*e.g.*, Lindström and Agrell 1999; Piersma and Baker 2000; Zöckler and Lysenko 2000; Rehfisch and Crick 2003; Piersma and Lindström 2004; Meltofte *et al.* 2007). Relatively low genetic diversity, which is thought to be a consequence of survival through past climate-driven population bottlenecks, may put shorebirds at more risk from human-induced climate variation than other avian taxa (Meltofte *et al.* 2007); low genetic diversity may result in reduced adaptive capacity as well as increased risks when population sizes drop to low levels.

In the short term, red knots may benefit if warmer temperatures result in fewer years of delayed horseshoe crab spawning in Delaware Bay (Smith and Michaels 2006) or fewer occurrences of late snow melt in the breeding grounds (Meltofte *et al.* 2007). However, there are indications that changes in the abundance and quality of red knot prey are already under way (Jones *et al.* 2010; Escudero *et al.* 2012), and prey species face ongoing climate-related threats from warmer temperatures (Philippart *et al.* 2003; Rehfisch and Crick 2003; Fabry *et al.* 2008; Jones *et al.* 2010), ocean acidification (National Research Council (NRC) 2010), and possibly increased prevalence of disease and parasites (Ward and Lafferty 2004). In addition, red knots face imminent threats from loss of habitat caused by sea level rise (Titus 1990; Galbraith *et al.* 2002; NRC 2010), and increasing asynchronies (''mismatches'') between the timing of their annual breeding, migration, and wintering cycles and the windows of peak food availability on which the birds depend (Baker *et al.* 2004; van Gils *et al.* 2005a; Meltofte *et al.* 2007; McGowan *et al.* 2011; Smith *et al.* 2011).

Several threats are related to the possibility of changing storm patterns. While variation in weather is a natural occurrence and is normally not considered a threat to the survival of a species, persistent changes in the frequency, intensity, or timing of storms at key locations where red knots congregate (*e.g.*, key stopover areas) can pose a threat. Storms impact migratory shorebirds like the red knot both directly and indirectly. Direct impacts include energetic costs from a longer migration route as birds avoid storms, blowing birds off course, and outright mortality (Niles *et al.* 2010). Indirect impacts include changes to habitat suitability, storm-

induced asynchronies between migration stopover periods and the times of peak prey availability, and possible prompting of birds to take refuge in areas where shorebird hunting is still practiced (Dey *et al.* 2011b; Nebel 2011; Niles *et al.* 2012b).

With Arctic warming, vegetation conditions in the red knot's breeding grounds are expected to change, causing the zone of nesting habitat to shift and perhaps contract, but this process may take decades to unfold (Kaplan *et al.* 2003; Meltofte *et al.* 2007; Feng *et al.* 2012). That said; ecological shifts (*e.g.*, changes in predation patterns and pressures) in the Arctic may appear sooner than predicted. High uncertainty exists about when and how changing interactions among vegetation, predators, competitors, prey, parasites, and pathogens may affect the red knot, but the impacts are potentially profound (Ims and Fuglei 2005; Meltofte *et al.* 2007; Schmidt *et al.* 2012; Fraser *et al.* 2013).

Due to background rates of sea level rise and the naturally dynamic nature of coastal habitats, we conclude that red knots are adapted to moderate (although sometimes abrupt) rates of habitat change in their wintering and migration areas. However, rates of sea level rise are accelerating beyond those that have occurred over recent millennia. In most of the red knot's nonbreeding range, shorelines are expected to undergo dramatic reconfigurations over the next century as a result of accelerating sea level rise. Extensive areas of marsh are likely to become inundated, which may reduce foraging and roosting habitats. Marshes may be able to establish farther inland, but the rate of new marsh formation (*e.g.*, intertidal sediment accumulation, development of hydric soils, colonization of marsh vegetation) may be slower than the rate of deterioration of existing marsh, particularly under higher sea level rise scenarios. The primary red knot foraging habitats (*i.e.*, intertidal flats and sandy beaches) will likely be locally or regionally inundated, but replacement habitats are likely to reform along the shoreline in its new position. However, if shorelines experience a decades-long period of high instability and landward migration, the formation rate of new beach habitats may be slower than the inundation rate of existing habitats. In addition, low-lying and narrow islands (*e.g.*, in the Caribbean and along the Gulf and Atlantic coasts) may disintegrate rather than migrate, representing a net loss of red knot habitat. Superimposed on these changes are widespread human attempts to stabilize the shoreline, which are known to exacerbate losses of intertidal habitats by blocking their landward migration. The cumulative loss of habitat across the nonbreeding range could affect the ability of red knots to complete their annual cycles, possibly affecting fitness and survival, and is thereby likely to negatively influence the long-term survival of the red knot.

In summary, climate change is expected to affect red knot fitness and, therefore, survival through direct and indirect effects on breeding and nonbreeding habitat, food availability, and timing of the birds' annual cycle. Ecosystem changes in the Arctic (*e.g.*, changes in predation patterns and pressures) may also reduce reproductive output. Together, these anticipated changes will likely negatively influence the long-term survival of the red knot.

Reduced food availability

Commercial harvest of horseshoe crabs has been implicated as a causal factor in the decline of the red knot populations in the 2000s, by decreasing the availability of horseshoe crab eggs in the Delaware Bay stopover (Niles *et al.* 2008). Due to harvest restrictions and other conservation actions, horseshoe crab populations showed some signs of recovery in the early 2000s, with apparent signs of red knot stabilization (survey counts, rates of weight gain) occurring a few years later (as might be expected due to biological lag times). Since about 2005, however, horseshoe crab population growth has stagnated for unknown reasons. Under the current management framework, the present horseshoe crab harvest is not considered a threat to the red knot. However, it is not yet known if the horseshoe crab egg resource will continue to adequately support red knot populations over the next 5 to 10 years. In addition, implementation of the current management framework could be impeded by insufficient funding.

The causal role of reduced Delaware Bay food supplies in driving red knot population declines shows the vulnerability of red knots to declines in the quality or quantity of their prey. This vulnerability has also been demonstrated in other *C. canutus* subspecies, although not to the severe extent experienced by the *rufa* subspecies. In addition to the fact that horseshoe crab population growth has stagnated, red knots now face several emerging threats to their food supplies throughout their nonbreeding range. These threats include: small prey sizes (from unknown causes) at two key wintering sites on Tierra del Fuego; warming water temperatures that may cause mollusk population declines and range contractions (including the likely loss of a key prey species from the Virginia spring stopover within the next decade); ocean acidification to which mollusks are particularly vulnerable; physical habitat changes from climate change affecting invertebrate communities; possibly increasing rates of mollusk diseases due to climate change; invasive marine species from ballast water and aquaculture; and the burial and crushing of invertebrate prey from sand placement and recreational activities. Although threats to food quality and quantity are widespread, red knots in localized areas have shown some adaptive capacity to switch prey when the preferred prey species became reduced (Musmeci *et al.* 2011; Escudero *et al.* 2012), suggesting some adaptive capacity to cope with this threat. Nonetheless, based on the combination of documented past impacts and a spectrum of ongoing and emerging threats, we conclude that reduced quality and quantity of food supplies is a threat to the *rufa* red knot at the subspecies level, and the threat is likely to continue into the future.

Asynchronies ("mismatches") in the red knot's annual cycle

The red knot's life history strategy makes this species inherently vulnerable to mismatches in timing between its annual cycle and those periods of optimal food and weather conditions upon which it depends. For unknown reasons, more red knots arrived late in Delaware Bay in the early 2000s, which is generally accepted as a key causative factor (along with reduced supplies of horseshoe crab eggs) behind red knot population declines that were observed over this same

timeframe. Thus, the red knot's sensitivity to timing asynchronies has been demonstrated through a population-level response. Both adequate supplies of horseshoe crab eggs and high-quality foraging habitat in Delaware Bay, can serve to partially mitigate minor asynchronies at this key stopover site. However, the factors that caused delays in the spring migrations of red knots from Argentina and Chile are still unknown, and we have no information to indicate if this delay will reverse, persist, or intensify.

Superimposed on this existing threat of late arrivals in Delaware Bay are new threats of asynchronies emerging due to climate change. Climate change is likely to affect the reproductive timing of horseshoe crabs in Delaware Bay, mollusk prey species at other stopover sites, or both, possibly pushing the peak seasonal availability of food outside of the windows when red knots rely on them. In addition, both field studies and modeling have shown strong links between the red knot's reproductive output and conditions in the Arctic including insect abundance and snow cover. Climate change may also cause shifts in the period of optimal Arctic conditions relative to the time period when red knots currently breed.

The red knots' adaptive capacity to deal with numerous changes in the timing of resource availability across its geographic range is largely unknown. A few examples suggest some flexibility in migration strategies. However, available information suggests that the timing of the red knot's annual cycle is controlled at least partly by celestial and endogenous cues, while the reproductive seasons of prey species, including horseshoe crabs and mollusks, are largely driven by environmental cues such as water temperature. These differences between the timing cues of red knots and their prey suggest limitations on the adaptive capacity of red knots to deal with numerous changes in the timing of resource availability across their geographic range. Based on the combination of documented past impacts and a spectrum of ongoing and emerging threats, we conclude that asynchronies (mismatches between the timing of the red knot's annual cycles and the periods of favorable food and weather upon which it depends) are likely to cause deleterious subspecies-level effects.

Shoreline stabilization and coastal development

Much of the U.S. coast within the range of the red knot is already extensively developed. Direct loss of shorebird habitats occurred over the past century as substantial commercial and residential developments were constructed in and adjacent to ocean and estuarine beaches along the Atlantic and Gulf coasts. In addition, red knot habitat was also lost indirectly, as sediment supplies were reduced and stabilization structures were constructed to protect developed areas. Sea level rise and human activities within coastal watersheds can lead to long-term reductions in sediment supply to the coast. The damming of rivers, bulk-heading of highlands, and armoring of coastal bluffs have reduced erosion in natural source areas and consequently the sediment loads reaching coastal areas. Although it is difficult to quantify, the cumulative reduction in sediment supply from human activities may contribute substantially to the long-term shoreline

erosion rate. Along coastlines subject to sediment deficits, the amount of sediment supplied to the coast is less than that lost to storms and coastal sinks (inlet channels, bays, and upland deposits), leading to long-term shoreline recession (Greene 2002; Herrington 2003; Morton 2003; Morton *et al.* 2004; Defeo *et al.* 2009; Climate Change Science Program [CCSP] 2009; Florida Oceans and Coastal Council 2010; Coastal Protection and Restoration Authority of Louisiana 2012).

The mid-Atlantic coast from New York to Virginia is the most urbanized shoreline in the country, except for parts of Florida and southern California. In New York and New Jersey, hard structures and beach nourishment programs cover much of the coastline. The U.S. southeastern coast from North Carolina to Florida is the least urbanized along the Atlantic coast, although both coasts of Florida are urbanizing rapidly. Texas has the most extensive sandy coastline in the Gulf, and much of the area is sparsely developed (Leatherman 1989). Region-wide, about 40 percent of the southeast and Gulf coast is already developed (Rice 2012; Service 2012). Not all of the remaining 60 percent in the ‘‘undeveloped’’ category, however, is still available for development because about 43 percent (about 910 mi) of beaches across this region are considered preserved. Preserved beaches include those in public or nongovernmental conservation ownership and those under conservation easements.

Past and ongoing stabilization projects fundamentally alter the naturally dynamic coastal processes that create and maintain beach strand and bayside habitats, including those habitat components that red knots rely upon. Past loss of stopover and wintering habitat likely reduce the resilience of the red knot by making it more dependent on those habitats that remain, and more vulnerable to threats (*e.g.*, disturbance, predation, reduce quality or abundance of prey, increased intraspecific and interspecific competition) within those restricted habitats.

Hard structures

Hard shoreline stabilization projects are typically designed to protect property (and its human inhabitants) not beaches (Pilkey and Howard 1981; Kana 2011). Structural development along the shoreline and manipulation of natural inlets upset the naturally dynamic coastal processes and result in loss or degradation of beach habitat (Melvin *et al.* 1991). As beaches narrow, the reduced habitat can directly lower the diversity and abundance of biota (life forms), especially in the upper intertidal zone. Shorebirds may be impacted both by reduced habitat area for roosting and foraging, and by declining intertidal prey resources, as has been documented in California (Dugan and Hubbard 2006; Defeo *et al.* 2009).

In Delaware Bay, hard structures also cause or accelerate loss of horseshoe crab spawning habitat (Botton *et al.* 1988; Botton *et al.* in Shuster *et al.* 2003; CCSP 2009), and shorebird habitat may continue to be lost where bulkheads have been built (Clark in Farrell and Martin 1997). In addition to directly eliminating red knot habitat, hard structures interfere with the creation of new shorebird habitats by interrupting the natural processes of over-wash and inlet

formation. Where hard stabilization is installed, the eventual loss of the beach and its associated habitats is virtually assured (Rice 2009) in the absence of beach nourishment, and therefore, may impact red knots as discussed below. Where they are maintained, hard structures are likely to significantly increase the amount of red knot habitat lost as sea levels continue to rise.

In a few isolated locations, however, hard structures may enhance red knot habitat, or may provide artificial habitat. In Delaware Bay, for example, Botton *et al.* (1994) found creek mouths, jetties, and other artificial obstructions can act to concentrate drifting horseshoe crab eggs and thereby attract shorebirds. Another example comes from the Delaware side of the bay, where a seawall and jetty at Mispillion Harbor protect the confluence of the Mispillion River and Cedar Creek. These structures create a low energy environment in the harbor, which seems to provide highly suitable conditions for horseshoe crab spawning over a wider variation of weather and sea conditions than anywhere else in the bay. Horseshoe crab egg densities at Mispillion Harbor are consistently an order of magnitude higher than at other bay beaches (Dey *et al.* 2011a), and this site consistently supports upwards of 15 to 20 percent of all red knots recorded in Delaware Bay (Lathrop 2005). In Florida, red knots have been observed on multiple instances using artificial structures such as docks, piers, jetties, causeways, and construction barriers. The Service does not have any information regarding the frequency, regularity, timing, or significance of this use of artificial habitats.

Mechanical sediment transport

Several types of sediment transport are employed to stabilize shorelines, protect development, maintain navigation channels, and provide for recreation (U.S. Corps of Engineers [Corps] 2002; Kana 2011; Gebert 2012). The effects of these projects are typically expected to be relatively short in duration, usually less than 10 years, but often these actions are carried out every few years in the same area, resulting in a more lasting impact on habitat suitability for shorebirds. Mechanical sediment transport practices include beach nourishment, sediment back-passing, sand scraping, and dredging. Since the 1970s, 90 percent of the Federal appropriation for shore protection has been for beach nourishment (Corps 2002), which has become the preferred course of action to address shoreline erosion in the U.S. (Greene 2002; Morton and Miller 2005; Kana 2011).

Where shorebird habitat has been severely reduced or eliminated by hard stabilization structures, beach nourishment may be the only means available to replace any habitat for as long as the hard structures are maintained (Nordstrom and Mauriello 2001), although such habitat will persist only with regular nourishment episodes (typically on the order of every 2 to 6 years). In Delaware Bay, beach nourishment has been recommended to prevent loss of spawning habitat for horseshoe crabs (Atlantic States Marine Fisheries Commission [ASMFC] 1998; Carter *et al.* in Guilfoyle *et al.* 2007; Kalasz 2008), and is being pursued as a means of restoring shorebird habitat in Delaware Bay following Hurricane Sandy (Corps 2012; Niles *et al.* 2013). Beach nourishment was part of a 2009 project to maintain important shorebird foraging habitat at

Mispillion Harbor, Delaware (Siok and Wilson 2011). However, red knots may be directly disturbed if beach nourishment takes place while the birds are present. On New Jersey's Atlantic coast, beach nourishment has typically been scheduled for the fall, when red knots are present, because of various constraints at other times of year. In addition to causing disturbance during construction, beach nourishment often increases recreational use of the widened beaches that, without careful management, can increase disturbance of red knots. Beach nourishment can also temporarily depress, and sometimes permanently alter, the invertebrate prey base on which shorebirds depend (Peterson *et al.* 2006).

In addition to disturbing the birds and impacting the prey base, beach nourishment can affect the quality and quantity of red knot habitat (Greene 2002). The artificial beach created by nourishment may provide only suboptimal habitat for red knots, as a steeper beach profile is created when sand is stacked on the beach during the nourishment process. In some cases, nourishment is accompanied by the planting of dense beach grasses, which can directly degrade habitat, as red knots require sparse vegetation to avoid predation. By precluding over-wash and Aeolian transport, especially where large artificial dunes are constructed, beach nourishment can also lead to further erosion on the bayside and promote bayside vegetation growth, both of which can degrade the red knot's preferred foraging and roosting habitats (sparsely vegetated flats in or adjacent to intertidal areas). Preclusion of over-wash also impedes the formation of new red knot habitats. Beach nourishment can also encourage further development, bringing further habitat impacts, reducing future alternative management options such as a retreat from the coast, and perpetuating the developed and stabilized conditions that may ultimately lead to inundation where beaches are prevented from migrating (Greene 2002).

Following placement of sediments much coarser than those native to the beach, Peterson *et al.* (2006) found that the area of intertidal-shallow sub-tidal shorebird foraging habitat was reduced by 14 to 29 percent at a site in North Carolina. Presence of coarse shell material armored the substrate surface against shorebird probing, further reducing foraging habitat by 33 percent, and probably also inhibiting manipulation of prey when encountered by a bird's bill (Peterson *et al.* 2006). In addition to this physical change from adding coarse sediment, nourishment that places sediment dissimilar to the native beach also substantially increases impacts to the red knot's invertebrate prey base (Peterson *et al.* 2006).

Many of the effects of sediment back-passing (a technique that reverses the natural migration of sediment by mechanically [via trucks] or hydraulically [via pipes] transporting sand from accreting, downdrift areas of the beach to eroding, up-drift areas of the beach) and beach scraping (mechanically redistributing beach sand from the littoral zone [along the edge of the sea] to the upper beach to increase the size of the primary dune or to provide a source of sediment for beaches that have no existing dune) are similar to those for beach nourishment (Lindquist and Manning 2001; Service 2011b), including disturbance during and after construction, alteration of prey resources, reduced habitat area and quality, and precluded formation of new habitats. Relative to

beach nourishment, sediment back-passing and beach scraping can involve considerably more driving of heavy trucks and other equipment on the beach including areas outside the sand placement footprint, potentially impacting shorebird prey resources over a larger area (Service 2011b). In addition, these practices can directly remove sand from red knot habitats, as is the case in one red knot concentration area in New Jersey (Service 2011b). Back-passing and sand scraping can involve routine episodes of sand removal or transport that maintain the beach in a narrower condition, indefinitely reducing the quantity of back-beach roosting habitat.

The common practice of inlet and nearshore dredging can affect red knot habitats. Dredging often involves removal of sediment from sand bars, shoals, and inlets in the near-shore zone, directly impacting optimal red knot roosting and foraging habitats (Winn and Harrington in Guilfoyle *et al.* 2006; Harrington in Guilfoyle *et al.* 2007; Harrington 2008). These ephemeral habitats are even more valuable to red knots because they tend to receive less recreational use than the main beach strand. In addition to causing this direct habitat loss, the dredging of sand bars and shoals can preclude the creation and maintenance of red knot habitats by removing sand sources that would otherwise act as natural breakwaters and weld onto the shore over time (Morton 2003; Hayes and Michel 2008). Further, removing these sand features can cause or worsen localized erosion by altering depth contours and changing wave refraction (Hayes and Michel 2008), potentially degrading other nearby red knot habitats indirectly because inlet dynamics exert a strong influence on the adjacent shorelines. Studying barrier islands in Virginia and North Carolina, Fenster and Dolan (1996) found inlet influences extend 3.4 to 8.1 mi, and that inlets dominate shoreline changes for up to 2.7 mi. Changing the location of dominant channels at inlets can create profound alterations to the adjacent shoreline (Nordstrom 2000).

Wrack removal and beach cleaning

Wrack on beaches and baysides provides important foraging and roosting habitat for red knots and many other shorebirds on their winter, breeding, and migration grounds. Because shorebird numbers are positively correlated with wrack cover and biomass of their invertebrate prey that feed on wrack (Tarr and Tarr 1987; Dugan *et al.* 2003; Hubbard and Dugan 2003), beach grooming will lower bird numbers (Defeo *et al.* 2009). Beach cleaning or grooming can result in abnormally broad unvegetated zones that are inhospitable to dune formation or plant colonization, thereby enhancing the likelihood of erosion (Defeo *et al.* 2009).

The Service estimates 240 of 825 mi (29 percent) of sandy beach shoreline in Florida are cleaned or raked on various schedules (*i.e.*, daily, weekly, monthly) (Florida Department of Environmental Protection [DEP] 2008). Service biologists estimate South Carolina mechanically cleans approximately 34 of its 187 shoreline mi (18 percent), and Texas mechanically cleans approximately 20 of its 367 shoreline mi (5.4 percent). In Louisiana, beach raking occurs on Grand Isle (the State's only inhabited island) along approximately 8 mi of shoreline, roughly 2 percent of the State's 397 sandy shoreline mi.

Tilling beaches to reduce soil compaction, as sometimes required by the Service for sea turtle protection after beach nourishment activities, also has similar impacts to removing wrack and disturbing the invertebrate fauna. Recently, the Service improved sea turtle protection provisions in Florida; these provisions now require tilling, when needed, to be above the primary wrack line, not within it, which will reduce the negative effects.

Invasive vegetation

A recently identified threat to red knot is the spread of coastal invasive plants into suitable red knot habitat. Like most invasive species, coastal exotic plants reproduce and spread quickly and exhibit dense growth habits, often outcompeting native plant species. If left uncontrolled, invasive plants cause a habitat shift from open or sparsely vegetated sand to dense vegetation, resulting in the loss or degradation of red knot roosting habitat, which is especially important during high tides and migration periods.

Beach vitex (*Vitex rotundifolia*) is a woody vine introduced into the southeastern U.S. as a dune stabilization and ornamental plant (Westbrooks and Madsen 2006). It currently occupies a very small percentage of its potential range in the U.S.; however, it is expected to grow well in coastal communities throughout the southeastern U.S. from Virginia to Florida, and west to Texas (Westbrooks and Madsen 2006).

Unquantified amounts of crowfoot grass (*Dactyloctenium aegyptium*) grow invasively along portions of the Florida coastline. It forms thick bunches or mats that may change the vegetative structure of coastal plant communities and alter shorebird habitat. The Australian pine (*Casuarina equisetifolia*) also changes the vegetative structure of the coastal community in south Florida and islands within the Bahamas. Shorebirds prefer foraging in open areas where they are able to see potential predators, and tall trees provide good perches for avian predators. Australian pines potentially impact shorebirds, including the red knot, by reducing attractiveness of foraging habitat and/or increasing avian predation.

The propensity of these exotic species to spread, and their tenacity once established, make them a persistent threat, partially countered by increasing landowner awareness and willingness to undertake eradication activities.

Aquaculture and agriculture

In some localized areas within the red knot's range, aquaculture or agricultural activities are impacting habitat quality and quantity. Those impacts, however, occur mainly in Canada, Brazil, Río Gallegos (southern Argentina), and Bahía Lomas (Chilean Tierra del Fuego). In the U.S., Luckenbach (2007) found aquaculture of clams (*Mercenaria mercenaria*) in the lower

Chesapeake Bay occurs in close proximity to shorebird foraging areas. The current distribution of clam aquaculture in the very low intertidal zone minimizes the amount of direct overlap with shorebird foraging habitats, but if clam aquaculture expands farther into the intertidal zone, more shorebird impacts (*e.g.*, habitat alteration) may occur. However, these Chesapeake Bay intertidal zones are not considered the primary habitat for red knots (Cohen *et al.* 2009), and red knots were not among the shorebirds observed in this study (Luckenbach 2007). Likewise, oyster aquaculture is practiced in Delaware Bay (New Jersey Department of Environmental Protection [NJDEP] 2011), but we have no information to indicate that this activity is affecting red knots.

Hunting

Since the late 19th century, hunters concerned about the future of wildlife and the outdoor tradition have made countless contributions to conservation. In many cases, managed hunting is an important tool for wildlife management. However, unregulated or illegal hunting can cause population declines, as was documented in the 1800s for red knots in the U.S. While no longer a concern in the U.S., under-regulated or illegal hunting of red knots and other shorebirds is ongoing in parts of the Caribbean and South America.

Scientific study

Considerable care is taken to minimize disturbance caused to shorebirds from these research activities. Numbers of birds per catch and total numbers caught over the season are limited, and careful handling protocols are followed, including a 3-hour limit on holding times (Niles *et al.* 2008; Niles *et al.* 2010). Despite these measures, hundreds of red knots are temporarily stressed during the course of annual research, and mortality, though rare, does occasionally occur (Taylor 1981). However, we conclude that these research activities are not a threat to the red knot because evaluations have shown no effects of these short-term stresses on red knot survival. Further, the rare, carefully documented, and properly permitted mortality of an individual bird in the course of well-founded research does not affect red knot populations or the overall subspecies.

Disease

Red knots are exposed to parasites and disease throughout their annual cycle. Susceptibility to disease may be higher when the energy demands of migration have weakened the immune system. Studying red knots in Delaware Bay in 2007, Buehler *et al.* (2010) found several indices of immune function were lower in birds recovering protein after migration than in birds storing fat to fuel the next leg of the migration. These authors hypothesized fueling birds may have an increased rate of infection or may be bolstering immune defense, or recovering birds may be immuno-compromised because of the physical strain of migratory flight or as a result of adaptive energy tradeoffs between immune function and migration, or both (Buehler *et al.* 2010). A number of known parasites (*e.g.*, sporozoans, hookworms, flatworms, and ectoparasites) and

viruses (*e.g.*, avian influenza and avian paramyxovirus) have been documented in red knots, but we have no evidence disease is a current threat to the red knot.

Predation

In wintering and migration areas, the most common predators of red knots are peregrine falcons (*Falco peregrinus*), harrier hawks (*Circus* spp.), accipiters (*Accipiter* spp.), merlins (*Falco columbarius*), short-eared owls (*Asio flammeus*), and greater black-backed gulls (*Larus marinus*) (Niles *et al.* 2008). In addition to greater black-backed gulls, other large gulls (*e.g.*, herring gulls [*Larus* spp.]) are anecdotally known to prey on shorebirds (Breese 2010). Predation by a great horned owl (*B. virginianus*) has been documented in Florida. Nearly all documented predation of wintering red knots in Florida has been by avian, not terrestrial, predators. However in migration areas like Delaware Bay, terrestrial predators such as red foxes (*V. vulpes*) and feral cats may be a threat to red knots by causing disturbance, but direct mortality from these predators may be low (Niles *et al.* 2008).

Raptor predation has been shown to be an important mortality factor for shorebirds at several sites (Piersma *et al.* 1993). However, Niles *et al.* (2008) concluded that increased raptor populations have not been shown to affect the size of shorebird populations. Based on studies of other red knot subspecies in the Dutch Wadden Sea, Piersma *et al.* (1993) concluded that the chance for an individual to be attacked and captured is small, as long as the birds remain in the open and in large flocks so that approaching raptors are likely to be detected. Although direct mortality from predation is generally considered relatively low in nonbreeding areas, predators also impact red knots by affecting habitat use and migration strategies (Stillman *et al.* 2005; Niles *et al.* 2008) and by causing disturbance, thereby potentially affecting red knots' rates of feeding and weight gain.

In wintering and migration areas, predation is not directly impacting red knot populations despite some direct mortality. At key stopover sites, however, localized predation pressures are likely to exacerbate other threats to red knot populations, such as habitat loss, food shortages, and asynchronies between the birds' stopover period and the occurrence of favorable food and weather conditions. Predation pressures worsen these threats by pushing red knots out of otherwise suitable foraging and roosting habitats, causing disturbance, and possibly causing changes to stopover duration or other aspects of the migration strategy.

Although little information is available from the breeding grounds, the long-tailed jaeger (*Stercorarius longicaudus*) is prominently mentioned as a predator of red knot chicks in most accounts. Other avian predators include parasitic jaeger (*S. parasiticus*), pomarine jaeger (*S. pomarinus*), herring gull, glaucous gull (*L. hyperboreus*), gyrfalcon (*F. rusticolus*), peregrine falcon, and snowy owl. Mammalian predators include arctic fox and sometimes arctic wolves (*Canis lupus arctos*) (Committee on the Status of Endangered Wildlife in Canada [COSEWIC]

2007; Niles *et al.* 2008). Predation pressure on Arctic-nesting shorebird clutches varies widely regionally, inter-annually, and even within each nesting season, with nest losses to predators ranging from close to 0 percent to near 100 percent (Meltofte *et al.* 2007), depending on ecological factors. In the Arctic, 3-to 4-year lemming cycles give rise to similar cycles in the predation of shorebird nests. When lemmings are abundant, predators concentrate on the lemmings, and shorebirds breed successfully. When lemmings are in short supply, predators switch to shorebird eggs and chicks (Summers and Underhill 1987; Blomqvist *et al.* 2002; Service 2003; COSEWIC 2007; Meltofte *et al.* 2007; Niles *et al.* 2008).

In addition to affecting reproductive output, these cyclic predation pressures have been shown to influence shorebird nesting chronology and distribution. Studying 12 shorebird species, including red knot, over 11 years at four sites in the eastern Canadian Arctic, Smith *et al.* (2010) found that both snow conditions and predator abundance have significant effects on the chronology of breeding. Higher predator abundance resulted in earlier nesting than would be predicted by snow cover alone (Smith *et al.* 2010). Based on the adaptations of various species to deal with predators, Larson (1960) concluded the distribution and abundance of red knots and other Arctic-breeding shorebirds were strongly influenced by arctic fox and rodent cycles, such that birds were in low numbers or absent in areas without lemmings because foxes preyed predominately on birds in those areas (Fraser *et al.* 2013). Unsuccessful breeding seasons contributed to at least some of the observed reductions in the red knot population in the 2000s. However, rodent-predator cycles have always affected the productivity of Arctic-breeding shorebirds and have generally caused only minor year-to-year changes in otherwise stable populations (Niles *et al.* 2008).

Human disturbance

Red knots are exposed to disturbance from recreational and other human activities throughout their nonbreeding range because red knots and recreational users (*e.g.*, pedestrians, offroad vehicles, dog walkers, boaters) are concentrated on the same beaches (Niles *et al.* 2008; Tarr 2008). Recreational activities affect red knots both directly and indirectly. These activities can cause habitat damage (Anders and Leatherman 1987; Schlacher and Thompson 2008), cause shorebirds to abandon otherwise preferred habitats, negatively affect the birds' energy balances, and reduce the amount of available prey. In Florida, the most immediate and tangible threat to migrating and wintering red knots is chronic disturbance (Niles *et al.* 2006, 2008), which may affect the ability of birds to maintain adequate weights in some areas (Niles 2009). These effects are likely to exacerbate other threats to the red knot, such as habitat loss, asynchronies in the annual cycle, and competition with gulls.

Harmful algal blooms

A harmful algal bloom (HAB) is the proliferation of a toxic or nuisance algal species (which can be microscopic or macroscopic, such as seaweed) that negatively affects natural resources or humans (Florida Fish and Wildlife Conservation Commission [FWC] 2011). For shorebirds, shellfish are a key route of exposure to algal toxins. When toxic algae are filtered from the water as food by shellfish, their toxins accumulate in those shellfish to levels that can be lethal to animals that eat the shellfish (Anderson 2007).

Algal toxins may be a direct cause of death in seabirds and shorebirds via an acute or lethal exposure, or birds can be exposed to chronic, sub-lethal levels of a toxin over the course of an extended bloom. Sub-acute doses may contribute to mortality due to an impaired ability to forage productively, disrupted migration behavior, reduced nesting success, or increased vulnerability to predation, dehydration, disease, or injury (van Deventer 2007).

Sick or dying birds often seek shelter in dense vegetation; thus, those that succumb to HAB exposure are not often observed or documented. Birds that are debilitated or die in exposed areas are subject to predation or may be swept away in tidal areas. When extensive fish kills occur from HABs, the carcasses of smaller birds such as shorebirds may go undetected. Some areas affected by HABs are remote and rarely visited. Thus, mortality of shorebirds associated with HABs is likely underreported.

To date, direct impacts to red knots from HABs have been documented only in Texas and Florida, although a large die-off in Uruguay may have also been linked to an HAB. We conclude some level of undocumented red knot mortality from HABs likely occurs most years, based on probable underreporting of shorebird mortalities from HABs and the direct exposure of red knots to algal toxins (particularly via contaminated prey) throughout the knot's nonbreeding range. We have no documented evidence HABs were a driving factor in red knot population declines in the 2000s. However, HAB frequency and duration have increased and do not show signs of abating over the next few decades. Combined with other threats, ongoing and possibly increasing mortality from HABs may affect the red knot at the population level.

Environmental contaminants

Although red knots are exposed to a variety of contaminants across their nonbreeding range, we have no evidence that such exposure is impacting health, survival, or reproduction at the subspecies level. Exposure risks exist in localized red knot habitats in Canada, but best available data suggest shorebirds in Canada are not impacted by background levels of contamination. Levels of most metals in red knot feathers from the Delaware Bay have been somewhat high, but generally similar to levels reported from other studies of shorebirds. One preliminary study suggests organochlorines and trace metals are not elevated in Delaware Bay shorebirds, although

this finding cannot be confirmed without updated testing. Levels of metals in horseshoe crabs are generally low in the Delaware Bay region and not likely impacting red knots or recovery of the crab population.

Horseshoe crab reproduction does not appear impacted by the mosquito control chemical methoprene (at least through the first juvenile molt) or by ambient water quality in mid-Atlantic estuaries. Shorebirds have been impacted by pesticide exposure, but use of the specific chemical that caused a piping plover death in Florida has subsequently been banned in the U.S. Exposure of shorebirds to agricultural pollutants in rice fields may occur regionally in parts of South America, but red knot usage of rice field habitats was low in the several countries surveyed. Finally, localized urban pollution has been shown to impact South American red knot habitats, but we are unaware of any documented health effects or population-level impacts. Thus, we conclude that environmental contaminants are not a threat to the red knot.

Oil spills

The red knot has the potential to be exposed to oil spills and leaks throughout its migration and wintering range. Red knots are exposed to large-scale petroleum extraction and transportation operations in many key wintering and stopover habitats including Tierra del Fuego, Patagonia, the Gulf of Mexico, Delaware Bay, and the Gulf of St. Lawrence. To date, the documented effects to red knots from oil spills and leaks have been minimal; however, information regarding any oiling of red knots during the Deepwater Horizon spill has not yet been released. We conclude that high potential exists for small or medium spills to impact moderate numbers of red knots or their habitats, such that one or more such events is likely over the next few decades, based on the proximity of key red knot habitats to high-volume oil operations. Risk of a spill may decrease with improved spill contingency planning, infrastructure safety upgrades, and improved spill response and recovery methods. However, these decreases in risk (*e.g.,* per barrel extracted or transported) could be offset if the total volume of petroleum extraction and transport continues to grow. A major spill affecting habitats in a key red knot concentration area (*e.g.,* Tierra del Fuego, Gulf coasts of Florida or Texas, Delaware Bay, Mingan Archipelago) while knots are present is less likely, but would be expected to cause population-level impacts.

Wind energy development

Within the red knot's U.S. wintering and migration range, substantial development of offshore wind facilities is planned, and the number of wind turbines installed on land has increased considerably over the past decade. The rate of wind energy development will likely continue to increase into the future as the U.S. looks to decrease reliance on the traditional sources of energy (*e.g.,* fossil fuels). Wind turbines can have a direct (*e.g.,* collision mortality) and indirect (*e.g.,* migration disruption, displacement from habitat) impact on shorebirds. We have no information on wind energy development trends in other countries, but risks of red knot

collisions would likely be similar wherever large numbers of turbines are constructed along migratory pathways, either on land or offshore.

We are not aware of any documented red knot mortalities at any wind turbines to date, but low levels of red knot mortality from turbine collisions may be occurring now based on the number of turbines along the red knot's migratory routes and the frequency with which red knots traverse these corridors. Based on the current number and geographic distribution of wind turbines, if any such mortality is occurring, it is likely not causing subspecies-level effects. However, as build-out of offshore, coastal, and inland wind energy infrastructure progresses, increasing mortality from wind turbine collisions may contribute to a subspecies-level effect due to the red knot's vulnerability to direct human-caused mortality. We anticipate the threat to red knots from wind turbines will be primarily related to collision or behavioral changes during migratory or daily flights. Unless facilities are constructed at key stopover or wintering habitats, we do not expect wind energy development to cause significant direct habitat loss or degradation or displacement of red knots from otherwise suitable habitats.

Threats summary

After assessing the best scientific and commercial data available regarding past, present, and future threats to the red knot the Service has identified that the primary threats to the red knot are habitat loss and degradation due to sea level rise, shoreline stabilization, and Arctic warming as well as reduced food availability and asynchronies in the annual cycle. Other threats are moderate in comparison to the primary threats; however, cumulatively, they could become significant when working in concert with the primary threats if they further reduce the species' resiliency. Such secondary threats include hunting, predation, human disturbance, harmful algal blooms, oil spills, and wind energy development, all of which affect red knots across their range. Although conservation efforts (*e.g.*, management of the horseshoe crab population and regulatory mechanisms for the species and its habitat) are being implemented in many areas of the red knot's range and reduce some threats, significant risks to the subspecies remain.

Ongoing Conservation Efforts

We are unaware of any broad-scale conservation measures to reduce the threat of destruction, modification, or curtailment of the red knot's habitat or range. Specifically, no conservation measures are specifically aimed at reducing sea level rise or warming conditions in the Arctic. Shorebird reserves have been established at several key red knot sites in South America, and regional efforts are in progress to develop and implement urban development plans to help protect red knot habitats at some of these sites. For example, a shorebird conservation plan is being implemented for Chiloé Island on the Pacific coast of Chile and work is underway to establish a new national park on the Joulter Cays, a group of small uninhabited islands and flats that support red knots in the Bahamas (Service 2014). In the U.S., the Service is working with

partners to minimize the effects of shoreline stabilization on shorebirds and other beach species, and there are efforts in Delaware Bay to maintain horseshoe crab spawning habitat.

At some key U.S. stopovers, including the Atlantic coast of Virginia, Delaware Bay, and Cape Cod, considerable habitat is in public or private conservation ownership. Delaware has improved and increased red knot roosting habitat through impoundment management, and has conducted adaptive planning to increase impoundment resiliency to climate change and sea level rise (Service 2014b). In addition, local or regional efforts are ongoing to control several species of invasive beach vegetation. While additional best management practices could be implemented to address shoreline development and stabilization, beach cleaning, invasive species, agriculture, and aquaculture, we do not have any information that specific, large-scale actions are being taken to address these concerns such that those efforts would benefit red knot populations or the subspecies as a whole.

A few countries where shorebird hunting is legal have implemented voluntary restrictions on red knot hunting, increased hunter education efforts, established “no-shoot” shorebird refuges, and are developing models of sustainable harvest (Service 2014b). Ongoing scientific research has benefitted red knot conservation in general and, through leg-band recoveries, has provided documentation of hunting-related mortality. Research activities continue to adhere to best practices for the careful capture and handling of red knots.

We are unaware of any conservation efforts to reduce disease and predation of the red knot. That said, land managers in some areas of the U.S. have begun to remove peregrine nesting platforms in key locations where they are having the greatest impact on shorebirds (Service 2014b).

Researchers continued efforts conducting wintering surveys and examining the origins of red knots on the wintering grounds and their movement patterns up to the Artic, will provide valuable information as the Service develops a recovery plan for the species.

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