Species Status Assessment Report for the Rufa Red Knot (*Calidris canutus rufa*)

Version 1.1

Photo credit: G. Breese, USFWS

September 2020
North Atlantic-Appalachian Region (Interior Region 1)
New Jersey Field Office, Galloway, New Jersey

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Recommended Citation:
U.S. Fish and Wildlife Service. 2020. Species status assessment report for the rufa red knot (*Calidris canutus rufa*). Version 1.1. Ecological Services New Jersey Field Office, Galloway, New Jersey.

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Acknowledgements

This draft SSA report was prepared by Wendy Walsh (U.S. Fish and Wildlife Service, New Jersey Ecological Services Field Office, Galloway, New Jersey) with support from Anne Hecht (U.S. Fish and Wildlife Service, North Atlantic-Appalachian Regional Office, Hadley, Massachusetts). It incorporates information provided in response to an August 2019 request to partner organizations (including state wildlife agencies) and species experts for the best available information about rufa red knot abundance and locations, current and evolving habitat conditions, and factors that affect the species and its habitat. In addition, approximately 80 biologists from at least 40 agencies and organizations participated in four webinars in October 2019 to engage in detailed discussion of factors affecting the status of subspecies across its annual cycle. Several of these biologists followed up with detailed written input regarding the status of the red knot. This document underwent expert, partner, and peer review in May 2020. We thank the many individuals who provided substantive information and insights for this SSA.

The first uses of technical terms are in **bold text** and are defined in the glossary.

Introduction

The Species Status Assessment (SSA) Framework is an analytical approach developed by the U.S. Fish and Wildlife Service (Service) to deliver foundational science for informing all Endangered Species Act (16 U.S.C. 1531 *et seq*.) (ESA) decisions. An SSA is a focused, repeatable, and rigorous scientific assessment to result in better assessments, improved and more transparent and defensible decision making, and clearer and more concise documents. Identification of what most influences a species' condition affords timely opportunities to work with partners to implement conservation efforts in advance of ESA decisions. An SSA begins with a compilation of the best available information on the species (taxonomy, life history, and habitat) and its ecological needs at the individual, population, and/or species levels based on how environmental factors are understood to act on the species and its habitat. Next, an SSA describes the current condition of the species' habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings (*i.e.*, areas representative of geographic, genetic, or life history variation across the range of the species). Lastly, an SSA forecasts the species' response to plausible future scenarios of environmental conditions and conservation efforts assuming the species is not listed under the ESA and is therefore not subject to the protections, funding, and other benefits of ESA listing. Overall, an SSA uses the conservation biology principles of **resiliency**, **redundancy**, and **representation** (collectively known as the "3Rs") as a lens to evaluate the current and future condition of the species. As a result, the SSA characterizes a species' ability to sustain populations in the wild over time based on the best scientific understanding of current and future abundance and distribution within the species' ecological settings. The SSA provides decision makers with a scientifically rigorous analysis on which to base the determination of status, along with key uncertainties, and the best available scientific information for making other ESA decisions (*e.g.*, consultations, permitting, recovery planning) (Service 2016, p. 4).

This report summarizes the results of an SSA conducted for the rufa red knot (*Calidris canutus rufa*). We, the Service, listed the rufa red knot as a threatened species throughout its entire range under the ESA in January 2015 (79 FR 73705-73748). The objective of this SSA report is to describe the elements that contribute to the **viability** of the rufa red knot based on the best available scientific and commercial information. Through this description, we summarize what the subspecies needs to support resilient, redundant, representative populations, its current condition in terms of those needs, and its forecasted future condition under plausible future scenarios. We consider the likely environmental changes—past, current, and future—to help us understand what factors drive the viability of the subspecies.

Species Biology

Detailed information on the life history, biology, and current status of the rufa red knot is found in the supplemental listing document (Service 2014, pp. 22-116) and summarized here. Below we provide citations only for new information that has become available since the listing; please see the supplemental listing document for citations for all the other information summarized below. Throughout this document, "rufa red knot," "red knot," and "knot" are used interchangeably to refer to the subspecies *Calidris canutus rufa*. "*Calidris canutus*" and "*C. canutus*" are used to refer to the species as a whole or to birds of unknown subspecies.

References to other particular subspecies are so indicated by use of the Latin name. “Winter” is consistently used to refer to the **nonbreeding** period of the red knot life cycle when the birds are not undertaking migratory movements, typically at least December to February (longer in some regions), although this period is actually summer in the Southern Hemisphere. Likewise, although the seasons are reversed in the Southern Hemisphere, “spring” is used throughout to refer to the nonbreeding period of the red knot life cycle when the birds are undertaking northbound migratory movements and “fall” is used to refer to the nonbreeding period when the birds are undertaking southbound migratory movements.

The rufa red knot is a medium-sized shorebird that migrates annually between its breeding grounds in the central Canadian Arctic and four wintering regions: the Southeast United States and through the Caribbean; the Western Gulf of Mexico from Mississippi through Central America; northern Brazil and extending west along the northern coast of South America; and Tierra del Fuego at the southern tip of South America (mainly in Chile) and extending north along the Patagonian coast of Argentina (figure 1). During both the northbound (spring) and southbound (fall) migrations, red knots use key **staging** and **stopover** areas to rest and feed (see box 1 and table 1). The rufa red knot’s typical life span is at least 7 years, with the oldest known wild bird at least 21 years old. Age of first breeding is at least 2 years.

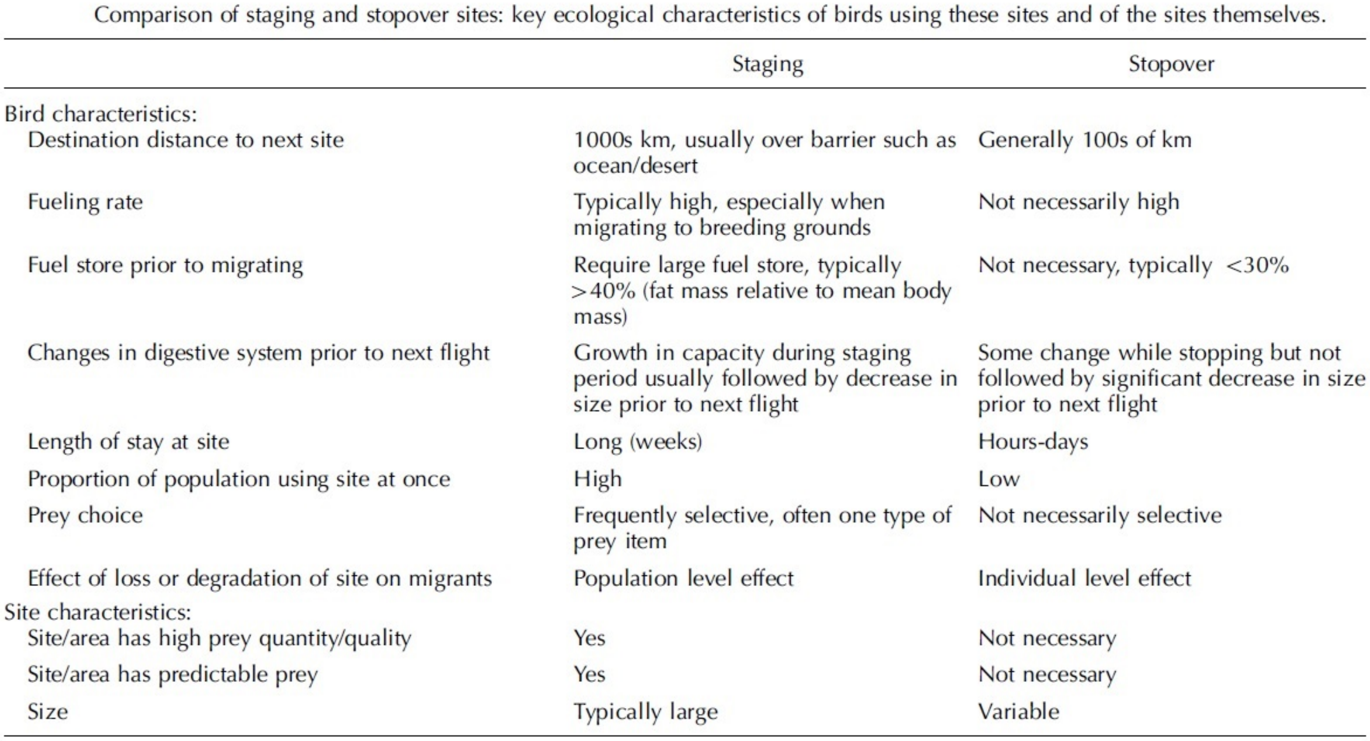
Box 1. As per Warnock (2010), stopover habitat is defined in this document as places where migrant birds stop to rest, drink, and eat, while staging areas (a subset of stopover habitats) are defined as those stopover sites with abundant, predictable food resources where birds prepare for an energetic challenge (usually a long flight over a barrier such as an ocean or a desert) requiring substantial fuel stores and physiological changes without which significant fitness costs are incurred. Warnock (2010) gives three conditions that staging areas must meet for birds to overcome these energetic challenges: (1) the site must provide predictable, abundant, accessible fuel, especially in the face of time constraints during spring migration or during molting when mobility is limited; (2) the site must provide other critical resources (such as water and resting places) to accommodate birds (often many thousands of birds) for longer periods of time (often weeks) and, (3) the site must have low levels of disturbance (predators or human-induced disturbance). Distinctions between staging areas and other stopover habitats are given in table 1.

Description, Taxonomy, and Population Structure

Description: The rufa red knot is a medium-sized shorebird about 9 to 11 inches (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. 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.

Taxonomy: Historical writers reported considerable confusion around the names of commonly hunted shorebirds in the United States. Many different scientific and common names have been used for the rufa red knot since the early 1800s; here we give the currently accepted classification. *Calidris canutus* is classified in the Class Aves, Order Charadriiformes (shorebirds), Family Scolopacidae (sandpipers and allies), Subfamily Scolopacinae.

Table 1. Comparison of staging areas and other stopover habitats (Warnock 2010)



Comparison of staging and stopover sites: key ecological characteristics of birds using these sites and of the sites themselves.

	Staging	Stopover
Bird characteristics:		
Destination distance to next site	1000s km, usually over barrier such as ocean/desert	Generally 100s of km
Fueling rate	Typically high, especially when migrating to breeding grounds	Not necessarily high
Fuel store prior to migrating	Require large fuel store, typically >40% (fat mass relative to mean body mass)	Not necessary, typically <30%
Changes in digestive system prior to next flight	Growth in capacity during staging period usually followed by decrease in size prior to next flight	Some change while stopping but not followed by significant decrease in size prior to next flight
Length of stay at site	Long (weeks)	Hours-days
Proportion of population using site at once	High	Low
Prey choice	Frequently selective, often one type of prey item	Not necessarily selective
Effect of loss or degradation of site on migrants	Population level effect	Individual level effect
Site characteristics:		
Site/area has high prey quantity/quality	Yes	Not necessary
Site/area has predictable prey	Yes	Not necessary
Size	Typically large	Variable

Six subspecies of *Calidris canutus* are recognized, each with distinctive migration routes, and annual cycles. Although the various subspecies exhibit aggregate differences in morphological traits (*i.e.*, body size and plumage characteristics), they cannot be reliably distinguished in the field based on appearance alone. Each subspecies is believed to occupy a distinct breeding area in various parts of the Arctic, and this is being borne out by newer **tracking** technologies. However, some subspecies overlap in certain wintering and migration areas. *Calidris canutus roselaari* breeds in western Alaska and on Wrangel Island in eastern Russia and winters on the Pacific coast from northern Mexico through Panama and possibly farther south. The nonbreeding ranges of *C.c. roselaari* and *C.c. rufa* are known to overlap in a few locations, and other overlaps may be identified in the future. However, **geolocator** data confirm the existence of distinct breeding areas for the rufa and roselaari subspecies.

Populations: Based on the detailed information in the supplemental listing document, we consider the four red knot wintering regions (figure 1) to support separate populations. Red knots show very high fidelity to each of the four wintering regions, and habitats and diet vary appreciably among these regions (Service 2014, pp. 47, 63-66, 71-73). Evidence suggests that at least three of the wintering populations are genetically distinct (Baker *et al.* 2013, entire; Baker *et al.* 2011, entire), which would indicate some degree of behavioral and/or geographic breeding segregation. Stable isotope, tracking, and genetic analyses suggest that red knots from different wintering regions partially segregate (in time and/or space) in migration areas (Kazyak *et al.* 2018; pp. 1-2, 8; Service 2014, pp. 48-63, 76-79). Birds from different wintering populations show marked differences in migration strategy (*e.g.*, timing, routes, long “jumps” versus shorter “hops,” timing of feather molt, degree of reliance on particular staging areas) and also show, on average, morphological differences (Service 2014, pp. 45-46). Finally, these four red knot populations also differ considerably in current status and **threats** (Service 2014, pp. 84-313). As a biological unit, each population's health reflects influences on its demographic parameters across the whole year and the whole migratory range. So, for example, when we discuss the current condition of the Southern wintering population, that analysis reflects factors affecting the population in Tierra del Fuego, the Delaware Bay staging area, the Arctic, and points in between.

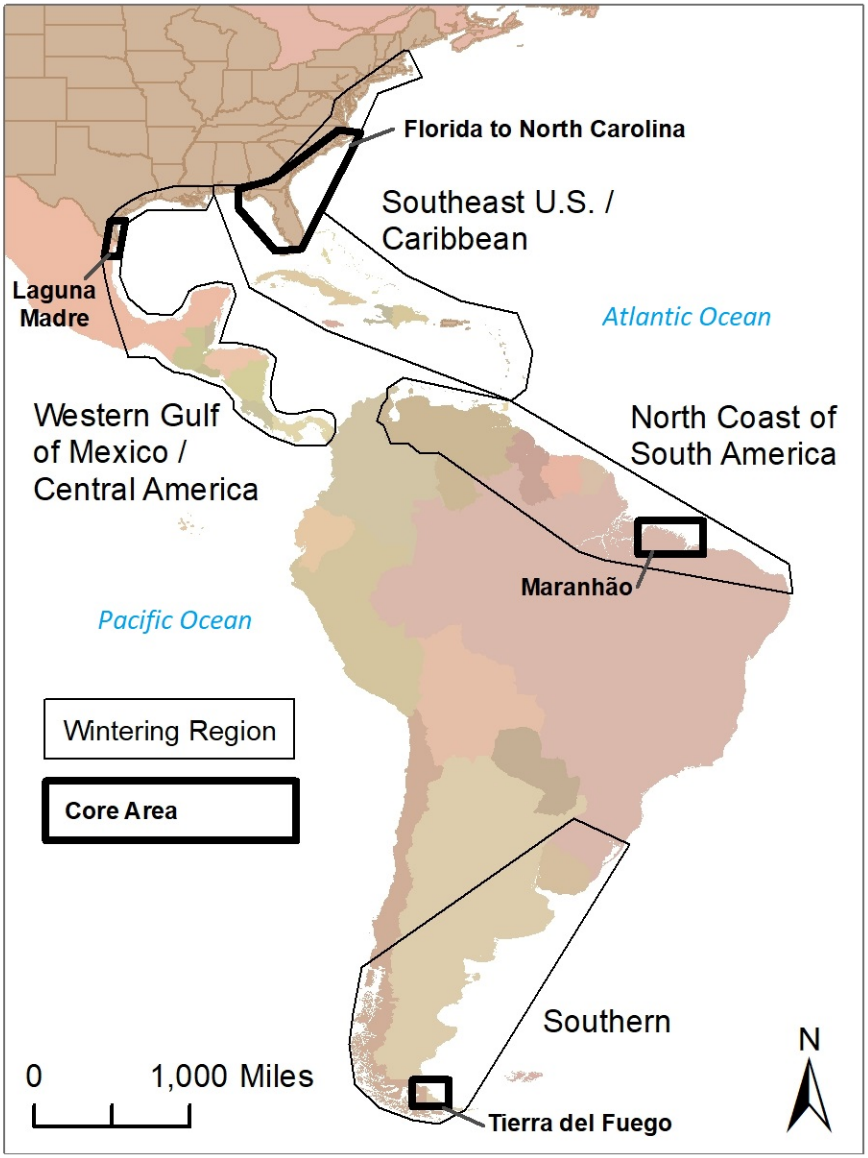


Figure 1. Rufa Red Knot Wintering Regions

Breeding

Breeding Range: The red knot breeds in the central Canadian Arctic, from the islands of northern Hudson Bay to the Foxe Basin shorelines of Prince Charles and Baffin Islands, and west to Victoria Island (Lathrop *et al.* 2018, pp. 652, 660). The distribution of rufa red knots from different wintering regions across the breeding grounds is poorly known.

Breeding Habitat and Diet: Red knots generally nest in dry, slightly elevated tundra locations, often on windswept slopes with little vegetation. Best available information indicates nest sites are within 600 feet of a freshwater wetland, and, although nests are typically within 31 miles (50 kilometers [km]) of the ocean, knots do not typically use saltwater habitats on the breeding grounds. However, the total number of rufa red knot nests studied to date is small and highly concentrated on just one island (Smith pers. comm. 2019). Thus, it is possible that a greater diversity of nesting and foraging habitats is utilized across the breeding range but not yet documented. Nests may be scraped into patches of mountain avens (*Dryas octopetala*) plants, or in low spreading vegetation on **hummocky** ground containing lichens, leaves, and moss. After the eggs hatch, red knot chicks and adults quickly move away from high nesting terrain to lower, freshwater wetland habitats. On the breeding grounds, the red knot's diet consists mostly of terrestrial invertebrates such as insects and other **arthropods**. However, early in the breeding season, before insects and other macroinvertebrates are active and accessible, *Calidris canutus* will eat grass shoots, seeds, and other vegetable matter.

Breeding Biology and Behavior: Pair bonds form soon after the birds arrive on the breeding grounds, in late May or early June, and remain intact until shortly after the eggs hatch. Female rufa red knots lay only one **clutch** per season and, as far as is known, do not lay a replacement clutch if the first is lost (Niles *et al.* 2008, p.27). Some knots are thought to be able to lay a second clutch if the first is lost early in incubation, though not later (Morrison pers. comm. 2020). The usual clutch size is four eggs, though three-egg clutches have been recorded. 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 foraging for themselves. 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 about 25 days later (around August 10) males also abandon the newly **fledged** juveniles and move south. Not long after, they are followed by the juveniles. Breeding success of High Arctic shorebirds such as *Calidris canutus* varies dramatically among years in a somewhat cyclical manner. Two main factors seem to be responsible for this annual variation: abundance of arctic lemmings (*Dicrostonyx torquatus* and *Lemmus sibericus*) (by indirectly affecting predation pressure on shorebirds) and weather. The growth rate of *C. canutus* 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.

Wintering and Migration

Nonbreeding Range: Geolocator and **resightings** data show definitively that the rufa nonbreeding range includes nearly the entire Atlantic and Caribbean coasts of South America and the Caribbean islands; Chiloé Island on the south-central Pacific coast of Chile; the Pacific coast of Panama; the North American Gulf and Atlantic coasts from Tamaulipas, Mexico through Quebec, Canada; the interior of South America; and the interior of the United States and Canada west at least as far as the Great Plains. *Calidris canutus roselaari* also occurs in certain parts of this established rufa nonbreeding range. Available data are limited but suggest that the nonbreeding ranges of *C.c. roselaari* and *C.c. rufa* overlap, at least in Texas during spring and in Panama and Chiloé (Newstead pers. comm. 2020) during winter. However, geolocator and resightings data provide strong evidence that *Calidris canutus* on the Pacific coast from northeastern Russia to Las Garzas, Mexico are the roselaari subspecies, and we conclude from the best available data that the rufa red knot does not occur in this region of the Pacific.

<u>Wintering Areas</u>: Wintering areas for the rufa red knot include the Atlantic coasts of Argentina and Chile (particularly the island of Tierra del Fuego that spans both countries); the northern coast of South America (particularly in the Brazilian State of Maranhão); the western Gulf of Mexico from the (Mexican State of) Tamaulipas through Texas (particularly at Laguna Madre) to Mississippi, and extending south along both coasts of Central America; and the Southeast United States from Florida (particularly the central Gulf coast) to North Carolina with additional birds throughout the Caribbean (including the Bahamas). Smaller numbers of knots winter in Uruguay and Lagoa do Peixe (Brazil), and along the mid-Atlantic and the Northeast United States. *Calidris canutus* is also known to winter along the Pacific coasts of Mexico, Central America, and South America (between Las Garzas and Chiloé), but it is not yet clear if all these birds are the rufa subspecies. Winter area fidelity appears to be high, with minimal intra- and inter-annual movement of birds among wintering regions. Researchers often distinguish between those rufa red knots that winter the farthest south (in Argentina and Chile), and therefore undertake the longest-distance migrations ("southern-wintering"), from those that winter farther north in northern Brazil and the Southeast United States ("northern-wintering"), with some notable physiological, genetic, and ecological differences between the two groups.

<u>Migration Biology and Behavior</u>: Each year some red knots make one of the longest distance migrations known in the animal kingdom, traveling up to 19,000 miles (30,000 km) annually. Red knots undertake long flights that may span thousands of miles without stopping. As *Calidris canutus* 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, the leg muscles, **gizzard**, stomach, intestines, and liver all decrease in size, while the pectoral (chest) muscles and heart increase in size. Due to these physiological changes, *C. canutus* 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, *C. canutus* requires stopovers rich in easily digested food to achieve adequate weight gain that fuels both the next migratory flight and, upon arrival in the Arctic, a body transformation to breeding condition. At some stages of migration, very high proportions of entire shorebird populations may use a single migration staging site to prepare for long flights. Large proportions of the red knot's rangewide population can occur together at a small number of nonbreeding locations, leaving populations vulnerable to loss of key resources. For example, Delaware Bay provides the final Atlantic coast stopover for an estimated 50 to 80 percent of all rufa red knots making their way to the arctic breeding grounds each spring. Although birds from all four wintering populations mix in Delaware Bay, several lines of evidence suggest that birds from the Southern wintering region are more reliant on this staging area relative to birds that winter elsewhere across the range. Individual red knots show moderate fidelity to particular migration staging areas between years.

<u>Northbound Migration</u>: Well-known spring stopover areas along the Atlantic coast of the Americas include Río Gallegos, Península Valdés, San Antonio Oeste, Bahía Blanca, Punta Rasa, and Bahía Samborombón (Patagonia, Argentina); Lagoa do Peixe (eastern Brazil, State of

Rio Grande do Sul); Maranhão (northern Brazil); the Southeast United States (*i.e.*, the Carolinas to Florida); the Virginia barrier islands (United States); and Delaware Bay (Delaware and New Jersey, United States) (see figure 2, below, and figure 4 in the supplemental listing document (Service 2014, p. 50)). 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 of South and North America. Although a few birds may depart before the end of January, the main red knot movement north from Tierra del Fuego occurs in February. Birds moving north from Argentina may make several stops along the coast, and typically arrive in northern Brazil in April. Departure from Brazil tends to occur in the first half of May. Many knots marked in Argentina and Chile are seen on the Atlantic coasts of Florida, Georgia, South Carolina, and North Carolina during, but not before, May. Available data indicate that red knots wintering in the Southeast use at least two distinct spring migration routes—coastal (moving north along the coast to the mid-Atlantic before departing for the Arctic) and inland (departing overland for the Arctic directly from the Southeast coast).

<u>Southbound Migration</u>: Departure from the breeding grounds begins in mid-July and continues through August. Females are thought to leave first, followed by males and then juveniles. Adult *Calidris canutus* pass through stopover sites along the migratory route earlier in years with low reproductive success than in years with high reproductive success. Along the U.S. Atlantic coast, southbound red knots start arriving in July. Numbers of adults peak in mid-August and most depart by late September, although geolocators and resightings have shown some birds (especially northern-wintering knots) stay through November. Well-known fall stopover sites include southwest Hudson Bay (including the Nelson River delta), James Bay, and the Mingan Archipelago in Canada; the coasts of Massachusetts and New Jersey and the mouth of the Altamaha River in Georgia in the United States; the Caribbean (especially Cuba); and the northern coast of South America from Brazil to Guyana (see figure 2, below, and figure 4 in the supplemental listing document (Service 2014, p. 50)). However, birds can occur all along the coasts in suitable habitats. In one study of northern-wintering red knots, the total time spent along the U.S. Atlantic coast (including spring, fall, and for some birds winter) averaged 218 days (range 121 to 269 days), or about 60 percent of the calendar year.

<u>Midcontinental Migration</u>: Geolocator results from red knots wintering in Texas have shown that these birds typically use a central, overland flyway across the midcontinental United States, with birds departing Texas between May 16 and May 21 and using stopover areas in the Northern Great Plains and along southern Hudson Bay. Texas-wintering birds typically use a similar and direct interior flyway across the midcontinental United States during the southbound migration, using southbound stopover sites on the south shore of Hudson Bay (Nelson River Delta to James Bay). Geolocator results suggest that rufa red knots generally exhibit flyway fidelity (*i.e.*, not switching between Atlantic coast and midcontinental routes). However, the geolocator data do show some instances of switching between these two flyways. Several Texas-wintering birds have been shown to use the “typical” midcontinental flyway in spring, but then follow a fall migration route along the U.S. Atlantic coast before returning to Texas via the Gulf coast. To date, no known geolocator tracks from Texas birds have shown use of the Atlantic coast during spring migration, but some resighting data suggest that this may also occur. Even for the same individual bird, the actual routes and number of stopovers can vary considerably from year to year. In one study, red knots wintering in the Northwest Gulf of Mexico spent nearly the entire

nonbreeding phase of their annual cycle (286 days, or 78.4 percent of the calendar year) on the Texas coast. New geolocator data since the listing show that red knots wintering in Louisiana show little exchange with Texas-wintering birds, and tend to migrate along the Mississippi River basin rather than across the Great Plains (Newstead pers. comm. 2019).

Juvenile Habitats: There is little information on where juvenile red knots spend the winter months, and there may be at least partial segregation of juvenile and adult red knots on the wintering grounds. After leaving the Arctic after fledging, juveniles are thought to occupy nonbreeding habitats year-round for their first 2 years.

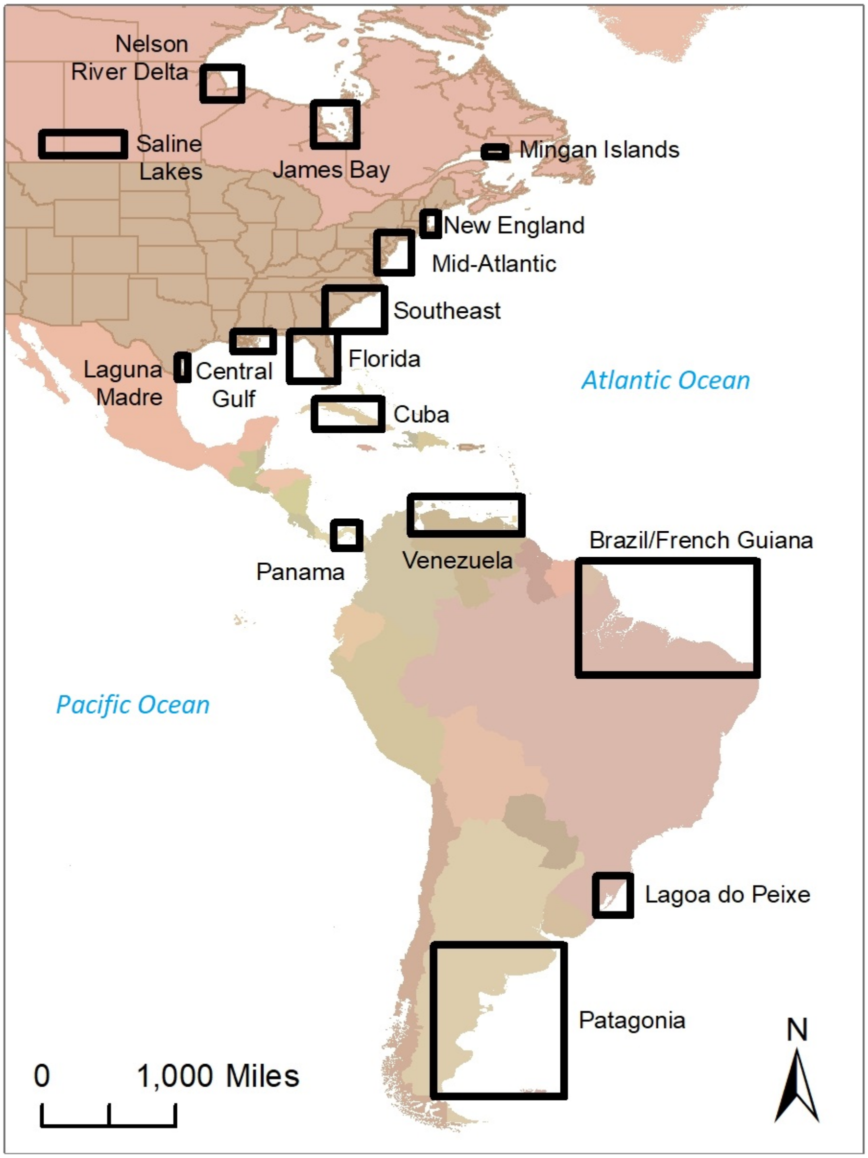


Figure 2. Important Rufa Red Knot Migration Stopover Areas (Spring and Fall)

Nonbreeding Habitat and Diet

Nonbreeding Habitat: Coastal habitats used by red knots in migration and wintering areas are similar in character, generally coastal marine and **estuarine** habitats with large areas of exposed intertidal sediments. Migration and wintering habitats include both high-energy ocean- or bay-front areas, as well as tidal flats in more sheltered bays and lagoons. Preferred wintering and migration habitats are muddy or sandy coastal areas, specifically, bays and estuaries, tidal flats, and unimproved tidal inlets. Along the U.S. Atlantic coast, dynamic and ephemeral features are important red knot habitats, including sand spits, islets, shoals, and sandbars, features often associated with inlets. 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. In nonbreeding habitats, *Calidris canutus* require sparse vegetation and open landscapes to avoid predation.

Available information suggests that red knots use inland saline lakes as stopover habitat in the Northern Great Plains. We have little information to indicate whether or not red knots may also utilize inland freshwater habitats during migration, but data suggest that certain freshwater areas (*e.g.*, wetlands, riverine sandbars) may warrant further study as potential stopover habitats. Available data indicate that small numbers of red knots sometimes use manmade freshwater habitats (*e.g.*, impoundments) along inland migration routes.

Nonbreeding Diet: Across all six subspecies, *Calidris canutus* 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. The mollusk prey is swallowed whole and crushed in the gizzard, which in *C. canutus* is the largest (relative to body size) among any shorebird species evaluated. Large gizzards are among this species' adaptations to a mollusk diet, allowing *C. canutus* to grind the hard shells of its prey. *Calidris canutus* prefer thin-shelled over thick-shelled prey species because they are easier to digest and provide a more favorable meat-to-mass ratio (higher prey quality). From studies of other subspecies, some researchers concluded that *C. canutus* cannot ingest prey with a circumference greater than 1.2 inches (30 millimeters [mm]). For rufa red knots, prey lengths of 0.16 to 0.79 inch (4 to 20 mm) have been observed. Foraging activity is largely dictated by tidal conditions, as *C. canutus* rarely wade in water more than 0.8 to 1.2 inches (2 to 3 cm) deep. Due to bill morphology, *C. canutus* is limited to foraging on only shallow-buried prey, within the top 0.8 to 1.2 inches (2 to 3 cm) of sediment. Along the U.S. Atlantic and Gulf coasts, *Donax* and *Mulinia* clams and blue mussel (*Mytilus edulis*) **spat** are key prey items. A prominent departure from typical prey items occurs each spring when red knots feed on the eggs of horseshoe crabs, particularly (but not exclusively) in the key Delaware Bay migration staging area. Delaware Bay serves as the principal spring migration staging area for the red knot because of the abundance and availability of horseshoe crab eggs. In Delaware Bay, horseshoe crab eggs are a **superabundant** source of easily digestible food. Away from the coasts, the red knot's diet is poorly known but may include brine shrimp or insects.

Subspecies Needs

Table 2 summarizes the rufa red knot's needs based on the detailed information in the supplemental listing document (Service 2014, pp. 22-79).

Individual Needs: The resource needs of individual rufa red knots are described above in terms of habitat and food requirements. The timing of food resources (*e.g.*, insect prey on the breeding grounds, horseshoe crab eggs or mollusks at stopover areas) is a critical need for this highly migratory subspecies, and across all habitats red knots require sparse vegetation because open vistas are considered a key element in predator defense. The degree to which juveniles segregate from adults during wintering and migration is poorly known. Although juvenile habitats and diets are thought to be similar to adults, certain nonbreeding areas may be disproportionately important to juvenile birds.

Population Needs: At the population level, the red knot requires the maintenance of demographic parameters sufficient for stable or growing populations. These demographic rates are primarily driven by the quality, quantity, and distribution of breeding and nonbreeding habitats; the degree of synchronicity in the availability of food resources across the range and across the annual cycle; and the frequency and severity of discrete, stochastic events that depress reproductive and survival rates (*e.g.*, late snow melt in the Arctic, tropical storms during migration, red tides on the wintering grounds, periodic spikes in predation pressure). For example, red knot populations need, at least in some years, favorable weather conditions (*e.g.*, suitably timed snowmelt for nesting) and low predation pressure on the breeding grounds, which together allow for high rates of hatching and fledging.[1] Similarly, populations require survival rates for juveniles and adults to be above minimum threshold levels during the migration and wintering periods.

Subspecies Needs: At the subspecies level, the rufa red knot requires multiple resilient populations displaying genetic and ecological variation across latitudes, habitats, and migration strategies. This diversity within the subspecies is the "raw material" that may allow the rufa red knot to adapt to pervasive and ongoing changes in a variety of environmental conditions.

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[1] Breeding success of High Arctic shorebirds varies dramatically among years in a somewhat cyclical manner, largely driven by rodent-mediated predation pressure and weather. Periodic years of low reproductive output are not a threat to the red knot. However, potential trends of increasing frequency, severity, or geographic extent of reproductive "bad years," as might be expected with climate change, are a threat to this subspecies.

Table 2. Red knot resource needs

Season	Life Stage	Needs
Winter	adults	Wide, sparsely vegetated beaches, shoals, tidal mud or sand flats, or mangrove-dominated shorelines, with ample small (generally ≤0.8 inch (20 mm) long) mollusk prey (typically snails, clams, and mussels). Arthropods and other invertebrate prey may be locally important.[2] Foraging areas are intertidal, from the **wrack** line seaward to a water depth of 2 to 3 cm, with prey probed from the surface to a depth of 2 to 3 cm. Roosting areas are supratidal areas with open vistas, located near[3] foraging areas.
Migration	adults	- A reliable network of coastal and inland staging areas with abundant, high-quality[4] prey timed to occur when birds are present and allowing particularly high rates of weight gain; AND - An ample supply of other coastal and inland stopover habitats distributed across the range, allowing birds to shift among habitat patches (on daily, seasonal, and annual scales) based on food, predators, disturbance, weather, tides, and other conditions. - Coastal staging and stopover habitats are generally similar to wintering habitats, except that in some areas the primary food shifts from small mollusks to horseshoe crab eggs. - Inland staging and stopover habitats are less well known. Alkaline or saline lakes in the northern plains (U.S. and Canada) may be both staging areas and stopover habitats. Other stopover habitats may include riverine wetlands and sandbars, and manmade impoundments.
Year-round	juveniles, nonbreeding adults	Generally thought to be similar to adult wintering and migration habitats, though juveniles may partially segregate from adults. All juveniles (<2 years old) and some adults (*e.g.*, those that lack adequate fitness to breed in a particular year) do not migrate to the arctic breeding grounds and remain in nonbreeding habitats throughout June and early July.
Breeding	adults, eggs, chicks	Upland tundra for nesting, with low, sparse, herbaceous vegetation (*e.g.*, *Dryas* spp., lichens, moss), located near[5] freshwater wetland or lake-edge foraging areas with suitably timed insect hatch to provide abundant prey when chicks are present. In at least in some years, favorable weather conditions (*e.g.*, suitably timed snowmelt for nesting) and low predation pressure, which together allow high rates of hatching and fledging.

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[2] See Service 2014 (table 1, pp. 70-73) for documented prey species across the nonbreeding range.

[3] Roosting areas immediately adjacent to foraging areas have been documented, and are presumed to be the most energetically advantageous. However, migrants foraging in Delaware Bay are known to roost at night and during spring high tides on New Jersey's Atlantic coast (Service 2014, p. 64), a distance of at least 8 miles (13 km).

[4] High-quality prey are in the necessary size range and depth for red knots to consume, and have a high meat-to-mass ratio (*e.g.*, thin-shelled mollusks). Horseshoe crab eggs are a high-quality food, and are eaten preferentially when and where they are available.

[5] Best available information indicates nest sites are within 600 feet of a freshwater wetland and, although nests are typically within 31 miles (50 km) of the ocean, knots do not typically use saltwater habitats on the breeding grounds (Service 2014, pp. 29-30). However, the total number of rufa red knot nests studied to date is small and highly concentrated on just one island (Smith pers. comm. 2019). Thus it is possible that a greater diversity of nesting and foraging habitats is utilized across the breeding range but not yet documented.

Factors Influencing Viability

Conservation Efforts: Rufa red knot populations benefit from a range of past and ongoing conservation efforts. These are described in the Recovery Outline (Service 2019, pp. 5-9), discussed further below (under Historical Condition), and summarized here. Passage of the Migratory Bird Treaty Act in 1918 (40 Stat. 755; 16 U.S.C. 703-712) (MBTA) is credited with ending the overhunting of rufa red knots in the United States, allowing populations to at least partially recover from substantial declines that occurred in the 1800s. International efforts are now underway to curtail red knot hunting in the Caribbean and South America. Many important red knot nonbreeding habitats identified to date are included in the Western Hemisphere Shorebird Reserve Network[6] (WHSRN), a science-based, partnership-driven, conservation initiative for protecting the ecological integrity of essential habitats for shorebirds throughout the Americas. For example, WHSRN partners in Chile have established the Centro Bahía Lomas for research and management of the most important site in the Southern wintering region (Bahía Lomas on the island of Tierra del Fuego). In Delaware Bay—the single most important migration staging area—intensive State-led survey and marking efforts support conservation, including management of disturbance, of intertidal oyster aquaculture, and of horseshoe crab harvests. Across the range of the rufa red knot, marking and tracking of birds (*e.g.*, through the Banded Birds database,[7] geolocators, the Motus[8] network) is leading to better understanding and management of nonbreeding habitats. The Atlantic Flyway Shorebird Initiative,[9] which includes red knot as a focal species, is working across jurisdictions from Canada to Argentina to address habitat, predation, human disturbance, hunting, and knowledge gaps. A similar effort, the Midcontinent Shorebird Conservation Initiative, is currently in the early planning phases and is also expected to select red knot as a focal species (Newstead pers. comm. 2020).

Threats Definition: Despite these conservation efforts, the rufa red knot faces numerous threats across its range on multiple geographic and temporal scales. These threats are affecting the red knot now and will continue to have subspecies-level effects into the future (79 FR 73705-73748). The Service defines "threat" as any action or condition that is known to or is reasonably likely to negatively affect individuals of a species. This includes those actions or conditions that have a direct impact on individuals, as well as those that affect individuals through alteration of their habitat or other required resources. Depending on the context, we use the term "threat" as a general term to describe—either together or separately—the source of the action or condition that negatively affects the species (*e.g.*, housing development), or the action or condition itself, which includes direct impacts (*e.g.*, disturbing individuals) and stressors (*e.g.*, habitat or resource loss). The mere identification of "threats" is not sufficient to compel a finding that a species meets the statutory definition of an endangered species or of a threatened species. Describing the negative effects of the threats in light of the exposure, timing, and scale at the population and species levels provides a clear basis upon which we make a listing determination.

Such an assessment was conducted in the red knot listing final rule, and a full analysis of threats can be found in the supplemental listing document (Service 2014, pp. 124-313). A framework for

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[6] https://whsrn.org/

[7] http://bandedbirds.org/

[8] https://motus.org/

[9] https://atlanticflywayshorebirds.org/

classifying threats, and a summary assessment of threats to the red knot, are presented below in tables 3 and 4, respectively.

Primary Threats: In the final listing rule, the Service determined that the rufa red knot is threatened under the ESA due to the following primary threats: loss of breeding and nonbreeding habitat (including sea level rise, coastal engineering, coastal development, and arctic ecosystem change); 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. These threats that are driving the red knot's status as a threatened species under the ESA are classified as High Severity in table 4.

Secondary threats: In the final listing rule the Service also evaluated other, secondary factors that likely cause additive red knot mortality. Individually the secondary factors are not expected to have effects at the level of the listed taxon. Cumulatively, however, these factors are expected to exacerbate the effects of the primary threats, as they further reduce the subspecies' resiliency and possibly representation and redundancy. These secondary factors include hunting in nonbreeding areas; predation in nonbreeding areas; harmful algal blooms; human disturbance; oil spills; and wind energy development, especially near the coasts. These secondary threats are classified as Moderate Severity in table 4.

Low Severity Threats: Classified as Low Severity in table 4 are those threats that were evaluated in the final listing rule, but which the Service concluded are not contributing to the red knot's threatened status under the ESA. These include beach cleaning, agriculture, research activities, and disease.

Geographic Variability: The classifications in table 4 are based on the Service's rangewide assessment of threats to the red knot. Due to geographic variability, management priorities in a particular local area may differ from those shown in table 4. For example, in an area with abundant intertidal habitat that is not facing any imminent threats, addressing coastal engineering or development may be a lower priority than managing a localized predation problem, despite the fact that, at a rangewide scale, the Service considers coastal engineering/development more urgent than predation in nonbreeding habitats.

Manageability: Manageability of threats is assessed here without regard to the current or projected availability of regulatory mechanisms or funding, including those afforded by the ESA, to implement management actions. Thus, it reflects only the potential feasibility of management.

Table 3. Threat classification categories

Life Phase	Breeding (B) Migration (M) Wintering (W)
Severity	High - threat is driving ESA threatened status Moderate - threat causes additive mortality and/or negative synergistic effects Low - minor or potential threat
Certainty	High - Very likely to occur/continue and to impact subspecies in predictable ways Moderate - Very likely to occur/continue, but subspecies impacts are not well known or are unpredictable Low - Likelihood of threat occurring/continuing is uncertain and/or severity of impacts is uncertain
Scope	Rangewide - includes threats that act throughout either the breeding or nonbreeding range, but may not act across both Regional - threats that act across an entire wintering region or migration flyway; or across a substantial portion of a wintering region, flyway, or the breeding range Local - threats that act at the scale of a discrete action or activity, or a geographic clustering of actions or activities
Urgency of Management Response	High - immediate need, 1 to 3 years Moderate - 3 to 5 years Low - 6+ years
Manageability	Short-term - action at a local or regional scale can abate this threat within 10 years Long-term - action at a local or regional scale can abate this threat within 25 years Intractable - this threat cannot be directly abated by action at the geographic and temporal scales considered in recovery plans. However, monitoring may be important, and abating other threats may indirectly help by conserving the subspecies' **adaptive capacity** to cope with this threat (*i.e.*, by sustaining/ enhancing resiliency, representation and/or redundancy)

Table 4. Classification of threats to the red knot

Threat	Life Phase	Severity	Certainty	Scope	Urgency of Management Response*	Manageability
Sea level rise	MW	High	High	Rangewide	NA	Intractable**
Coastal engineering***	MW	High	High	Regional	High	Long-term
Coastal development	MW	High	High	Rangewide	High	Long-term
Beach cleaning	MW	Low	High	Regional	Low	Short-term
Invasive vegetation	MW	Moderate	High	Regional	Moderate	Short-term
Agriculture	MW	Low	Low	Local	Low	Long-term
Aquaculture	MW	Moderate	High	Local	High	Short-term
Arctic ecosystem change	B	High	Moderate	Rangewide	NA	Intractable
Arctic human development	B	Low	Low	Local	Moderate	Long-term
Sport hunting	MW	Low	Moderate	Regional	Low	Short-term
Subsistence hunting	MW	Moderate	Low	Regional	Moderate	Short-term
Research activities	MW	Low	High	Local	Low	Short-term
Parasites	BMW	Low	Low	Rangewide	NA	Intractable
Disease	BMW	Low	Moderate	Rangewide	NA	Intractable
Predation in nonbreeding areas	MW	Moderate	High	Rangewide	Moderate	Short-term
Predation in breeding areas	B	High	Moderate	Rangewide	NA	Intractable
Reduced nonbreeding food availability from marine ecosystem change (*e.g.*, ocean acidification, ocean warming, marine diseases/ parasites/ invasive species)	MW	Moderate	Low	Rangewide	NA	Intractable
Reduced nonbreeding food availability from proximate human activity (*e.g.*, marine harvest, sand placement, beach driving)	MW	High	High	Regional	High	Short-term
Timing asynchronies	BMW	High	Moderate	Rangewide	NA	Intractable
Human disturbance	MW	Moderate	High	Regional	High	Short-term
Competition with gulls	M	Low	Low	Local	Low	Long-term
Wind energy development	MW	Moderate	Moderate	Regional	High	Short-term
Harmful algal blooms	MW	Moderate	Low	Regional	NA	Intractable
Oil spills	MW	Moderate	Moderate	Regional	High	Long-term

* Urgency is not applicable (NA) to intractable threats.

** The accelerating global and regional rates of sea level rise cannot be slowed by direct action under a recovery plan. However, recovery actions can include responses to sea level rise aimed at slowing or offsetting the associated habitat impacts. For example, carefully designed **living shorelines** or **beach nourishment** projects may help retain or restore intertidal habitats impacted by sea level rise.

*** Coastal engineering includes all activities described under Shoreline Stabilization in the supplemental listing document, such as hard structures, beach nourishment, and dredging. Such activities are often, but not always, conducted in response to sea level rise. Hard structures are known to exacerbate losses of intertidal habitats by blocking their migration. When not precluded by human structures or interventions, landward and/or longshore migration of intertidal habitats is the natural, geologic response of many coastal systems under rates of slow to moderate sea level rise (Service 2014, pp. 126-159).

Historical Condition

Historical Hunting: The supplemental listing document (Service 2014, pp. 79-84; 180-181) describes a historical decline in red knots in the United States caused by overhunting throughout the 1800s. Following passage of the MBTA, red knot numbers appeared to rebound during the first half of the 20th century. It is unclear whether the red knot population fully recovered its historical abundance following the period of unregulated hunting, and it is possible this episode left the species more vulnerable to new threats that emerged over the second half of the 20th century. This era of intensive hunting has also been implicated as one factor, along with coastal development, that may have led to changing use of spring stopover areas along the Atlantic coast, possibly including increased reliance on Delaware Bay, as discussed further below.

Delaware Bay Staging Area Discovery: It was the discovery of a massive shorebird staging phenomenon in Delaware Bay in the early 1980s that led to the first major milestone in red knot conservation since passage of the MBTA almost 70 years earlier. In 1986, Delaware Bay was designated the first WHSRN site due to its hemispheric significance to red knots and several other shorebird species. Subsequent WHSRN designations have included important red knot sites in Chile, Argentina, Brazil, the United States, and Canada. For decades, various partners associated with WHSRN have been spearheading shorebird conservation across this network, which now includes most major red knot migration and wintering areas.

Although the current importance of Delaware Bay as a red knot staging area is undisputed, its historical role is less clear. Delaware Bay was not known as a major shorebird stopover area until the early 1980s, despite earlier detailed shorebird studies in the South Jersey region. It is unclear if the large magnitude of the shorebird-horseshoe crab phenomenon was simply missed by science until the early 1980s, or if the distribution of red knots and other shorebirds changed over the period of the historical record. For much of the early and mid-20th century, the shorebird 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 previous overhunting, as mentioned above) and horseshoe crabs (caused by intensive harvest for fertilizer and livestock feed). Alternatively, it may be that the red knot did not make extensive use of Delaware Bay prior to its population decline at the end of the 19th century. 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. This second theory is supported by the fact that the spring migration was historically more spread out along the mid-Atlantic, rather than highly concentrated as it is now (*e.g.*, in Delaware Bay and Virginia). We have no definitive information indicating how long shorebirds has been reliant on horseshoe crab eggs in Delaware Bay prior to the early 1980s (Service 2014, pp. 83-84).

Since discovery of the importance of Delaware Bay, research and conservation efforts have developed in this key staging area and in many other areas, involving numerous partners. Annual spring counts have been conducted across Delaware Bay since the early 1980s, as have extensive bird marking, research, and conservation efforts such as managing disturbance to the birds. This work in Delaware Bay is led by the States of New Jersey and Delaware in partnership with the Service and numerous agency, academic, and conservation groups from around the world. One of those partners, the Canadian Wildlife Service, documented the southernmost (and historically the largest) red knot wintering area in Argentina and Chile (particularly the island of Tierra del Fuego that spans both countries) during a comprehensive South American shorebird survey from 1982 through 1985. Various partners have subsequently documented three other wintering regions and numerous migration stopovers across the red knot's range.

Horseshoe Crab Harvest: Delaware Bay was also the focus of the next major threat to red knot populations following their recovery from overhunting in earlier decades. The 1990s saw steep increases in the harvest of horseshoe crabs, this time for the bait and biomedical industries. Shorebird numbers in Delaware Bay saw modest declines in the 1990s, and several lines of evidence indicated that reduced availability of horseshoe crab eggs was negatively impacting rates of shorebird weight gain and survival. By 1998, the Atlantic States Marine Fisheries Commission (ASMFC) adopted the first Fishery Management Plan for horseshoe crabs, last revised in 2012 (ASMFC 2012, entire). This was the first and is still the only ASMFC plan aimed at managing a harvested species (horseshoe crab) specifically to protect a dependent species (red knot). Unfortunately, red knot numbers in Delaware Bay and Tierra del Fuego continued to drop—now precipitously—through the mid-2000s, resulting in petitions for ESA listing starting in 2004. By 2012, red knot numbers appeared to have stabilized, though at a much reduced level relative to the 1980s. The Service has determined that the horseshoe crab bait harvest has been adequately managed at least since 2013 (Service 2014, p. 230), when the 2012 plan update went into effect (ASMFC 2012, entire). However, the continued sufficiency of future crab egg supplies remains uncertain and the management of this fishery remains controversial.

Coastal Development: Coastal development since the mid-20th century was accompanied not only by shoreline stabilization, as discussed above, but also by increased levels of recreation and other human activities that can result in disturbance to red knots. Excessive disturbance can impact red knot energy budgets and weight gain, and can also preclude red knot use of otherwise preferred foraging and roosting habitat (Hunt *et al.* 2018, pp. 18-22, 36; Watts 2017, p. 66; Service 2014, pp. 269-272). At a landscape scale, development and disturbance are thought to have significantly reduced red knot use of Mustang Island, Texas and the Gulf coast of Florida in recent decades (Service 2014, pp. 267, 270).

Current Condition

For the purpose of this assessment, we define viability as a description of the ability of the species to sustain populations in the wild over multiple generations through time. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation, and redundancy. Together, these "3Rs," and their core parameters of abundance, distribution, and diversity, constitute the key characteristics that contribute to a species' ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole (Service 2016, pp. 9, 19). Each of the 3Rs is discussed further below. The current condition of each population is described below and summarized in table 9.

Resiliency

Resiliency describes the ability of populations to withstand stochastic events. Resiliency is positively related to population size and growth rate and may be influenced by the degree of connectivity among populations. Generally speaking, populations need abundant individuals within habitat patches of adequate area and quality in order to withstand or bounce back from environmental or demographic stochastic events (Service 2016, p. 12). Rufa red knot populations experience high levels of environmental stochasticity stemming from several aspects of their life history. For example, the coastal habitats occupied by red knots for most of the year are highly dynamic and subject to seasonal and multi-year cycles of erosion and accretion, as well as landform migration (Service 2014, pp. 67, 134). Stochastic weather events commonly affect food availability in both stopover and breeding habitats, and major storms can dramatically alter migration routes (Service 2014, pp. 253-265). Breeding success varies dramatically among years based largely on stochastic factors of weather and predation pressure (Service 2014, p. 32), as discussed above.

<u>Wintering Population Estimates</u>: For the red knot, we evaluate resiliency primarily as a function of population size, which we conclude is best measured on the wintering grounds. Counts on the wintering grounds 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 migration stopover areas. This minimizes errors associated with turnover or double-counting that can occur during migration counts (Service 2014, p. 85). The population data given below has been updated since the listing to include the best information that is currently available. Relative to the time of listing, the abundance estimate for the Southern wintering region is about the same, and estimates for the Southeast United States/Caribbean and Western Gulf of Mexico/Central America wintering regions have been refined slightly. However, there has been a substantial increase in the estimated abundance of red knots wintering in Brazil, likely due to improved survey methods (Mizrahi 2020, p. 6). Population estimates for each of the four wintering regions are discussed in more detail below. Though clearly also important to resiliency, habitat conditions on the wintering grounds are discussed under redundancy, below.

Aerial surveys of Tierra del Fuego (Chile and Argentina) and the adjacent Patagonian coast to the north (Argentina) have been conducted since 2000, and previously in the early 1980s, by the same observers using consistent methodology (Morrison *et al.* 2004, p. 61-63). This is the best available long-term data set for a wintering region. As shown in table 5 and figure 3, counts have been markedly lower in recent years. Comparing the average counts for Tierra del Fuego for the 1980s and 2000 (52,244) with the period 2018 to 2020 (11,608), the recent counts are more than 75 percent lower than the earlier counts. Since 2011, the Southern wintering population has stabilized at a relatively low level.

An independent population estimate for the Southern wintering region, based on modeling using resighting data from Río Grande, Argentina, supports the observation that declines did not begin until after 2000. González *et al.* (2004, p. 361) estimated the 1995 wintering population in Argentina and Chile at 74,193 (95-percent confidence interval 50,000 to 110,000). This same model produced population estimates that were within 5 to 15 percent of the aerial counts from 2001 to 2003, increasing confidence based on corroboration between the two methods.

Table 5. Aerial counts and modeled population size estimates of red knots in the Southern wintering region, winters 1982 to 2020

Year	Tierra del Fuego* Aerial Count	Patagonia* Aerial Count	Total Aerial Count	Modeled Estimate Tierra del Fuego and Patagonia
1982		14,314[a]		
1985	53,232[a]			
1995				74,193[b]
2000	51,255[c]			
2001	29,745[c]**			32,623[b]
2002	27,242[c]	2,029[c]	29,271[c]	34,140[b]
2003	29,915[c]	560[c]	30,475[c]	28,966[b]
2004	30,778[d]	880[d]	31,658[d]	
2005	17,653[e]			
2006	17,211[e]			
2007	17,360[e]			
2008	14,800[e]			
2009	17,780[e]			
2010	16,260[e]			
2011	9,850[e]			
2012	14,200[d]	574[d]	14,774[d]	
2013	10,105[e]			
2014	14,200[e]			
2015	12,780[e]			
2016	11,150[f]			
2017	13,127[f]			
2018	9,840[g]			
2019	13,190[h]			
2020	11,795[i]			

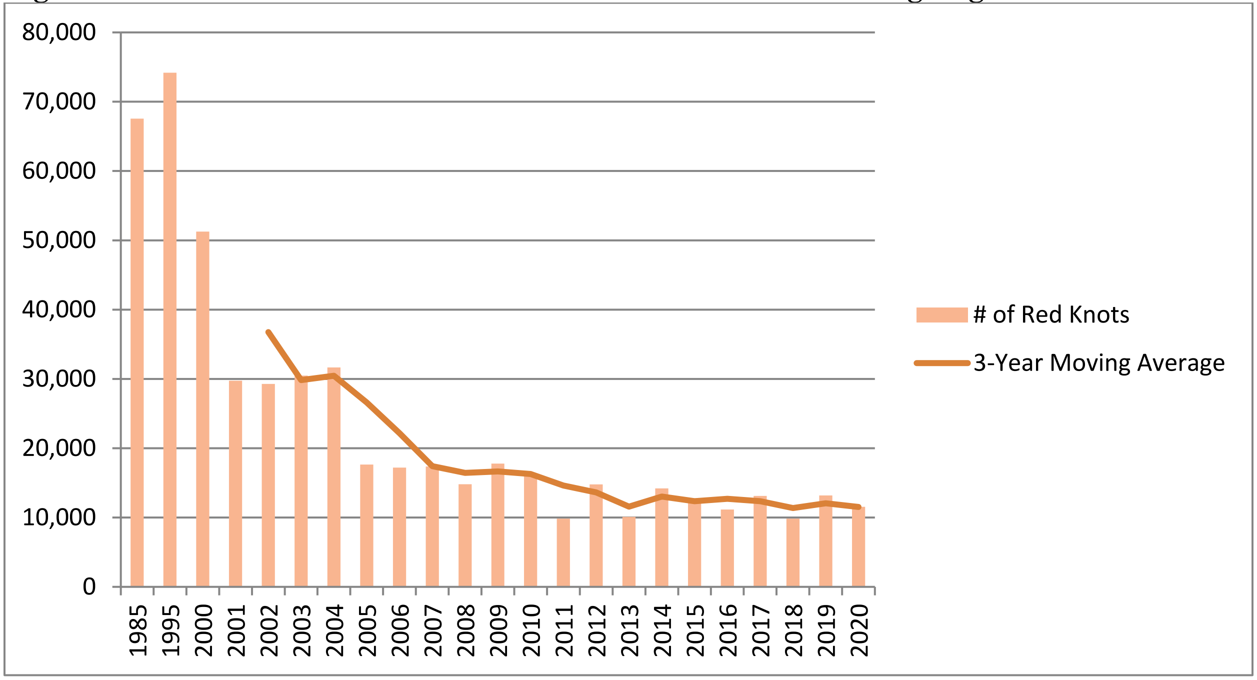
Table 5 footnotes and sources:

*See figure 3 in the supplemental listing document (Service 2014, p. 43) for a map.

**Only the single largest wintering area (Bahía Lomas) and one small adjacent site were surveyed on Tierra del Fuego in 2001.

(a) Morrison and Ross 1989, pp. 226, 252
(b) González *et al.* 2004, p. 361
(c) Morrison *et al.* 2004, p. 65
(d) Morrison pers. comm. 2014
(e) Dey *et al.* 2015, p. 3
(f) WHSRN 2017
(g) WHSRN 2018a
(h) WHSRN 2019
(i) WHSRN 2020

Figure 3. Red Knot Numbers and Trend in the Southern Wintering Region*



*Where counts for both Tierra del Fuego and Patagonia are available for a given year, they are added together in the chart. As the only available baseline data, the 1982 count for Patagonia has been added to the 1985 count for Tierra del Fuego. The 1995 number is based on modeling (González *et al.* 2004, p. 361), while all others are from aerial surveys. See table 5, above.

As shown in table 5, declines were even sharper (about 96 percent) along the roughly 1,000 miles (1600 km) of Patagonian coast than in the core area on Tierra del Fuego. The population thus appears to have contracted to the core sites, leaving few birds at the "peripheral" Patagonian sites (COSEWIC 2007, p. 11). Based on the sharp numerical declines and marked geographic contraction, we conclude the Southern wintering population currently has low resiliency. Based on the high-quality, long-term survey data set, we have high confidence in this conclusion. The ability of the Southern population to withstand stochastic disturbance is further compromised by the disproportionately high reliance of this population on a single spring migration staging area, Delaware Bay (Service 2014, pp. 76-79), and by its extremely long migration.

Population sizes and trends for the other three wintering regions are far less certain. Based on best available information, we conclude that the North Coast of South America wintering population is currently about 31,000 birds (Mizrahi 2020, p. 6), the Southeast United States/Caribbean population is about 15,500 birds including about 5,100 in the Caribbean (Lyons *et al.* 2017, p. 11), and the Western Gulf of Mexico/Central America population is about 5,500 birds (a rough estimate of 2,000 to 4,000 in Texas and Northern Mexico and at least 2,500 in Louisiana, with no numerical estimates available for Central America (Newstead pers. comm. 2019, 2020)). All of these estimates are associated with lower certainty due to sporadic and inconsistent survey and modeling efforts, but the estimate for the Western Gulf of Mexico/Central America population is particularly uncertain.

Table 6. Current Estimates of Rufa Red Knot Abundance by Wintering Region

Wintering Population	Current Abundance Estimate	Certainty	Source
Southern	11,600	High	WHSRN 2020, 2019, 2018a
Northern Brazil	31,000	Moderate	Mizrahi 2020, p. 6
Southeast U.S./Caribbean	15,500	Moderate	Lyons *et al.* 2017, p. 11
Western Gulf of Mexico/Central America	5,500	Low	Newstead pers. comm. 2019, 2020
Total	**63,600**		

Available data are insufficient to draw any conclusions about trends in the North Coast of South America population. Based on the changing survey methods we do not interpret the newer, larger estimate for this population as an increase, but also we lack any evidence of a decline. We conclude that this population is at least stable, and we conclude (with moderate confidence) that the North Coast of South America population has high resiliency based on the relatively large population size and lack of evidence of any declines.

We have no evidence that the Southeast United States/Caribbean population has declined, and earlier regional abundance estimates suggest this population has been roughly stable since the 1980s (Service 2014, pp. 91-92). We conclude with moderate confidence that the Southeast United States/Caribbean population has moderate resiliency based on the relatively smaller population size but apparent stability.

Several lines of evidence suggest the Western Gulf of Mexico/Central America population may be declining (*e.g.*, expert opinion, Christmas Bird Count data, long-term surveys of two areas in Texas). However, certainty about this conclusion is low (Newstead pers. comm. 2019, Service 2014, pp. 89-91). Given the low numbers and possible downward trend, we consider the Western Gulf of Mexico/Central America population to have low resiliency, though conclusions about the resiliency of this population are highly uncertain.

Population Trend Synthesis: As discussed below, data from a long-term aerial survey of Delaware Bay show a similar decline (about 70 percent) as the Southern wintering population, and over roughly the same time period (Service 2019, pp. 31-33). Data sets associated with lower confidence, from three South American spring stopovers, also suggest declines roughly over this same timeframe. Surveys from Virginia (spring) also suggest a decline. Analyses of long-term population trends using national or regional data from volunteer shorebird surveys and other sources have also generally concluded that rufa red knot numbers declined, probably sharply, around this time (Service 2014, pp. 114-116). The Southern wintering population, which had been the largest and which is disproportionately reliant on Delaware Bay, has since stabilized but shows no sign of recovery to date. As discussed in detail in the supplemental listing document, overharvest of the horseshoe crab in Delaware Bay is considered the key causal factor in this decline, though numerous other past, ongoing, and emerging threats have also been identified as discussed above.

In summary, the sharp decline of the Southern wintering population that occurred in the 2000s (likely due to horseshoe crab overharvest in Delaware Bay) and its stabilization since 2011 are corroborated by declining counts at certain stopover areas and by analyses of other data sets. The decline of the Southern population drove a decline of the subspecies as a whole (Service 2014, pp. 84-116). Although less reliant on Delaware Bay, the Northwestern Gulf of Mexico/Central American wintering population is also thought to have declined in recent decades, while the other two wintering populations are considered stable.

Full Life-Cycle Assessment: Characterizing resiliency based primarily on estimates of red knot abundance in each of the four wintering populations necessarily reflects demographic influences across the subspecies' entire annual cycle, not just on the wintering grounds (*i.e.*, abundance trends reflect adult survival across the wintering, migration, and breeding periods; reproductive rates; and rates of juvenile survival and recruitment). Reduced food availability in Delaware Bay due to commercial harvest and subsequent population decline of the horseshoe crab is considered a primary causal factor in the decline of the red knot in the early 2000s, particularly the Southern wintering population (Service 2014, pp. 230-248). Although horseshoe crab egg availability is not currently thought to be limiting red knot populations, newer information continues to underscore the importance of food supplies at the Delaware Bay staging area to the rest of the annual cycle (Duijns *et al.* 2017, entire). However, we generally lack data indicating which phase(s) of the life cycle are currently limiting the abundance of each wintering population and of rufa as a whole. A further complication is that red knots from the four wintering populations at least partially co-occur during migration and possibly on the breeding grounds (Service 2014, pp. 29, 46, 54, 76-79). Thus, we generally cannot distinguish how the migration and breeding phases may be differentially influencing the resiliency of the four wintering populations. Although evidence indicates disproportionate use of certain migration areas by a particular wintering population (or temporally staggered use by multiple wintering populations) (Kazyak *et al.* 2018, pp. 1-2, 8; Service 2014, pp. 45-46, 76-79), we are limited by available information to mainly considering how the migration and breeding phases may be affecting the resiliency of rufa as a whole.

Migration: Studies have shown red knot survival rates are influenced by the condition (weight) of birds leaving the Delaware Bay staging area in spring. Insufficient horseshoe crab eggs is the best supported explanation for the decline in the early 2000s of the Southern wintering population, which is more reliant on Delaware Bay relative to other wintering populations. A long-term aerial survey of Delaware Bay 1-day peak counts allows for trend analysis. Due to high stochasticity in the data, we look at a 3-year moving average of these aerial counts. With inconsistent survey coverage, the 3-year average from 1981 to 1983 (the earliest time period) was just under 60,000 birds. Regular surveys began in 1986. From 1989 to 1991 the 3-year averages were between 56,000 and 59,000, but then began to drop. The 3-year average hit a low point of below 15,000 birds from 2005 through 2008, and did not climb back above 20,000 birds until 2013. The average of the most recent counts, from 2018 through 2020, was just over 27,300 birds, or less than half of the numbers recorded in the 1980s. Three-year average counts were relatively steady from 2013 through 2020 (Niles pers. comm. 2020; Service 2019, pp. 31-33). Likewise, modeled estimates of the total stopover population in Delaware Bay were generally steady from 2011 through 2019, averaging about 47,600 red knots (Lyons 2019, p. 6). Under the current fishery management framework, the present horseshoe crab harvest is not considered a threat to the red knot because harvest levels are tied to red knot populations via scientific modeling. Although the future sufficiency of crab eggs remains uncertain, most data suggest that the volume of horseshoe crab eggs is currently sufficient to support the Delaware Bay's stopover population of red knots at its present size (Service 2014, pp. 230-248). Given a rangewide estimate of 63,600 total red knots, Delaware Bay's recent stopover population of about 47,600 knots represents about 75 percent of total rufa. This is consistent with an earlier estimate that the bay supported roughly 50 to 80 percent of all rufa red knots during spring migration (Brown *et al.* 2001, p. 10). Thus, although the rangewide abundance of rufa red knots remains substantially reduced, the proportion of birds using Delaware Bay appears to be stable.

We are not aware of any other staging areas that have experienced a similarly serious impairment as the Delaware Bay food shortage of the early 2000s. However, the vulnerability of red knots to conditions at staging areas is well-established (Duijns *et al.* 2017, entire; Service 2014, pp 49-51; Iwamura *et al.* 2013, entire). Aside from the horseshoe crab harvest, a number of other stressors have been identified in Delaware Bay (Partnership for the Delaware Estuary 2017, entire; Smith *et al.* 2017a, entire) and are likely also operating in other staging areas (DeFeo *et al.* 2009, entire; Kennish 2002, entire). Conditions in staging areas may be limiting the resiliency of one or more rufa red knot populations.

Relative to staging areas, other individual stopover habitats are generally considered to have less impact on the resiliency of rufa populations, though the cumulative contribution of stopover habitats to this subspecies' resiliency is significant. As described above (under Factors Influencing Viability), a number of threats are known to be affecting migration habitats and migrating birds across the range of the rufa red knot. Thus, the best available information suggests that conditions during migration are limiting the resiliency of one or more rufa red knot populations.

Conditions in nonbreeding areas influence survival of juvenile birds as well as adults. Because juveniles do not breed until at least age 2, the recruitment rate into the breeding population depends largely on the food and habitat conditions these young birds encounter in nonbreeding areas during the first 2 years. Modeling by Schwarzer (2011, pp. 29-30) involving birds banded from 2005 through 2010 found that, across multiple years, the red knot population in Florida (part of the larger Southeast/Caribbean population) was stable at around 8.75 percent juveniles among wintering birds; the population increased with 13 percent juveniles. Other modeling suggests that a higher percentage of juveniles may be needed for population growth (Wilson and Morrison 2018, p. 2), and may further elucidate whether the prevalence of juveniles is an indicator of population trend.

Breeding: The resiliency of all four red knot wintering populations is strongly influenced by conditions on the breeding grounds. The Canadian Arctic where red knots breed is among the fastest warming regions on Earth, and both tundra and freshwater ecosystems are changing rapidly in response (Service 2014, pp. 168-177). Due to the vast size and remoteness of the region and the fact that red knots are solitary nesters, however, only the basics of breeding biology are known, and many presumptions are extrapolated from other subspecies. Smith (pers. comm. 2019) estimates that only about 50 to 75 rufa red knot nests have been directly documented to date, with 80 to 90 percent of those on just one island (for a summary of this work on breeding rufa see Service 2014, pp. 27-33).

Preliminary analysis suggests that an average reproductive rate in the range of 1.5 to 2 chicks per pair may be necessary for a stable population (Wilson and Morrison 2018, pp. 1-2), but further work is needed to refine this estimate. Productivity trends cannot be determined by direct observation, though attempts are made to infer "good" and "bad" breeding years from the timing and relative abundance of adult males, adult females, and juveniles observed during fall migration surveys. One review of historical data by Fraser *et al.* (2013, entire) suggests that conditions on the breeding grounds may already be impacting red knot resiliency. This review found indications that disruption of the rodent cycle, possibly driven by climate change, could have been a factor in the red knot decline observed in the 2000s, by shifting predation pressure from rodents to shorebirds.[10] However, additional studies would be needed to support this hypothesis (Fraser *et al.* 2013, p. 13). Changes on the breeding grounds could be impairing the resiliency of one or more red knot populations, but available information does not support firm conclusions regarding effects (or lack thereof) on current levels of resiliency.

As discussed above, some evidence indicates that at least three of the wintering populations may be genetically distinct (Baker *et al.* 2013, entire), suggesting breeding segregation of wintering populations. However, we do not yet have a full picture of the degree to which segregation is occurring, nor do we know if segregation is achieved by way of geographic separation, mate selection, or both. If segregation is at least partially geographic, then red knots from different wintering regions could be differentially affected by ongoing artic ecosystem changes across the vast expanse of their breeding grounds.

Representation

Representation describes the ability of a species to adapt to changing environmental conditions over time. It is characterized by the breadth of genetic and environmental diversity within and among populations. Measures may include the number of varied niches occupied, gene diversity, heterozygosity, or alleles per locus (Service 2016, p. 12). Here, we focus primarily on the extent to which this aspect of a species' current condition reflects changes from its historical condition. See Adaptive Capacity, below, for additional discussion of *inherent* adaptive capacity and its role in shaping the red knot's future condition.

Wintering Populations: The four wintering regions (figure 1) reflect the population structure as well as the physical and biological diversity within the rufa red knot subspecies, and are therefore the central metric of representation. This conclusion is premised on the high fidelity of red knots to each of the four wintering regions (Service 2014, p. 47) as well as evidence that red knots from the various wintering regions show genetic differences (Baker *et al.* 2013, entire). Genetic differentiation indicates geographic and/or behavioral segregation on the breeding

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[10] Abundance of arctic rodents, such as lemmings, is often cyclical, although less so in North America than in Eurasia. 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 typically breed successfully. When lemmings are in short supply, predators switch to shorebird eggs and chicks (Service 2014, p. 197). Thus, the dampening of lemming cycles may lead to more regular or constant predation pressure.

grounds and is a key component of representation. Other elements of representation are also encompassed by the four wintering regions. For example, birds from different wintering populations show marked differences in migration strategy (*e.g.*, timing, routes, long "jumps" versus shorter "hops," timing of feather molt, reliance on different staging areas) and also show, on average, morphological differences (Service 2014, pp. 45-46).

Despite sharp and well-documented declines in the Southern wintering population, and likely declines in the Western Gulf of Mexico/Central America population, these populations continue to persist. It is possible that declines in these populations, especially the Southern population, have resulted in some loss of genetic diversity and adaptive potential, but we have no information assessing whether this occurred. Birds from all four wintering populations continue to exhibit the same general patterns of habitat use and **migration biology** as in earlier decades, suggesting that the unique features of each population remain generally intact. Thus, we conclude with moderate certainty that the geographic distribution of the four wintering populations and the unique features of each as discussed above (*e.g.*, habitat, diet, migration strategy, timing of feather molt, average morphological features) currently remains undiminished. Available data show that genetic differences exist among at least three of the wintering populations (Baker *et al.* 2013, entire), indicating that conservation of the four wintering populations largely preserves the red knot's genetic diversity, which, in turn, supports adaptive capacity. The red knot's inherent adaptive capacity is limited by several aspects of its life history (see Adaptive Capacity, below). Effectively conserving that adaptive capacity (by maintaining unimpaired representation) is critical to maximizing the red knot's ability to respond to several intractable threats (many driven by climate change) facing this subspecies (see Factors Influencing Viability, above, and Future Condition, below).

Migration: Red knots show some flexibility in migration routes and in their selection of staging areas from year to year (Service 2014, pp. 51, 53, 58-60). Conserving the network of staging areas distributed across the various migration routes is essential to retaining the red knot's adaptive capacity (representation) (*i.e.*, maintaining the diversity of migration strategies is necessary if red knots are to have any chance of adapting to climate change and other threats). Aside from horseshoe crab harvest, a number of stressors have been identified in Delaware Bay (Partnership for the Delaware Estuary 2017, entire; Smith *et al.* 2017a, entire) and are likely also operating in other staging areas (Iwamura *et al.* 2013, entire; DeFeo *et al.* 2009, entire; Kennish 2002, entire). However, we have no evidence that conditions in staging areas are currently impairing representation of the red knot (*i.e.*, staging area impairments are not presently known to be limiting the flexibility of rufa red knots in selecting among migration strategies).

As with staging areas, maintaining adequate stopover habitats distributed across the various migration routes is important to retaining the red knot's representation by allowing for a variety of migration routes and strategies, both among and within wintering populations and from year to year. We lack data to assess whether or not loss or impairment of stopover habitats to date has already impacted representation of the red knot. For example, some evidence suggests that development along the mid-Atlantic U.S. coast may have historically altered patterns of habitat use during spring migration, possibly eliminating a previously viable migration strategy (Service 2014, p. 83). It is unknown if other threats, such as excessive disturbance, may be currently precluding the use of certain stopover habitats to the point of reducing representation (*i.e.*, limiting the range of migration strategies employed by different groups of birds). We conclude with moderate to low confidence that representation may be somewhat impaired by the condition of stopover habitats.

Breeding: A contraction of the breeding range could represent a loss of representation, even if the overall carrying capacity of the breeding grounds is not immediately reduced. We have no information that any portions of the red knot's breeding grounds have yet become unsuitable at either local or regional scales. However, the rapid pace of vegetative and other ecosystem changes in the Arctic is well documented, and uncertainty exists around the geographic limits of the rufa breeding range (Service 2014, pp. 27-29, 168-177). We conclude that any impairment of the red knot's adaptive capacity to date as a result of changes in the breeding range is unknown because it cannot be detected with available data.

Redundancy

Redundancy describes the ability of a species to withstand or bounce back from catastrophic events (*e.g.*, rescue effect); it's about spreading risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the species' ecological settings and across the species' range. It can be measured by population number, resiliency, spatial extent, and degree of connectivity (Service 2016, p. 13).

Wintering Populations: Within some wintering regions, red knots are known to relocate both within and between years (Service 2014, pp. 43-44, 91), suggesting that each wintering region supports just one wintering population. With four (geographically) large and distinct populations, each an important component of representation, we do not consider any wintering population to be redundant because none would be able to rescue or replace another one that might be impacted by a catastrophic event. Thus, we do not evaluate redundancy based on numbers of populations. Instead, we consider redundancy in terms of the quality and spatial extent of both regularly occupied and total habitat in each region. The extent of regularly occupied habitat provides a measure of demographic vulnerability to discrete catastrophic events. For example, if red knots are typically concentrated in just a small portion of a wintering or migration region, then a large percent of that population may be injured or killed by an event such as an oil spill or harmful algal bloom. The extent of total habitat (including areas that are regularly occupied, intermittently occupied, and suitable but typically unoccupied) provides a measure of vulnerability to longer-term catastrophic events. For example, if only small portions of a wintering or migration region provide suitable habitat and management conditions (*e.g.*, the rest of the region is rendered unsuitable by excessive human disturbance or development), then loss of a key resource in those small portions would leave the birds nowhere to relocate. Examples of more permanent catastrophic events include loss of intertidal habitats from sea level rise rates that are too fast for shoreline migration to keep pace, or loss of a key food resource due to shifts in the range or seasonal reproductive timing of the prey species such as may occur with warming and acidifying coastal waters. To summarize, we evaluate redundancy by asking—for each population and during each season—how spread out are the red knots, and where could they go if they lost a key area?

The Southern population has not only contracted down to the island of Tierra del Fuego, but has also contracted within the island as well. In the 1980s, over 9,500 red knots were documented on the Argentinian side of Tierra del Fuego (at Bahía San Sebastián and Río Grande, totaling about 160 shoreline miles [260 km]) in addition to the main concentration area on the Chilean side (nearly 42,000 knots along about 65 shoreline miles [105 km] in Bahía Lomas) (Morrison and Ross 1989, p. 40, Niles *et al*. 2008, pp. 148-149). In recent years nearly all of the red knots counted during the annual aerial survey have been found in Bahía Lomas. In 2019, over 99 percent of all the red knots occurred in just two flocks in Bahía Lomas totaling 13,100 birds, with only 90 birds at Río Grande. Río Grande was once the other major wintering area in Tierra del Fuego, with counts in the range of 3,500 to 5,000 birds as recently as 2008, but numbers have fallen drastically since then (WHSRN 2019). In 2020, about 250 birds occurred on the Argentinian side of Tierra del Fuego, still only about 2 percent of the total (WHSRN 2020). Thus, we conclude with high certainty that redundancy of the Southern wintering population (when on the wintering grounds) is currently poor, and this population is extremely vulnerable to a catastrophic event, such as an oil spill (Service 2014, pp. 290-291; WHSRN 2018b). The loss of redundancy (*i.e.*, substantial contraction of the regularly occupied areas) of this population has largely been driven by a population decline, not primarily by habitat loss or degradation. Thus, the currently low level of redundancy is at least partially reversible, though some portions of both Patagonia and Tierra del Fuego have experienced considerable development and potential for birds to be disturbed by human activities (Service 2014, pp 161-162, 268-269).

The North Coast of South America wintering population occurs mainly in the North-Central Brazil survey segment (Service 2014, p. 88), which includes more than 300 miles (480 km) of coastline. On the ground, far more than 300 miles are available given the highly complex and indented coastline, most of which is remote and suitable for red knots. We have no information indicating that knots are highly clustered or have contracted along this coastline. Localized or even regional catastrophic events in one part of this region would be unlikely to affect other parts, or to impact a disproportionate number of red knots. Peripheral wintering habitats in this region extend hundreds of miles east and west of the core area, further contributing to redundancy. However, this area currently supports the largest number of wintering rufa red knots—currently nearly three times as many as the Southern region—mostly in the core area, resulting in a relatively high density of wintering birds. Offshore petroleum exploration and extraction is occurring in this region, and the largest oil spills can impact upwards of 1,000 miles (1,600 km) of shoreline (Holba and Woods 2019, p. 4; Service 2014, pp. 289-292). In 2019 and early 2020, oil contamination from an unknown source was documented along about 2,500 miles (4,000 km) of Brazil's northeast shoreline (Law 2020), potentially overlapping the core wintering area and likely overlapping the eastern peripheral area (see figure 1). Any impacts to red knots from this oil contamination event are not yet known. We conclude with moderate confidence that the redundancy of this region is moderately impaired based on the relatively high density of birds in the core area and the documented potential for a large-scale catastrophic event that could span most or all of the core area.

The Caribbean supports an estimated 5,100 wintering red knots, and the Southeast United States supports about 10,400 wintering birds (Lyons *et al.* 2017, p. 11), with smaller numbers of red knots wintering farther north along the U.S. Atlantic coast (eBird 2020). Development, shoreline stabilization, and human disturbance have caused red knots to reduce their use of some previously important portions of this wintering region. For example, knot numbers have dropped considerably along the Gulf coast of Florida. Although Florida's Gulf coast remains an important wintering area, it is believed that many red knots relocated to Georgia and South Carolina (Service 2014, p. 91). Redundancy of this population is bolstered by its vast geographic size (about 1,500 U.S. shoreline miles [2,400 km] (Rice 2012, p. 6)) and large numbers of islands (both barrier and Caribbean), making it unlikely that a catastrophic event in one area would impact red knots in another part of this region. However, this region is highly susceptible to tropical storms (NOAA undated), which could directly impact wintering birds but may be even more likely to disrupt habitats or food supplies just as wintering birds are arriving. Despite this large size of this region, we note that birds are clumped and disproportionately reliant on a few key areas. Although significant numbers of birds are thought to have shifted from the Gulf coast of Florida to Georgia and the Carolinas in recent years, the remaining capacity of birds to shift to a different portion of this region (*i.e.*, in the event of a catastrophic event) is not well known, and may be limited by past and ongoing threats such as coastal development and disturbance. We conclude with moderate confidence that redundancy in this region is moderately impaired.

The northern portion of the Western Gulf of Mexico/Central America wintering region extends from Mississippi to northern Mexico, covering over 600 miles (1,000 km) of coastline. Much of this area is undeveloped (Rice 2012, p. 6) and suitable for red knots. Data from ebird (2020) suggest that red knots are relatively spread out along this section of coastline. Most catastrophic events in one part of this region would be unlikely to affect other parts. However, much of this region was impacted by the Deepwater Horizon oil spill in 2010 (Service 2014, 288-289), and Hurricane Harvey impacted this entire area as a Category 4 storm in August 2017 (National Weather Service undated). We are aware of only one direct observation of a single oiled red knot from the Deepwater Horizon spill (Newstead pers. comm. 2020), and we lack information on any impacts to red knots from Hurricane Harvey. But these events demonstrate the potential for large-scale catastrophic events to impact a substantial portion of this wintering region. Thus, despite its large size and habitat availability, the redundancy of this wintering region is moderate. Additional rufa red knots are believed to occur along both coastlines of central Mexico through Panama; we have little information on the condition of habitats in these areas, but the large number of additional shoreline miles further contributes to redundancy.

<u>Migration</u>: No staging areas are considered redundant. Instead each is considered a necessary stepping stone along the red knot's migration routes. Over longer time-scales, it is possible (but far from assured) that red knots have some capacity to adapt to new staging areas. But in the short-term, a catastrophic event at a staging area could impact a very large percentage of all red knots, likely with disproportionate effects on a particular wintering population (Service 2014, pp. 49-51, 76-79). Every staging areas is essential to the red knot's continued viability (see Future Condition below).

Unlike staging areas, the supply of other stopover habitats may be thought of in terms of redundancy because loss or impairment of a particular stopover habitat (though locally important) is unlikely to impact an entire wintering population or the subspecies as a whole. A catastrophic event in a stopover habitat would only directly impact those red knots present in that stopover at the time (typically far fewer and for a shorter duration than may be found in a staging area). Also, the geographic expanse of potential stopover habitats is vast, such that birds would generally be able to relocate if any one particular stopover area suffers long-term degradation or even total loss of habitat value. However, not all potential stopovers actually feature the prey (abundance, quality, and timing) and other conditions needed to support red knots during migrations. Further, red knots require more stopover habitat than they collectively occupy in any one particular season or year because the birds must be able to respond to normal fluctuations in environmental factors such as prey distribution, predator density, and weather (Smith *et al.* 2017b, p. 3; Service 2014, pp. 51, 71, 195, 259). Finally, many areas that may have historically served as stopover habitat are now impacted by coastal development, human activity, accelerating sea level rise, and coastal engineering (Tetra Tech 2018, pp. 22-29; Rice 2017, p. 18; Service 2014, pp. 126-162, 266-269; Rice 2012, p. 6). Thus, considerable loss of redundancy in stopover habitats has already occurred and is likely one factor currently limiting the viability of the rufa red knot.

Breeding: A contraction of the breeding range, or patchy degradation of breeding habitat quality, could represent a loss of redundancy for a subspecies that depends on low breeding density to counter predation pressures. As discussed above, the rapid pace of vegetative and other ecosystem changes in the Arctic is well documented, and uncertainty exists around the geographic limits of the breeding range (Service 2014, pp. 27-29, 168-177). As with representation, we conclude that current impairment of redundancy as a result of changes in the breeding range is highly uncertain.

Future Condition

Future Scenarios

The supplemental listing document includes a detailed assessment of each threat into the foreseeable future, based on best available information regarding the trajectories of each threat as well as factors likely to alter those trajectories. Based on this analysis, the Service concluded that the red knot is likely to become endangered (in danger of extinction) in the foreseeable future, and thus meets the definition of threatened under the ESA. However, as with any assessment of future conditions, there is considerable uncertainty in projecting how threats may develop, how threats may interact with one another, the nature and intensity of conservation efforts to abate those threats, and how the subspecies may respond to those conservation efforts. Table 7 presents an assessment representing a range of possible future conditions, including the key areas of uncertainty as they are currently understood.

Climate Change: There is overwhelming evidence that human-caused climate change has already altered the environmental conditions faced by red knots. Human activities are estimated to have caused approximately 1.0° Celsius (C) of global warming above pre-industrial levels (***likely*** range of 0.8°C to 1.2°C). Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature for the decade 2006 to 2015 was 0.87°C (*likely* range of 0.75°C to 0.99°C) higher than the average over the period 1850 to 1900 (*very high* ***confidence***). Thus, estimated anthropogenic global warming matches the level of observed warming to within about 20 percent. Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic (IPCC 2018a, p. 4). Although there is no solid evidence that climate change is yet driving rufa red knot population trajectories, there are preliminary indications that impacts due to climate change are already occurring. Moreover, there is unambiguous evidence that fundamental environmental conditions are rapidly changing across the range of the rufa subspecies in ways that are likely to impact rufa populations in the next few decades. Indications that red knots are already experiencing climate-related environmental changes include the following.

- vanGils *et al.* (2016, entire) found evidence that climate change is impacting juvenile survival rates of *Calidris canutus canutus*. These authors found that *C.c. canutus* produces smaller offspring with shorter bills during Arctic summers with early snow melt. Snow on the breeding grounds of this subspecies has been melting an average of 0.5 days earlier each year. The smaller juveniles show reduced survival rates, possibly associated with these young birds eating fewer deeply buried bivalves and more shallowly buried seagrass rhizomes on the wintering grounds because their bills are too short to reach the deeper prey.

- Fraser *et al.* (2013, entire) found indications in the historical record consistent with a hypothesis that an interruption of the rodent cycle in red knot breeding habitat could have been a factor in the rufa decline observed in the 2000s; additional studies would be needed to support this hypothesis. Climate change may be contributing to depressions of rodent cycles, which can in turn lead to greater predation pressure on shorebird eggs and chicks (Service 2014, pp. 194-200).

- Kubelka *et al.* (2018, entire) found that shorebirds (including *Calidris canutus*) have experienced a worldwide increase in nest predation over the past 70 years. Historically, there existed a latitudinal gradient in nest predation, with the highest rates in the tropics; however, this pattern has recently been reversed in the Northern Hemisphere, most notably in the Arctic. This increased nest predation is consistent with climate-induced shifts in predator-prey relationships.[11]

- Tulp and Schekkerman (2008, entire) found that dates of peak arthropod abundance in the Arctic advanced, occurring 7 days earlier in 2003 than in 1973, causing an advancement of the optimal breeding date for birds. To take advantage of the new optimal breeding time, arctic shorebirds would need to advance the start of breeding. It is unclear if red knots are capable of this degree of seasonal advancement (Service 2014, pp. 249-253, 260-262), and the potential uncoupling of phenology of food resources and breeding events is a major concern for the red knot (COSEWIC 2007, p. 40).[12]

- Several studies have found increases in plant biomass linked to warming arctic temperatures. Importantly for red knot habitat, many studies have already found increased shrub abundance, biomass, ranges, and cover (*high confidence*); increased plant canopy heights; and decreased prevalence of bare ground. Ongoing increases in shrub cover in North American tundra and loss of tussock tundra (*i.e.*, red knot breeding habitat) are attributed to climate change with *high confidence* (IPCC 2014b, p. 32; Service 2014, 168-177).

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[11] We note there is scientific controversy regarding this study (Bulla *et al.* 2019, entire; Kubelka *el al.* 2019, entire)

[12] Although not yet documented for red knots, the links between temperature, prey, and reproductive success have been established in other northern-nesting shorebirds (Senner *et al.* 2016, entire; Service 2014, p. 262)

- Relevant to the red knot's prey species in nonbreeding areas, it is *virtually certain* that the global ocean has warmed unabated since 1970 and has taken up more than 90 percent of the excess heat in the climate system (*high confidence*). Since 1993, the rate of ocean warming has more than doubled (*likely*). Marine heatwaves have *very likely* doubled in frequency since 1982 and are increasing in intensity (*very high confidence*). A loss of oxygen has occurred from the surface to 3300 feet (1,000 meters [m]) deep (*medium confidence*) (IPCC 2019, p. 42). Due to their life history strategy, red knots are vulnerable to changes in the geographic ranges, abundance, community composition, and seasonal reproductive timing of mollusks and other invertebrate prey; such changes are already being driven by warming coastal waters.

- The southern limit of adult blue mussels has contracted from North Carolina to Delaware since 1960 due to increasing air and water temperatures. Mussel larvae have continued to recruit to southern locales via currents, but those recruits die early in the summer due to temperatures in excess of lethal physiological limits. Failure to recolonize southern regions will occur when reproducing populations at higher latitudes are beyond dispersal distance (Jones *et al.* 2010, pp. 2255–2256). This key prey resource may disappear from the red knot's Virginia spring stopover habitats (Karpanty *et al*. 2012, p. 1).

- Ocean acidification due to increased carbon dioxide emissions has resulted in a 0.1 pH unit decrease since the pre-industrial period, which is unprecedented in the last 65 million years (*high confidence*) (IPCC 2018b, p. 209) and is equivalent to a 26 percent increase in acidity (IPCC 2014a, p. 4). Mollusks, including taxa known to support red knots (*e.g.*, clams, mussels), are sensitive to changes in pH and associated carbonate chemistry (Service 2014, pp. 221-224).

- The Georgia Department of Natural Resources (2013, pp. 1-2) is concerned that a number of changes associated with global climate change (*e.g.*, ocean acidification, warming) may negatively affect the dwarf surf clam (*Mullinia lateralis*), the most important prey item for red knots migrating through Georgia.

- Over the period 1902 to 2015, global mean sea level rose by 0.5 foot (0.16 m) (*likely* range of 0.12 to 0.21 m) (IPCC 2019, p. 42). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*) (IPCC 2014a, p. 4). Extreme wave heights, which contribute to extreme sea level events and coastal erosion, have increased in the Southern and North Atlantic Oceans by around 0.4 inch (1.0 cm) per year and 0.3 inch (0.8 cm) per year (respectively) over the period 1985 to 2018 (*medium confidence*) (IPCC 2019, p. 42). The red knot is vulnerable to inundation of tidal flats and erosion of sandy beaches, which are typically caused or accelerated by climate-driven sea level rise (Vousdoukas *et al.* 2019, entire; Service 2014, pp. 126-143). Galbraith *et al.* (2002, p. 178) examined several scenarios of future sea level rise and projected major losses of intertidal habitat in Delaware Bay.

- Harmful algal blooms display range expansion and increased frequency in coastal areas since the 1980s in response to both climatic and nonclimatic drivers (*high confidence*). The observed trends in harmful algal blooms are attributed partly to the effects of ocean warming, marine heatwaves, oxygen loss, eutrophication and pollution (*high confidence*) (IPCC 2019

p. SPM-18). Harmful algal blooms, such as red tides, are known to cause sickness and mortality in red knots (Service 2014, pp. 275-282).

There is also overwhelming evidence that the climate will continue to change over coming decades. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (*high confidence*). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* range 0.1°C to 0.3°C) per decade due to past and ongoing emissions (*high confidence*) (IPCC 2018a, p. 4). However, the severity of future climate-related threats faced by red knots—particularly after 2035[13]—will be strongly influenced by the rates of greenhouse gas emissions over the next few decades (Terrando *et al.* 2020, p. 2; IPCC 2019, pp. SPM-7-8; 2018a, pp. 12-17; 2014a, pp. 8-16). Warming from past anthropogenic emissions (from the pre-industrial period to the present) will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*). However, these past emissions alone are unlikely to cause global warming of 1.5°C (*medium confidence*). Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate, risks are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (*e.g.*, about 2°C) (*high confidence*) (IPCC 2018a, p. 5). However, it is entirely possible that warming will exceed 1.5 or even 2°C in this century (see box 2). Therefore, the International Panel on Climate Change (IPCC) also evaluates other scenarios. In table 7, we present a scenario of extremely low future emissions and/or large-scale negative

Box 2. Anthropogenic greenhouse gas emissions are mainly driven by human population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions, and land use. The RCPs include a stringent mitigation (*i.e.*, low-emissions) scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high emissions (RCP8.5). Scenarios without additional efforts to constrain emissions (“baseline scenarios”) lead to pathways ranging between RCP6.0 and RCP8.5 (IPCC 2014a, p. 8). RCP2.6 represents a low emissions future with a two in three chance of limiting warming below 2°C by the end of the century. Achieving the RCP2.6 pathway would require implementation of negative emissions technologies at a not-yet-proven scale to remove greenhouse gases from the air, in addition to other mitigation strategies such as energy from sustainable sources and existing nature-based strategies. An even more stringent RCP1.9 pathway is considered most compatible with limiting global warming to below 1.5°C (IPCC 2019, p. 1-16).

Greenhouse gas emissions have risen at a rate of 1.5 percent per year in the last decade, stabilizing only briefly between 2014 and 2016 and reaching a new record in 2018. There is no sign of emissions peaking in the next few years. By 2030, emissions would need to be 25 and 55 percent lower than 2018 to put the world on the least-cost pathway to limiting global warming to 2°C and 1.5°C, respectively (UNEP 2019, pp. xiv-xv). Although current emissions continue to grow in line with the RCP8.5 trajectory (IPCC 2019, p. 1-16), one recent scientific commentary suggests that RCP8.5 should be considered a “worst case” rather than a “business as usual” scenario—one that's not out of the realm of possibility, but increasingly unlikely based on global climate policies and current energy trends (Hausfather and Peters 2019). However, characterizing the probabilities of various warming scenarios remains a topic of scientific debate (Mann 2020).

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[13] The global mean surface temperature change for the period 2016 to 2035 relative to 1986 to 2005 is similar across RCPs 2.6, 4.5, 6.0, and 8.5, and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*) (IPCC 2014a, p. 10).

emissions (warming stabilized at 1.5°C under Representative Concentration Pathway (RCP) 1.9), a moderate scenario (RCP4.5), and a high-emissions scenario (RCP8.5). Assessments of the red knot's vulnerability to climate change indicate a large increase in extinction risk due to the likely loss and degradation of breeding habitat (from arctic warming) and nonbreeding habitat (*e.g.*, from sea level rise), as well as the knot's high degree of habitat specialization, long migration distance, and high degree of dependence on ecological synchronicities (Galbraith *et al.* 2014, p. 7; Whitman *et al.* 2013, p. 19).

Other Threats: Not all threats to the red knot stem directly from climate change. Some threats relate to how humans may respond to climate change, for example whether humans abandon or harden coastal areas in response to sea level rise, and the extent to which new development may occur in a warming Arctic. Other threats, such as disturbance, are largely unrelated to climate change. It is in these categories of more proximate threats that management efforts may partially abate the impacts of climate change by increasing the resiliency of red knot populations, and where recovery actions under the ESA will likely focus. For the purposes of this SSA, inclusion of conservation efforts in these scenarios implies no assumptions about whether they can or will be implemented under the authority of the ESA. However, their consideration is appropriate in light of ongoing conservation efforts by a wide variety of governmental and nongovernmental organizations across the subspecies' range.

Scenarios: The future scenarios laid out in table 7 reflect a range of human responses to climate change, and a wide range in the level of conservation effort to protect the rufa red knot. Examining a range of projected climate outcomes based on multiple scenarios is a recommended best practice because it allows decision makers to better consider both short- and long-term risks and opportunities, and reduces the risk of failing to assess potentially important negative outcomes in the planning process (Terrando *et al.* 2020, p. 2).

The Low Threat/High Conservation Effort scenario envisions a future condition where rufa red knot conservation is prioritized and coordinated across nearly the entire Western Hemisphere. This most optimistic scenario relies not only on the most ambitious assumptions for slowing climate change, but also assumes a largely nonstructural human response to sea level rise, an unprecedented level of effort to restore and maintain coastal habitats, full recovery of horseshoe crab populations, and a resolute commitment to managing other human activities (*e.g.*, recreation, hunting) that impact red knots and their habitats. In contrast, the High Threat/Low Conservation Effort scenario reflects future conditions where climate change proceeds unabated along its current trajectory. This most pessimistic scenario also assumes a largely structural response to sea level rise and minimal efforts to abate other threats. The Moderate Threat/Moderate Conservation Effort scenario is intermediate between the other two.

These scenarios were developed to help envision the range of future outcomes. In reality, it may be unlikely that any one of these scenarios will be fully realized because the various factors may not all unfold in lockstep to produce a "worst," "intermediate," or "best-case" future for the rufa red knot. Instead it is likely that some factors will turn out consistent with "High Threat" scenario, others Moderate, and others Low. Still, the three scenarios provide a framework for current and future assessments, and will help inform recovery actions to reverse past population declines of the rufa red knot and put the subspecies on a path toward delisting.

Table 7. Future conditions scenarios

	Low Threat / High Conservation Effort	**Moderate Threat / Moderate Conservation Effort**	**High Threat / Low Conservation Effort**
Climate change trajectory	**RCP1.9**. Warming is limited to 1.5°C above pre-industrial levels.	**RCP4.5**. Relative to 1850 to 1900, global surface temperature change for the end of the 21st century is projected to be 2.5°C (*likely* range of 1.7 to 3.3°C) (IPCC 2019, p. SPM-8).	**RCP8.5**. Relative to 1850 to 1900, global surface temperature change for the end of the 21st century is projected to be 4.3°C (*likely* range of 3.2 to 5.4°C) (IPCC 2019, SPM-8).
Breeding habitat	High-latitude tundra is particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and this will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 0.6 to 1 million square miles (1.5 to 2.5 million square km) (*medium confidence*) (IPCC 2018a, p. 8).	Woody shrubs and trees are projected to expand to cover 24 to 52 percent of Arctic tundra by 2050 (*medium confidence*) (IPCC 2019, p. SPM-25) (RCP not specified). Modeling shows *Calidris canutus* habitat diminishing in area and retreating northward under RCP 4.5, apparently in response to spatial patterns of warming temperatures and decreasing snow cover duration. Taking the rufa and islandica subspecies together, suitable habitat is projected to diminish in area under RCP 4.5 by 54 percent. There is a wholesale decrease in predicted habitat suitability in the southern section of the rufa breeding range, while habitat suitability increases in selected locations in the central section of the rufa range. The new habitat areas predicted by the rufa model occur at the spatially distant end of the breeding range, requiring birds to travel farther to utilize the potential new habitat (Commission for Environmental Cooperation (CEC) 2016, p. viii).	Woody shrubs and trees are projected to expand to cover 24 to 52 percent of Arctic tundra by 2050 (*medium confidence*) (IPCC 2019, p. SPM-25) (RCP not specified). Modeling shows *Calidris canutus* habitat diminishing in area and retreating northward under RCP 8.5, apparently in response to spatial patterns of warming temperatures and decreasing snow cover duration. Taking the rufa and islandica subspecies together, suitable habitat is projected to diminish in area under RCP 8.5 by 75 percent. There is a wholesale decrease in predicted habitat suitability in the southern section of the rufa breeding range, while habitat suitability increases in selected locations in the central section of the rufa range. The new habitat areas predicted by the rufa model occur at the spatially distant end of the breeding range, requiring birds to travel farther to utilize the potential new habitat (CEC 2016, p. viii).
Global sea level rise by 2100 (relative to the period 1986 to 2005) (a)	0.26 to 0.77 m (IPCC 2018a, p. 7)	0.55 m (likely range 0.39 to 0.72 m). Local sea levels that historically occurred once per century are projected to occur at least annually at most locations by 2100 under all RCP scenarios (*high confidence*) (IPCC 2019, pp. SPM-23; 4-42). (b)	0.84 m (likely range 0.61 to 1.10 m). Local sea levels that historically occurred once per century are projected to occur at least annually at most locations by 2100 under all RCP scenarios (*high confidence*) (IPCC 2019, pp. SPM-23; 4-42). (b)

Table 7. Future conditions scenarios

	Low Threat / High Conservation Effort	**Moderate Threat / Moderate Conservation Effort**	**High Threat / Low Conservation Effort**
Human response to sea level rise	Primarily living shorelines and coastal retreat.	Mix of living shorelines/coastal retreat and hard stabilizing.	Primarily hard stabilizing.
Supply of nonbreeding habitats (c)	Net gain due to coastal retreat and unprecedented restoration efforts that more than offset sea level rise.	Minor losses due to substantial restoration efforts sufficient to nearly offset sea level rise.	Major losses due to sea level rise and hard stabilization.
Ocean temperature projections	Further increases in ocean temperatures, including more frequent marine heatwaves (*high confidence*) (IPCC 2018b, p. 212).	The oceans will continue warming under moderate (RCP4.5) to high emission trajectories (*high confidence*) and will only stabilize over the second half of the century in the case of low range scenarios such as RCP2.6 (IPCC 2014c, p. 1668).	Best estimates of ocean warming in the top 330 feet (100 m) are about 2.0°C by the end of the 21st century. For the period 2081 to 2100 relative to 1850 to 1900 (*medium confidence*): (a) the frequency of marine heatwaves is projected to increase by approximately 50 times; (b) the intensity of marine heatwaves is projected to increase about 10-fold (IPCC 2019, SPM-22, SM-6).
Ocean acidification projections	Ocean chemistry is changing with global temperature increases, with impacts projected at 1.5°C and, more so, at 2°C of warming (*high confidence*) (IPCC 2018b, p. 212).	Decrease in surface ocean pH by 2100 in the range of 0.14 to 0.15 (38 to 41 percent increase in acidity) (IPCC 2014a, p. 12).	Decrease in surface ocean pH by 2100 in the range of 0.30 to 0.32 (100 to 109 percent increase in acidity) (IPCC 2014a, p. 212).
Change in mollusk prey resources from marine ecosystem change	Due to ambitious climate mitigation actions, no change in current patterns of abundance, distribution or timing of the primary prey species in nonbreeding areas.	Decline of certain prey species in some nonbreeding areas. Timing asynchronies are occasional and moderate.	Loss of primary prey species in some nonbreeding areas. Timing asynchronies are routine and severe.
Horseshoe crab egg supply	Superabundance in Delaware Bay results in rates of red knot weight gain similar to the 1980s/early 1990s even as shorebird stopover populations increase. Adequate egg supplies support red knots in all other nonbreeding areas where this is an important food resource.	Abundance in Delaware Bay results in rates of red knot weight gain similar to those documented since 2010, with stable or increasing shorebird stopover populations. Adequate supplies support red knots in most other nonbreeding areas where this is an important food resource.	Shortages in Delaware Bay result in rates of red knot weight gain similar to those documented in the 2000s, even with stable or declining shorebird stopover populations. Supplies are inadequate to support red knots in most other nonbreeding areas where this had been an important food resource.

Table 7. Future conditions scenarios

	Low Threat / High Conservation Effort	**Moderate Threat / Moderate Conservation Effort**	**High Threat / Low Conservation Effort**
Nonbreeding habitat management	All important habitats are managed to limit mechanical beach cleaning, soft stabilization (*e.g.*, sediment manipulation, vegetation planning, sand fencing), invasive vegetation, disturbance from human activities (*e.g.*, recreation, driving, dogs, aquaculture), and densities of human-facilitated predators.	Many important habitats are managed to limit mechanical beach cleaning, soft stabilization (*e.g.*, sediment manipulation, vegetation planning, sand fencing), invasive vegetation, disturbance from human activities (*e.g.*, recreation, driving, dogs, aquaculture), and densities of human-facilitated predators.	Few important habitats are managed to limit mechanical beach cleaning, soft stabilization (*e.g.*, sediment manipulation, vegetation planning, sand fencing), invasive vegetation, disturbance from human activities (*e.g.*, recreation, driving, dogs, aquaculture), and densities of human-facilitated predators.
Additive mortality	Risks to red knots are fully considered and mortality minimized from hunting, oil spills, harmful algal blooms, wind energy development, and research activities.	Risks to red knots are typically considered and mortality limited from hunting, oil spills, harmful algal blooms, wind energy development, and research activities.	Risks to red knots are rarely considered and mortality is substantial from hunting, oil spills, harmful algal blooms, wind energy development, and research activities.

Table 7 footnotes:

(a) Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-meter rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (*medium confidence*) (IPCC 2018a, p. 7).

(b) "Historical centennial events" are influenced by factors such as storm surge, characteristic weather patterns, and coastal geomorphology. This conclusion of the IPCC (2019) means that, even for a small increase in sea-level, some areas will experience a large increase in the frequency of extreme flooding.

(c) Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems (*medium confidence*) (IPCC 2018a, p. 8).

Under the Low Threat/High Conservation Effort scenario shown in table 7, it is likely that, were this to be the future realized, red knot populations would be viable and self-sustaining, and that a status assessment conducted at some point in the future would likely conclude that the rufa subspecies no longer meets the definition of threatened. Under this scenario, ambitious climate mitigation would allow red knots to avoid the most catastrophic systematic impacts (*e.g.*, no loss of essential prey species in migration and wintering areas from marine ecosystem change; no rapid, widespread loss of nonbreeding habitat from sea level rise; no persistent reproductive failures from arctic ecosystem change). This scenario is also optimistic in assuming that the current representation of the rufa red knot remains high and that the inherent adaptive capacity of the rufa red knot (discussed further below) is sufficient to offset the still significant climate-related changes that will occur. Under the Low Threat/High Conservation Effort scenario, red knot population increases are achieved through successful and ongoing conservation actions including careful management of horseshoe crabs; highly protective management of nonbreeding habitats (*i.e.*, sharp reductions in threats such as disturbance and human-facilitated predators); and an increase in the supply of nonbreeding habitats (*i.e.*, due to human retreat from the coasts and unprecedented restoration efforts).

In contrast, under the High Threat/Low Conservation Effort scenario, we expect severe population declines and, given its already impaired condition, might foresee extirpation of the Southern wintering population. If this High Threat/Low Conservation Effort scenario were to be the future realized, a status assessment conducted at some point in the future would likely conclude that the red knot is endangered. Under the Moderate Threat/Moderate Conservation Effort, the rufa red knot would likely decline; if this were to be the future realized, we would expect a status assessment conducted at some point in the future to conclude that this subspecies remains threatened or has become endangered, depending on the speed and severity of response of the various populations.

Adaptive Capacity

Representation can be thought of as that portion of a species' inherent adaptive capacity that is still intact and available to be drawn upon in response to changing conditions; in other words the amount of intraspecific diversity (*e.g.*, genetic, phenotypic, behavioral, geographic, and other variability) that has been conserved. However, in comparing among species, there are important differences in *inherent* adaptive capacity that are also important and that we can try to characterize. One species with undiminished representation may have lower adaptive capacity than another species with impaired representation due to differences in intrinsic factors such as geographic distribution, physiology, ecological niche, and life history strategy.

Climate change vulnerability assessments of species—typically evaluating the factors of exposure, sensitivity, and adaptive capacity—inform adaptation planning and climate-smart conservation. Adaptive capacity (AC) is a species' ability to cope with or adjust to changing climatic conditions, and is the least understood and applied of these factors (Thurman *et al.* in press, p. 2). As summarized in table 4, the climate-related threats driving the red knot's threatened status cannot be directly abated by conservation actions (*e.g.*, under a recovery plan pursuant to the ESA). While conservation actions will play an important role in the future condition of the rufa red knot (as illustrated in table 7), the inherent adaptive capacity of this subspecies is likely to be of equal or even greater importance.

Thurman *et al*. (in press, entire) developed a standardized framework for evaluating AC across diverse taxa, and applied the framework to eight pilot species including the rufa red knot. These authors found the red knot to exhibit strong AC with regard to traits such as extent of occurrence, population size, climatic niche breadth, and physiological tolerances. However, this AC assessment echoes Galbraith *et al.* (2014, p. 7) in noting other areas where red knot AC is inherently low, such as commensalism with humans, genetic diversity, diet breadth, reproductive phenology, and fecundity (see table 8). The red knot's ratio of "high" to "low" AC classifications was equal to one of the other pilot species and lower than the other six (Thurman *et al.* in press). However, Thurman *et al*. (in press, p. 9) do not recommend classifying species with a single AC "score," but instead encourage examining connections among attributes leading to potential cascading impacts or evaluating attributes that, by themselves, are so important they may overwhelm all other considerations (i.e., "deal makers" or "deal breakers").

A key data gap (and potential "deal breaker") for red knot involves patterns and trends in reproductive rates, and the ability of this subspecies to cope with ecosystem changes on their breeding grounds. Some evidence suggests changes in the Arctic may already be manifesting in ways that impact the red knot (vanGils *et al.* 2016, entire; Fraser *et al.* 2013, entire), while other species experts have not observed substantial habitat or ecosystem changes to date and conclude that, thus far, localized impacts from overabundant snow geese (*Chen caerulescens*) are likely having more impact than climate-related changes (Smith pers. comm. 2019). In either case, the evidence is overwhelming that the Arctic is rapidly warming and that ecosystem changes will accelerate. The red knot's capacity to cope with changes on the breeding grounds ("adapt in place" and/or "shift in space") is still essentially unknown, as is the potential for changes across the vast breeding grounds to differentially affect the various red knot wintering populations. There are no currently available management options for increasing red knot reproductive rates if they are found to be adversely impacted by a warming Arctic.

The framework by Thurman *et al*. (in press, entire) captures our better understanding of red knot AC in nonbreeding areas. This assessment accurately depicts the red knot's low AC due to traits such as a high degree of diet and habitat specialization, and avoidance of human-dominated areas. Thurman *et al*. (in press, figure 4) also rate the red knot as having low AC with respect to site fidelity, migration timing, and migration distance, recognizing the very tight tolerances of this bird's life history in both time and space. This is underscored by the link that has been established between conditions in the Delaware Bay staging area and the decline of the Southern wintering population. Unlike the breeding grounds, however, considerable opportunities exist for management actions to support red knot adaptive capacity in nonbreeding areas. For example, habitats can be maintained through restoration or by facilitating the inland migration of beaches and tidal flats. Habitat quality can be maintained by avoiding impacts to key food resources, liming disturbance from human activities, and minimizing additive mortality from sources such as hunting and oil spills.

In summary, the future condition of the red knot will be determined by the degrees of threat and conservation effort (as shown in table 7), but also largely by the red knot's inherent AC (table 8).

Red knot AC can be characterized fairly well in nonbreeding birds but is essentially unknown on the breeding grounds. Based on the work of Galbraith *et al.* (2014, entire) and Thurman *et al.* (in press, entire), we characterize the red knot as being on the lower end of inherent AC, even though representation is not currently impaired. Supporting and maintaining the AC through a vigorous effort to reduce and eliminate all tractable threats in the migration and wintering range is, by necessity, the key management strategy for conserving the rufa red knot.

Table 8. Adaptive capacity assessment (Thurman *et al.* in press, Figure 4)

Attribute	Red Knot Classification
Distribution	
Extent of Occurrence	High
Area of Occupancy	High
Habitat Specialization	Moderate
Commensalism with Humans	Low
Geographic Rarity	Moderately high
Movement	
Dispersal Syndrome	NA
Dispersal Distance	NA
Dispersal Phase	NA
Site Fidelity	Low
Migration Frequency	High
Migration Demography	High
Migration Timing	Low
Migration Distance	Low
Evolutionary Potential	
Genetic Diversity	Low
Population Size	High
Hybridization Potential	Low
Ecological Role	
Competitive Ability	Low
Diet Breadth	Low
Diversity of Obligate Species	High
Abiotic Niche	
Seasonal Phenology	NA
Climatic Niche Breadth	High
Physiological Tolerance	High
Behavioral Regulation of Physiology	Moderate
Life History	
Reproductive Phenology	Low
Reproductive Mode	Moderate
Mating System	Moderately low
Fecundity	Low
Parity	High
Sex Ratio	Unknown
Sex Determination	High
Parental Investment	Moderately high
Demography	
Life Span	Moderately high
Generation Time	Moderately high
Age of Sexual Maturity	High
Age Structure	Low
Recruitment	Low

Table 9. Current and future condition (3Rs) summary

3Rs	Needs	Current Condition	Future Condition
Resiliency (robust populations able to withstand stochastic events)	- Coastal wintering habitats with sparse vegetation and adequate food. - Coastal and inland stopover habitats (including a network of staging areas) with sparse vegetation and ample food at the right times. - Tundra breeding habitat and freshwater arctic wetland or lake-edge foraging habitat with ample food at the right times. At least some years with favorable weather and predation conditions allowing for high reproductive output.	- Southern population has low resiliency due to the sharp and well-documented past decline in the 2000s, which has stabilized but not yet begun to recover. - Western Gulf of Mexico/Central America population has low resiliency due to small population size and probable past declines. - The Southeast U.S./Caribbean population has moderate resiliency based on population size and stability. - The North Coast of South America population has high resiliency based on population size and stability.	Low Threat/High Effort Scenario: Southeast U.S./ Caribbean and North Coast of South America populations stable. Western Gulf of Mexico/Central America and Southern populations increasing, but this assessment is very sensitive to the red knot's (essentially unknown) capacity to cope with inexorable ecosystem change on the breeding grounds. (Also see the extremely optimistic assumptions that underpin this scenario.) Moderate Threat/Moderate Effort Scenario: Populations experiencing small to moderate declines depending on the speed and severity of response of the various populations, with concomitant reductions in resiliency. High Threat/Low Effort Scenarios: Widespread ecosystem change in the Arctic results in prolonged increases in predation pressure, timing mismatches with food and weather conditions, and a possible overall net loss in the area of suitable breeding habitat, culminating in persistently reduced rates of reproductive output. Juvenile and adult survival is decreased by habitat loss, depressed food resources, timing mismatches, disturbance, and anthropogenic mortality on the nonbreeding grounds. Likely loss of the Southern wintering population based on its already impaired condition, and the greater energy demands and timing constraints associated with this longest-distance of the four migration strategies. Major reductions in both reproductive and survival rates translate to significantly smaller population sizes and substantially reduced resiliency across the other three wintering populations.

Table 9. Current and future condition (3Rs) summary

3Rs	Needs	Current Condition	Future Condition
Representation (Genetic and ecological diversity to maintain adaptive potential)	- Four distinct wintering regions display ecological variation across latitudes, habitats, and migration strategies. - Evidence suggests genetic differences among wintering populations. - Between and even within wintering populations, a diversity of migration strategies (*e.g.,* timing, routes, stopovers) allows birds to adapt to changing conditions over decades. - Latitudinal and longitudinal ranges of the breeding range are sufficient to support four distinct wintering populations and allows birds to adapt to changing conditions over decades.	- High representation with regard to the geographic distribution of the four wintering populations and the unique features of each. - Staging areas are not currently impairing representation of the red knot, because none are known to have been lost, and none are seriously degraded at present. - We lack adequate data to assess whether or not loss or impairment of stopover habitats to date has impacted representation. It is unknown if other threats, such as excessive disturbance, may be currently precluding use of certain stopover habitats to the point of reducing representation (*i.e.*, limiting the range of migration strategies employed by different groups of birds); some evidence suggests this may be occurring. - Any ongoing impairment of representation as a result of changes in the breeding range could not be detected with currently available data.	Low Threat/High Effort Scenario: Representation remains high with regard to the geographic distribution of the four wintering populations and the unique features of each, and with regard to staging areas. Representation may improve with restoration and management of stopover habitats that might increase the range of migration options and strategies. Even under this optimistic scenario, some reduction in representation is expected on the breeding grounds, as some portions of that very large area are very likely to become unsuitable for nesting and/or chick rearing. Moderate Threat/Moderate Effort Scenario: Moderate reductions in representation due to degradation of nonbreeding habitats and ecosystem change on the breeding grounds. High Threat/Low Effort Scenario: Likely loss of the Southern wintering population and its unique features. Probable degradation or even loss of staging areas, and very likely substantial losses of other stopover habitats, significantly reduce the range of migration strategies. Severe reductions in representation across the breeding grounds as portions of the range become unsuitable at local and regional scales.

Table 9. Current and future condition (3Rs) summary

3Rs	Needs	Current Condition	Future Condition
Redundancy (Number and distribution of populations to withstand catastrophic events)	- Supplies of wintering and stopover habitats are sufficient to allow birds to shift within and between years. - Multiple areas of suitable breeding habitat across the breeding grounds.	- Redundancy of the Southern wintering region is very poor, and this population is extremely vulnerable to a catastrophic event, such as an oil spill. However, this condition is believed to be at least partially reversible. - Redundancy of the North Coast of South America wintering region is moderately impaired by a relatively high density of wintering birds and documented potential for a large-scale catastrophic event that could span all or most of the core area. - Redundancy is moderately impaired for the Southeast U.S./Caribbean wintering region, as birds are highly clumped and disproportionately reliant on a few key areas. Although birds are thought to have made a regional shift in the past 20 years, the current ability of birds to shift to a different portion of this region (*i.e.*, in the event of a catastrophic event) is not well known and may be limited by past and ongoing threats such as coastal development and disturbance. - Redundancy of the Western Gulf of Mexico/Central American wintering region is relatively high, although both Hurricane Harvey and the Deepwater Horizon Oil Spill impacted a substantial portion of this region. The large number of additional shoreline miles in Central America further contributes to redundancy. - No staging areas are considered redundant. Instead each is considered a necessary stepping stone along the red knot's migration routes. A catastrophic event at a staging area could impact a very large percentage of all red knots, likely with disproportionate effects on a particular wintering population. - Considerable loss of redundancy in stopover habitats has already occurred and is likely one factor currently limiting the viability of the rufa red knot. - Any ongoing impairment of redundancy as a result of changes in the breeding range could not be detected with currently available data.	<u>Low Threat/High Effort Scenario</u>: We expect the Southern population would grow and spread out in its wintering range, improving redundancy. Redundancy would also improve in the Southeast U.S./Caribbean region and the Western Gulf of Mexico region due to habitat restoration and management of disturbance, and in the North Coast of South America due to stringent safeguards to protect the habitat from an oil spill. Redundancy of stopover habitats would increase due to coastal retreat, robust restoration, and active management. Even under this optimistic scenario, some reduction in redundancy is expected on the breeding grounds, as some portions of that very large area are very likely to become unsuitable for nesting and/or chick rearing. <u>Moderate Threat/Moderate Effort Scenario</u>: Moderate reductions in redundancy due to degradation of nonbreeding habitats and ecosystem change on the breeding grounds. <u>High Threat/Low Effort Scenario</u>: Although none of the wintering regions is considered redundant, we would expect loss of the Southern wintering population under this scenario. Likewise, no staging area is considered redundant, but we would expect one or more staging area to be degraded to the point of no longer functioning as a staging area. Severe reductions in redundancy are expected due to habitat loss in the remaining wintering and stopover areas. Severe reductions in redundancy across the breeding grounds are expected as portions of the range become unsuitable at local and regional scales.

Summary

The rufa red knot is a highly migratory shorebird that ranges across nearly the full latitude gradient of the Western Hemisphere. Outside of its arctic breeding grounds, this subspecies requires wide, sparsely vegetated beaches, shoals, tidal mud or sand flats, or mangrove-dominated shorelines; a reliable network of migration staging areas; and an ample supply of other migration stopover habitats that allow birds to shift among habitat patches as conditions change. For breeding, the red knot requires upland tundra with low, sparse, herbaceous vegetation, located near freshwater wetland or lake-edge foraging areas. Across the entire range and the entire annual cycle, the red knot also requires reliable food resources timed to coincide with those times when birds are present, a factor that contributes to low inherent adaptive capacity.

Strong historical evidence indicates that red knots were severely depleted by hunting in the 1800s, but at least partially recovered by the mid-1900s. During the 2000s, red knots from the Southern wintering population experienced a sharp decline that is generally attributed to the overharvest of the horseshoe crab and a resulting food shortage in the Delaware Bay staging area. The horseshoe crab harvest is now scientifically managed to avoid further impacts on red knots, but the Southern wintering population shows no signs of recovery to date. Although less reliant on Delaware Bay, the Northwestern Gulf of Mexico/Central American wintering population is also thought to have declined in recent decades. Two additional wintering populations, one on the north coast of South America and another in the Southeast United States and the Caribbean, are considered stable relative to the 1980s.

Although the red knot benefits from long-term and widespread conservation efforts, birds from all four wintering populations face threats from habitat loss and from several pervasive, climate-driven ecosystem changes. Additional threats include hunting, increased predation pressure, harmful algal blooms, human disturbance, oil spills, and wind energy development. Cumulatively, these threats are believed to be impairing the resiliency (as measured by population size) of the Southern and the Northwestern Gulf of Mexico/Central American wintering populations. Representation of the rufa red knot is generally considered undiminished because none of the four wintering populations, no staging areas, no migration strategies, and no components of genetic diversity are known to have been lost. All four wintering populations are considered to have moderately impaired redundancy due to the loss and degradation of stopover habitats, as well as widespread human disturbance, which cumulatively limit the ability of red knots to relocate should a catastrophic event occur in an important nonbreeding habitat. Uncertainty in our current condition 3Rs analysis is particularly high with regard to conditions on the arctic breeding grounds. There is overwhelming evidence that the Arctic is experiencing profound ecosystem change due to warming that is occurring two to three times higher than the global average, but information regarding the effects of these changes on the rufa red knot—and the subspecies' adaptive capacity to cope with these changes—is extremely limited due to the remoteness and inaccessibility of the region.

Projecting the viability of the rufa red knot into the future is associated with very high uncertainty, especially in light of the subspecies' limited inherent adaptive capacity and our limited knowledge of reproductive rates. However, we can envision a scenario of high viability for this subspecies given extremely optimistic assumptions for slowing climate change, the human response to climate change, the level and success of conservation effort, and the red knot's adaptive capacity. Under a more moderate scenario, we would expect viability to decline. Under the most pessimistic scenario, where climate change proceeds unabated along its current trajectory and conservation efforts are minimal, we would expect the Southern wintering population to be extirpated and the other populations to experience substantial declines. The pessimistic scenario and other undescribed scenarios having impacts between the pessimistic and moderate scenarios would likely result in endangerment of the rufa red knot.

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Glossary

adaptive capacity - a species' ability to cope with or adjust to changing climatic conditions (Thurman *et al.* in press).

arthropod - any invertebrate of the phylum Arthropoda, having a segmented body, jointed limbs, and usually a chitinous shell that undergoes moltings (*e.g.*, insects, spiders and other arachnids, crustaceans).

beach nourishment (or beach fill) - an engineering practice of deliberately adding sand (or gravel or cobbles) to an eroding beach, or the construction of a beach where only a small beach, or no beach, previously existed. Beach nourishment can alter the red knot prey base, and can interfere with the natural coastal processes that create and maintain red knot habitat. However, beach nourishment has also been used as an important restoration tool to replace or improve red knot habitat where it has been lost due to rapid sea level rise and/or infrastructure blocking its landward migration.

clutch - a group of eggs in a nest.

confidence - a set of standardized qualifiers used by the International Panel on Climate Change (IPCC) to express levels of confidence in key findings, ranging from *very low*, through *low*, *medium*, *high*, to *very high*. The assessment of confidence involves at least two dimensions, one being the type, quality, amount or internal consistency of individual lines of evidence, and the second being the level of agreement between different lines of evidence. Very high confidence findings must either be supported by a high level of agreement across multiple lines of mutually independent and individually robust lines of evidence or, if only a single line of evidence is available, by a very high level of understanding underlying that evidence. Findings of low or very low confidence are presented only if they address a topic of major concern.

estuarine - partially enclosed tidal area where freshwater and saltwater mixes; a place where a river meets the sea.

fledged - in young birds, able to fly.

geolocator - a small, light-sensitive device attached to the bird's leg that records periodic, time-stamped, ambient light levels; these data can be used to determine geographic location.

gizzard - in birds, a muscular organ used for grinding food.

hummocky - characterized by knolls or mounds.

likelihood - a calibrated language scale used by the International Panel on Climate Change (IPCC) to communicate assessed probabilities of outcomes, ranging from *exceptionally unlikely* (<1%), *extremely unlikely* (<5%), *very unlikely* (<10%), *unlikely* (<33%), *about as likely as not* (33–66%), *likely* (>66%), *very likely* (>90%), *extremely likely* (>95%) to *virtually certain* (>99%). These terms are normally only applied to findings associated with high or very high confidence.

living shoreline - a protected, stabilized coastal edge made of natural materials including plants, shell, natural fibers, sand, or rock. Unlike a vertical seawall, bulkhead or other structure, which impede the growth of plants and animals, living shorelines grow and adapt over time, while providing wildlife habitat.

migration biology - used in this document to mean a specific suite of behavioral and physiological adaptations that enables a population to successfully migrate; for example the degree of organ atrophy before a flight, the feeding strategy that allows birds to regain weight after a flight, the specific migration timing/duration/route, and the selection of staging/stopover areas.

mollusk - any invertebrate of the phylum Mollusca, typically having a calcareous shell of one, two, or more pieces that wholly or partly enclose the soft, unsegmented body (*e.g.*, chitons, snails, bivalves, squids, and octopuses).

nonbreeding - used in this document to refer to the collective wintering and migration portions of the annual cycle.

precocial - referring to young animals, born or hatched relatively mature, mobile and able to feed themselves almost immediately.

redundancy - the ability of a species to withstand or bounce back from catastrophic events (*e.g.*, rescue effect); it's about spreading risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the species' ecological settings and across the species' range. It can be measured by population number, resiliency, spatial extent, and degree of connectivity.

representation - the ability of a species to adapt to changing environmental conditions over time. It is characterized by the breadth of genetic and environmental diversity within and among populations. Measures may include the number of varied niches occupied, gene diversity, heterozygosity, or alleles per locus.

resightings - subsequent observations of marked birds. In recent decades, the use of uniquely inscribed, colored leg flags has permitted the development of a database that houses specific resighting histories of individual birds.

resiliency - the ability of populations to withstand stochastic events. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need abundant individuals within habitat patches of adequate area and quality in order to withstand or bounce back from environmental or demographic stochastic events.

spat - small, juvenile stages of mussel species.

staging areas - those stopover sites with abundant, predictable food resources where birds prepare for an energetic challenge (usually a long flight over a barrier such as an ocean or a desert) requiring substantial fuel stores and physiological changes without which significant fitness costs are incurred (see box 1 and table 1 in the text). Staging areas are a subset of stopover habitats.

stopover habitat - places where migrant birds stop to rest, drink, and eat (Warnock 2010); see also staging areas.

superabundance - refers to the large volume of horseshoe crab eggs needed to support red knots and other shorebirds at the Delaware Bay spring staging area. Female crabs deposit their eggs in the sand at a depth that is beyond the reach of red knots and most other shorebirds. Wave action and burrowing by subsequent spawning horseshoe crabs move eggs toward the surface. Thus, a high density of spawning horseshoe crabs is needed for the eggs to become available to shorebirds. Further, a very large number of surface-available eggs is needed to support this staging phenomenon because of the small size of the eggs and the large number of shorebirds. Although a single horseshoe crab egg contains a very small amount of energy, eggs are present in such large numbers (superabundance) in Delaware Bay that birds can eat enough in 2 weeks to nearly double their weights.

survival - the ability of an organism to survive from one time period to another (typically a year).

threat - any action or condition that is known to or is reasonably likely to negatively affect individuals of a species. This includes those actions or conditions that have a direct impact on individuals, as well as those that affect individuals through alteration of their habitat or other required resources. Depending on the context, we use the term "threat" as a general term to describe—either together or separately—the source of the action or condition that negatively affects the species (*e.g.*, housing development), or the action or condition itself, which includes direct impacts (*e.g.*, disturbing individuals) and stressors (*e.g.*, habitat or resource loss). The mere identification of "threats" is not sufficient to compel a finding that a species meets the statutory definition of an endangered or threatened species. Describing the negative effects of the threats in light of the exposure, timing, and scale at the population and species levels provides a clear basis upon which we make a listing determination. Such an assessment was conducted in the red knot listing final rule and supplemental document.

tracking - technology for remotely observing or documenting the movements of animals, for example radio-telemetry, digitally-encoded radio transmitters ("nanotags"), geolocators, and satellite transmitters.

viability - the ability of a species to sustain populations in the wild over multiple generations through time. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation, and redundancy. Together, these "3Rs," and their core parameters of abundance, distribution, and diversity, comprise the key characteristics that contribute to a species' ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole (Service 2016).

wrack - seaweed and other organic debris are deposited by the tides.