Rufa Red Knot
(Calidris canutus rufa)

5-Year Review:
Summary and Evaluation

Photo credit: Chuck Homler
https://commons.wikimedia.org/wiki/File:Red-Knot-for-Wiki.jpg

U.S. Fish and Wildlife Service
New Jersey Field Office
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5-YEAR REVIEW
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GENERAL INFORMATION

Species: rufa red knot *(Calidris canutus rufa)*
Date listed: January 12, 2015
FR citation(s): 79 FR 73706 (final listing rule, published December 11, 2014)
Classification: threatened species
Critical habitat: proposed rule published July 15, 2021
FR Notice citation announcing the species is under active review: 85 FR 64527

Methodology used to complete the review

In accordance with section 4(c)(2) of the Endangered Species Act of 1973, as amended (Act), the purpose of a 5-year review is to assess each threatened species and endangered species to determine whether its status has changed and it should be classified differently or removed from the Lists of Threatened and Endangered Wildlife and Plants. The U.S. Fish and Wildlife Service (Service) evaluated the biology and status of the rufa red knot as part of a Species Status Assessment (SSA) to inform development of a recovery plan, as well as this 5-year review.

The SSA report (Service 2020) was prepared by the New Jersey Ecological Services Field Office with support from the North Atlantic-Appalachian Regional Office, Hadley, Massachusetts. The SSA 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 this subspecies across its annual cycle. Several of these biologists followed up with detailed written input regarding the status of the rufa red knot. The draft SSA report underwent expert, partner, and peer review in May 2020. For this 5-year review, we also evaluated and considered all new information received since completion of the SSA in September 2020. In addition, we received and considered two public comments following the Notice of Initiation for this 5-year review.

REVIEW ANALYSIS

Distinct Population Segments

The final listing rule addressed the Distinct Population Segment (DPS) policy (79 FR 73715-17). There is no new relevant information for this subspecies regarding application of the DPS policy.

Recovery Criteria

Recovery Plan or Outline: Recovery Outline dated March 2019; draft Recovery Plan available for public comment May 12 through July 12, 2021.

Despite some important conservation efforts since listing, none of the Recovery Criteria included in the draft Recovery Plan have been met. All of the draft Recovery Criteria are based on current information and remain relevant. Collectively, the draft Recovery Criteria address all significant threats to rufa red knots, based on our current understanding as reflected in the SSA report. However, the draft Recovery Criteria may be refined as appropriate based on feedback received during the public comment period and will be reflected in the final recovery plan.

Updated Information and Current Species Status

Each year some rufa red knots make one of the longest distance migrations known in the animal kingdom, traveling up to 19,000 miles (30,000 kilometers (km)) annually (see Figures 1 and 2). Rufa red knots undertake long flights that may span thousands of miles without stopping. The rufa 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). Geolocator and resightings data show definitively that the rufa red knot 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 (Service 2020, pp. 8-9).

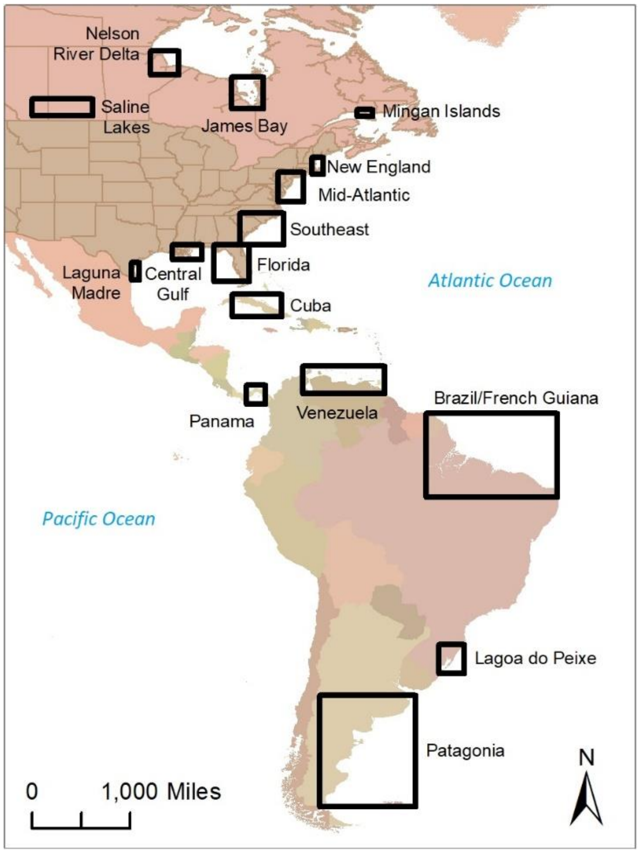

Figure 1. Important Rufa Red Knot Migration Stopover Areas

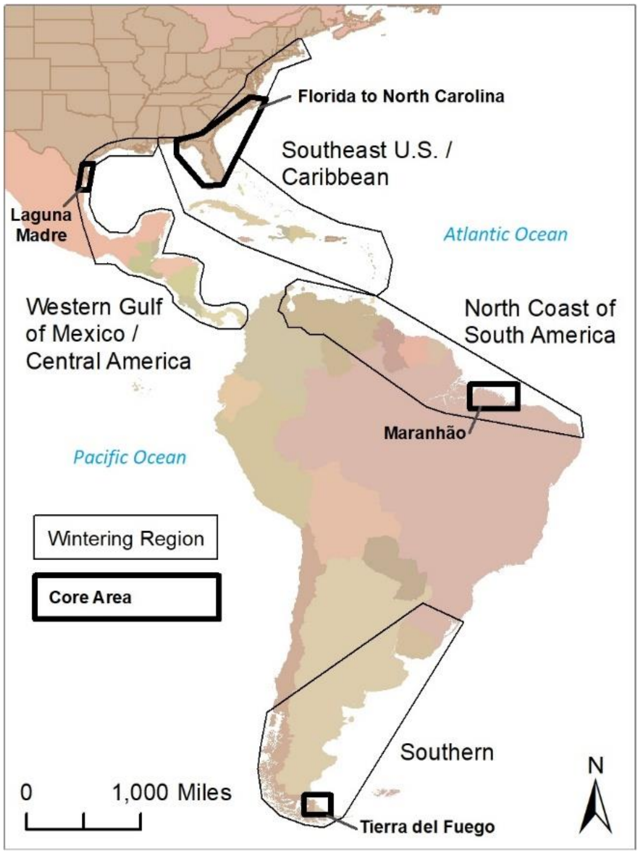

Figure 2. Rufa Red Knot Wintering Regions

Status and Trends

An in-depth analysis of the current condition of rufa red knot populations was conducted as part of the SSA (Service 2020, pp. 20-32). The distribution of rufa red knots from different wintering regions across the breeding grounds is poorly known. Based on best available information, the SSA report presents a current total rangewide abundance estimate of 63,600 rufa red knots, distributed across four geographically large wintering regions (see Figure 2). We conclude with moderate confidence that the North Coast of South America wintering population and the Southeast United States/Caribbean wintering population are stable relative to the 1980s. Several lines of evidence suggest the Western Gulf of Mexico/Central America wintering population may be declining, although certainty about this conclusion is low. The Southern wintering population (*i.e.*, birds wintering in Argentina and Chile) experienced a well-documented decline of about 75 percent during the 2000s, as well as a geographic contraction within these wintering grounds. The Southern wintering population has been stable since 2011, but has not shown any signs of recovery to date (Service 2020, pp. 21-25). See the SSA report for a detailed assessment of the resiliency, representation, and redundancy of each population and of the subspecies as a whole.

Aerial surveys conducted in May 2021 in Delaware Bay (in New Jersey and Delaware) found only about 7,000 rufa red knots during the peak of the spring stopover season (Niles pers. comm. 2021), the lowest count since surveys began in 1981. For context, the 3-year average count from 2018 to 2020 was 27,736 birds, and the previous 1-year record low count was 12,375 birds in 2007 (Lyons 2020, p. 6; Service 2019, p. 31). Delaware Bay has been the single most important spring stopover area, supporting an estimated 50 to 80 percent of all rufa red knots each year in May and early June (Service 2020, p. 26). Birds from the Southern wintering population are disproportionately reliant on Delaware Bay (Service 2014, pp. 76-79), prompting concern that the very low 2021 count in Delaware Bay could indicate a further decline in the already depleted Southern wintering population. However, the annual survey of Argentina and Chile found that the Southern wintering population remained low but stable in 2021 (Matus 2021), making this an unlikely explanation for the low count in Delaware Bay just 4 months later. Communications from partners in other well-known Atlantic coast spring stopover areas produced no reports of higher-than-usual rufa red knot numbers (Niles pers. comm. 2021). To date it is unclear if the recent low Delaware Bay count represents a decline in one or more of the other rufa red knot wintering populations, or if the low count reflects some still unknown weather or environmental condition(s) that caused birds to alter the normal geographic/temporal patterns of their northbound migration. A weather or environmentally driven disruption to the typical spring migration, rather than a true rufa red knot population decline, is somewhat more likely to be at least partly correct because other shorebird species were also present in Delaware Bay in significantly lower numbers in 2021 compared to recent years (Niles pers. comm. 2021). The annual aerial survey can capture only a 1-day count, timed to occur at or near the peak of rufa red knot abundance in the bay. The aerial survey cannot estimate the total number of birds that used the bay during the full stopover season, which is known as the total passage population. Total passage population has been estimated each year since 2011 using modeling and resighting data of marked birds, and typically shows less variability from year-to-year compared to the peak counts (Lyons 2020, entire). The 2021 total passage population estimate will be available in late August 2021 and will provide important context for this year’s low aerial peak count.

Biology and Habitat

The summary of biology and habitat information presented in the SSA report (Service 2020, pp. 4-12) remains relevant and accurate, but relies heavily on the earlier Supplemental Listing Document (Service 2014, pp. 22-116). Here we summarize the most important new biology and habitat information to become available since listing, particularly as it relates to the status of the rufa red knot as a threatened species under the Act.

Genetics

Verkuil *et al.* (2017, p. 84) investigated population structure in *Calidris canutus* using about 15,000 genome-wide single-nucleotide polymorphisms (SNPs). The SNP results support the identity of all recognized subspecies but imply a different evolutionary history than previously suggested. Surprisingly, *C.c. roselaari* does not appear to be closely related to *C.c. rufa* and *C.c. islandica*, instead forming a separate lineage with the Palearctic subspecies *C.c. rogersi*. In addition, this study showed that individuals from Western Alaska and Wrangel Island, Russia, which together are currently recognized as *C.c. roselaari*, are genetically distinguishable from each other (Verkuil *et al.* 2017, p. 84). This new picture of evolutionary history does not alter the validity of the rufa red knot as a recognized subspecies. Further analysis of both the rufa and roselaari subspecies is currently under way, building on this work with SNPs, and is expected to shed further light on the nonbreeding distribution and population structure of rufa red knots.

Kazyak *et al.* (2020, entire) found that certain microsatellite markers were not able to reliably distinguish *C.c. rufa* and *C.c. roselaari*, but did show evidence of population substructure within *C.c. rufa*. These microsatellite markers supported the presence of at least two populations of the rufa red knot with different migratory behaviors (route and/or phenology). Bayesian clustering analysis using the program STRUCTURE indicated that migrants using Massachusetts and Virginia represent a different population than those using the Mingan Archipelago in Quebec, Canada. Although rufa red knots routinely migrate long distances, these results suggest that there are mechanisms that limit gene flow among populations on the breeding grounds, such as geographic isolation or positive assortative mating (Kazyak *et al.* 2020, p. 2). These results support other evidence showing disproportionate use of certain migration areas by a particular wintering population and/or temporally staggered use by multiple wintering populations (Service 2014, pp. 48-63).

Baker *et al.* (2013, p. 1) assayed 410 loci detected with amplified fragment length polymorphisms and identified genetic differences among rufa red knots wintering in Florida, Brazil, and Tierra del Fuego. This was an important finding in our assessment of representation, as discussed in the SSA report (Service 2020, pp. 27-29).

Demographic Rates

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, p. 2). Modeling by Schwarzer (2011, pp. 29-30) previously found that the Florida population was stable with around 8.75 percent juveniles among wintering birds, and the modeled population grew when juveniles increased to 13 percent of wintering birds. However, more recent modeling suggests that a greater percentage of juveniles than the level suggested by the Schwarzer model may be needed for population growth (Wilson and Morrison 2018, p. 2); further work is needed on this question.

At Punta Rasa (Samborombón Bay) in northern Argentina, Martínez-Curci *et al.* (2015a, pp. 236, 239) found a sharp decline in the number of northbound migrant rufa red knots between 1985 and 2014, but an increase in the number of "summering" birds at this site during the arctic breeding season (austral winter[1]) across this same time period. Although the number of birds during the austral winter is relatively small, it is noteworthy that the percentage of such birds showing substantial amounts of breeding plumage increased from 10 to 15 percent in 1987, to 19 to 54 percent from 2011 to 2014. Further research is needed to determine why some mature adults do not go to their arctic breeding grounds and thereby fail to contribute to reproduction (Martínez-Curci *et al.* 2015a, p. 239). It is unknown if similar trends have occurred at other sites south of the breeding grounds because little systematic monitoring of rufa red knot nonbreeding habitats is conducted in June or early July.

Using an integrated population model and monitoring data collected from the Delaware side of Delaware Bay from 2005 to 2014, Tucker (2019, pp. 128, 162) found rufa red knot populations were most likely stable over this time period; adult survival probabilities were consistently high, averaging 0.90 (95 percent confidence interval (CI) 0.86 to 0.93); and average recruitment rate was 0.34 (95 percent confidence interval 0.01 to 2.1). This study found no strong association between vital rates and either arctic or stopover site conditions, but found that recruitment rate had the stronger effect on population growth rate. Confidence intervals on Tucker's (2019) recruitment rate estimate may be improved by the addition of data from the New Jersey side of Delaware Bay, an effort that is now under way in order to inform the modeling that is used by the Atlantic States Marine Fisheries Commission (ASMFC) for horseshoe crab (*Limulus polyphemus*) management.

A hemispheric analysis of survival data is in progress, looking at seasonal survival rates to determine where and when rufa red knot populations are limited (Smith 2019b, entire). The results of this study may be enhanced by a separate effort to analyze stable isotope data from existing feather samples, enabling attribution of individual birds captured and marked during migration to one of the wintering populations. By linking the survival modeling with the stable isotope data, researchers hope to produce survival estimates specific to the various wintering populations.

Breeding

Lathrop *et al*. (2018, p. 652) presented mapping of the rufa red knot breeding range based on maximum entropy modeling and geographic information system data on environmental characteristics. However, mapping and study of the breeding grounds remain limited by the very small number of rufa red knot nests documented to date (Lathrop *et al*. 2018, p. 651, 659; Smith pers. comm. 2019). The first successful deployments of satellite tracking devices on northbound rufa red knots took place in Delaware Bay and Texas in spring 2021 (Niles pers. comm. 2021;

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[1] Boreal refers to the Northern Hemisphere and austral to the Southern Hemisphere. The boreal winter (*e.g.*, December through February) is the austral summer. The arctic breeding season of June, part of the boreal summer, falls during the austral winter.

Newstead pers. comm. 2021). We expect this new technology will dramatically improve our understanding of the rufa red knot breeding range, and the ability of researchers to locate nests and to study breeding ecology, habitat, and demographic rates.

Migration

See Service (2014, pp. 48-63) for background on the rufa red knot's long and complex migration, its reliance on key staging areas and other migration stopover habitats, and its sensitivity to habitat and environmental conditions along its migratory routes. The importance of stopover habitats and migratory connectivity is further underscored in the SSA report (Service 2020, entire). New information that has become available since listing continues to support these conclusions while providing new context and insights that are helping to inform conservation efforts.

Duijns *et al.* (2019 pp. 1) tracked rufa red knots and other shorebird species fitted with nanotag radio transmitters across 13 North American sites between 2014 and 2016 and subsequently detected by a network of stationary receiving stations (Motus Wildlife Tracking System). Consistent with theoretical predictions, all species migrated faster during northbound migration compared to the southbound migration. These differences in migration speed between seasons were mainly driven by longer stopover durations in the fall. However, all species had higher airspeeds during southbound migration, even after accounting for seasonal differences in wind. These findings are consistent with our assessment of the severe time pressures faced by migrating rufa red knots and their vulnerability to timing asynchronies (Service 2014, pp. 249-266).

In 2014, McKellar *et al.* (2015, p. 201) surveyed coastal areas surrounding the Nelson River Delta on Canada's Hudson Bay, which was discovered as a migration stopover in the early 2010s thanks to geolocator tracking data. These authors found more than 4,200 rufa red knots, signifying a major stopover site. This study also documented at least 16 rufa red knots at the Nelson River stopover (from a total of 87) that had been outfitted with radio transmitters in Delaware Bay, suggesting strong migratory connectivity between these two sites. The Nelson River Delta is also an important stopover for birds using the midcontinental flyway (Newstead pers. comm. 2020, Service 2014, pp. 57-5); see *Western Gulf of Mexico, Central America, and the Pacific* below.

Lyons *et al.* (2017a, p. 197) used modeling and resighting of marked birds in 2008 to estimate a total southbound passage population size of 9,450 rufa red knots at the at the Mingan Archipelago in Canada. Birds arrived at this stopover in two distinct waves, separated by about 22 days and each with a skewed sex ratio. This pattern is believed to represent successful breeding, as males remain on the breeding grounds to care for chicks after females have departed (Lyons *et al.* 2017a, p. 197). Tracking such peaks at this and other far-northern fall stopovers is identified in the draft Recovery Plan as a possible metric for assessing trends in reproductive output over time.

Tucker (2019, pp 50-51) analyzed mark-resight observations of rufa red knots using the Delaware Bay stopover from 2005 to 2018 and found that apparent annual survival probability and the probability of returning to the site were both associated with prey availability during the stopover period. Across several shorebird species, use of this site typically peaked between May 26 and 28, but the proportion of the rufa red knot total passage population present during this peak period varied dramatically, ranging from 0.07 to 0.59.

Most studies of rufa red knot habitat use in Delaware Bay since the 1980s focused on foraging activity around the high tide. Burger *et al.* (2018, p. 232, 237) demonstrated that rufa red knots utilize the full expanse of wide tidal flats on the New Jersey side of the bay, foraging at the water's edge in high densities during high tide, then spreading out across the flats as the tide recedes.

Heller (2020, p. iii) analyzed fecal samples of rufa red knots from the Virginia stopover, and found that prey items included clams, mussels, flies, and crustaceans. While crustaceans were the most abundant prey on both sand (about 71 percent of total prey counted) and peat (about 75 percent) substrates, rufa red knots selected crustaceans less than expected given their availability. Rufa red knots preferentially selected clams and mussels, supporting their status as bivalve specialists in Virginia. Heller (2020, p. iii) found that rufa red knots selected those foraging locations with more prey, though flock size did not consistently relate to prey abundance. Tide, substrate, and water temperature affected prey availability. While different prey responded to these covariates in variable ways, prey were generally most abundant on peat banks at low tide.

Watts and Truitt (2015, p. 288) similarly found that rufa red knots using the Virginia spring stopover foraged on both peat banks and sandy beaches. In aerial surveys conducted in 1995, 1996, and 2005 to 2013, these authors found that intertidal peat banks were patchily distributed and represented only 6 percent of the shoreline. Mean rufa red knot densities were comparable between the two foraging habitats in the early stopover period but then diverged. By the third week of May, rufa red knot densities were 10 times higher on peat, on average, compared to sand. Rufa red knots exhibited wide annual variation in habitat use. The number of birds observed on peat varied from 13 to 91 percent of the total birds for a given year, presumably reflecting the underlying dynamics of respective bivalve populations. Prey dynamics along with the patchy distribution of peat appear to cause year-to-year variation in habitat use along the island chain. Watts and Truitt (2015, p. 288) surmised that the Virginia barrier islands are part of a terminal spring staging area for rufa red knots that stretches from New Jersey south through the Outer Banks of North Carolina.

Sanders (2019, p. 1) and Smith (pers. comm. 2021) reported on efforts to track rufa red knots outfitted with nanotags in the Southeastern U.S. and subsequently detected by the Motus network of stationary receivers. In spring of 2017 to 2018, this research team tagged 96 rufa red knots at three locations in South Carolina and 12 additional birds at one location on the Gulf coast of Florida. Of these 108 individuals, 73 birds (68 percent) were detected by at least one station in the Motus network during northbound migration. Of these, 33 birds were determined to be adults with sufficient detection data to infer the northbound migration route. Of these 33 adults, 24 birds (73 percent) skipped or likely skipped Delaware Bay while the remaining 9 birds (27 percent) stopped or likely stopped in Delaware Bay for at least one day. Most adult rufa red knots skipping Delaware Bay apparently travelled north over land through the eastern Great Lakes. A few of the birds that bypassed Delaware Bay migrated along the Atlantic coast, stopping around Maryland/Virginia or in New York Bay. Several of the birds that did stop in

Delaware Bay also stopped in coastal New Jersey, New York Bay and/or coastal New England (Smith pers. comm. 2021).

Kingsley-Smith *et al.* (2019, p. 1, 7, 10) found extensive evidence that horseshoe crabs use salt marsh habitat for spawning in South Carolina and that the eggs laid in this habitat will develop to the trilobite stage. Previous studies had suggested that salt marshes may be suboptimal on an individual basis in that eggs develop more slowly, or are less likely to reach the trilobite stage. However, given the extensive acreage of salt marsh habitat in South Carolina, these habitats could still support a significant component of horseshoe crab embryos at the population level. This study also investigated the roles of shoreline orientation, lunar cycle and erosional dynamics on the abundance of spawning horseshoe crabs observed on coastal beaches, as well as crab movements using tagged animals.

Using modeling and resighting data, Smith *et al.* (2017a, p. 3, 13-15, 19) estimated the total passage population along the Georgia coast in spring (April and May) 2013, 2015, and 2016 ranged from about 8,000 to nearly 14,000 rufa red knots per year. In spring 2016, the mean minimum length of stay in Georgia was 9.8 days. Based on these results as well as aerial and ground surveys, these authors concluded the Georgia Coast is a major stopover area annually for rufa red knots in spring migration, and in certain years in fall migration. The total passage population utilizing the coast in fall migration can exceed 23,000 birds. There appears to be less variation between years in spring versus fall total passage population, suggesting a more stable (but less abundant) food source for spring migrants (Smith *et al.* 2017a, p. 3).

Lyons *et al.* (2017b, p. 1) used modeling of 814 marked birds detected in 2011, along with stable isotope analysis to assign migrants to wintering regions, in order to calculate residency times at the Altamaha Delta stopover site in Georgia during southbound migration. Rufa red knots destined for the Southeast United States/Caribbean or the North Coast of South America wintering regions stayed in Georgia about 42 days, while birds heading for the Southern wintering region stayed only about 21 days (Lyons *et al.* 2017b, p. 1). These results are consistent with other findings showing differences in migration strategy based on wintering region (Service 2014, pp. 61-63) and consistent with the genetic findings discussed above; also see our analysis of representation in the SSA report (Service 2020, pp. 27-29).

Tuma (2020, pp. 10-11) used more than 24,000 observations of visible leg flags on rufa red knots from across the Southeastern U.S. spanning more than 10 years to estimate site fidelity and characterize movement patterns. Average site fidelity was 0.75 across the Southeast. This study revealed a high frequency of short-distance (“hop”) movements among seven key sites in South Carolina, Georgia, and Florida. This study also found evidence of movement between sites on the midcontinental flyway (Texas) and the Atlantic coast flyway. Tuma (2020, p. 11) concluded that the Southeast functions as a set of interconnected sites throughout the nonbreeding seasons by both migratory and wintering birds.

Aldabe *et al.* (2015, entire) characterized the role of Uruguay in the rufa red knot flyway, and also investigated phenology, minimum length of stay, connectivity with nearby Argentinian and Brazilian sites, and habitat use at a main Uruguayan site during northbound migration. Sites with more records of rufa red knots and the highest counts were relatively flat sandy beaches of the dissipative morphodynamic type, which have a higher abundance of potential prey, such as Barra del Chuy beach near the Brazilian border. Barra del Chuy and the nearby Rio Grande do Sul (Brazil) appear to function as a single stopover; however, this complex appears to function as an independent stopover relative to San Antonio Oeste in Argentina (Aldabe *et al.* 2015, pp. 221-222).

Martínez-Curci *et al.* (2015b, p. 75) provided the first systematic data set of austral winter shorebird species composition for Punta Rasa, Samborombón Bay, Argentina, including several Nearctic migrants with individuals remaining in the area during this season rather than moving north to breed. With about 150 rufa red knots, Punta Rasa is currently one of the South American sites that supports higher nonbreeding “summering” rufa red knot abundances during June, along with Lagoa do Peixe in Brazil.

Western Gulf of Mexico, Central America, and the Pacific

Based on geolocator data showing trajectories toward the different breeding grounds, nonbreeding birds of both the rufa and roselaari subspecies are known to occur in the Gulf of Mexico, particularly during migration. However, the vast majority of nonbreeding Gulf coast birds, particularly of the birds wintering in this region, appear to be rufa red knots. Recent research has found that rufa red knots in the northern Gulf of Mexico almost exclusively use the Central (for Texas-wintering birds) and Mississippi (for Louisiana-wintering birds) flyways on northbound migration, and mostly use these same midcontinental flyways for southbound migration, but with a low incidence of Atlantic coastal routes in fall (Newstead pers. comm. 2019; Service 2014, pp. 57-61).

A survey in January 2020 documented an important new wintering site, with about 2,000 rufa red knots on Louisiana’s Chandeleur Islands (Newstead pers. comm. 2020). Based on a variety of tracking, resight, and stable isotope data, Newstead (pers. comm. 2019) reported very little rufa red knot connectivity between Texas and Louisiana. Rufa red knots observed on the Mississippi coast include birds flagged in Louisiana, indicating at least some connectivity between these areas (Necaise pers. comm. 2021). Newstead (pers. comm. 2020) reported that two rufa red knots that wintered in Louisiana had previously been marked with visible leg flags in South Carolina—this is consistent with the connectivity between the midcontinental and Atlantic flyways reported by Tuma (2020) and others (Service 2014, pp. 58-60).

Many of the birds observed in Louisiana in spring have been shown to winter on the Pacific coasts of Central and South America, as far south as Chiloé Island on the southern Pacific coast of Chile (Newstead pers. comm. 2019; Newstead and LeBlanc 2018, entire). Geolocator data from one bird that stopped in Louisiana in spring showed the same migratory circuit two years in a row, with a southbound route out of the Arctic to Hudson Bay, then Suriname, then Peru, and finally to Chiloé where it spent the winter before returning to Louisiana in spring (Newstead pers. comm. 2020).

Navedo and Gutiérrez (2018, pp. 670-674) studied wintering *Calidris canutus* (of unknown subspecies) in two bays on Chiloé Island from 2014 to 2018. A total of 55 resightings corresponding to 14 marked individuals were recorded. There were no recorded interchanges between the two bays. All but two birds (86 percent) were flagged in the Gulf of Mexico, either in Texas or Louisiana, during their northbound migration. The remaining two birds were flagged in South Carolina and Argentina. Chiloé is used by a small but site-faithful population of *C. canutus* that segregate on the island. At a minimum, about 150 red knots used the two bays that were surveyed, and up to 15 bays on the island may provide suitable habitat. Although *C.c. roselaari* occurs in certain parts of the rufa nonbreeding range including Chiloé, several lines of evidence suggest that most of the birds on this island are rufa red knots. First, the Gulf of Mexico, which is primarily used by rufa red knots, shows the strongest connectivity with Chiloé. In addition, individuals spending the boreal winter at Chiloé have not been reported on the Pacific coast of North America (which is the *C.c. roselaari* flyway), despite a major resighting effort on the west coasts of the U.S. and Canada. Finally, others have resighted birds flagged in Delaware Bay on Chiloé, and resighted a bird flagged in Chiloé in Georgia. The migratory routes and stopover strategies used by Chiloé red knots are still poorly understood (Navedo and Gutiérrez 2018, pp. 670-674). See also Service 2014, pp. 40-41.

Gherardi-Fuentes *et al.* (2021, pp. 3-5) flagged 37 *Calidris canutus* (at least some likely rufa red knots) on Chiloé in November and March between 2017 and 2020. Of these birds, 24 have been later resighted on Chiloé. Several of these birds were also resighted across the Americas. After departing Chiloé in early April, one bird was seen a few days later in Yucatán, Mexico. In late April and early May, Chiloé-flagged birds have been reported in Paracas (Peru), Texas, Louisiana, and Florida. In late May, Chiloé-flagged birds have been observed in Paracas, Texas, Minnesota, and Manitoba (Canada). In mid-July, a bird was observed in Paracas. Southbound Chiloé-flagged birds were also reported in Florida in mid-August, and in Guatemala and Ecuador in early September (Gherardi-Fuentes *et al.* 2021, p. 5).

Threats Analysis

The SSA (Service 2020 pp. 15-18) synthesized and classified the detailed threats information contained in the Supplemental Listing Document (Service 2014, pp. 124-313); assessed the current condition of the rufa red knot using the conservation biology principles of resiliency, representation, and redundancy (“3 Rs”), including consideration of new information regarding genetics, demographics, and population structure (Service 2020 pp. 20-32); and presented three plausible future scenarios for rufa red knot population trajectories, considering current information about climate change and adaptive capacity, and making no assumption that conservation efforts would be carried out under the authority of the Act (Service 2020 pp. 32-45).

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. Table 4 in the SSA (Service 2020) classifies these threats that are driving the red knot’s status as a threatened species under the ESA as High Severity.

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. Table 4 in the SSA (Service 2020) classifies these secondary threats as Moderate Severity. Classified as Low Severity in table 4 in the SSA (Service 2020) 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.

Here we summarize important information on threats that has become available since the listing, particularly as it relates to the status of the rufa red knot as a threatened species under the Act. New climate change information since the listing that was previously considered in the SSA is not included in the summary below.

Factor A: Present or Threatened Destruction, Modification or Curtailment of Its Habitat or Range

<u>Accelerating Sea Level Rise</u>: FitzGerald *et al.* (2018) presented a conceptual model suggesting that a regime of accelerating sea level rise, as is predicted under some climate change scenarios, will result in diminished sand supplies along the coast, eventually leading to fragmentation of barrier island chains and the transition from stable to transgressive (landward moving) coastal systems. Several historical studies of barrier island systems throughout the world demonstrate barrier island response to changing tidal prism and illustrate different stages of this conceptual model (FitzGerald *et al.* 2018, pp. 3-4). Zhang *et al.* (2020, p. 8) found that sea level rise can directly affect hydrodynamics, sediment transport, and morphological stability of coastal bays, enhancing erosion of tidal flats and tidal channels and reducing the sediment-trapping capacity of bay beds. As discussed above (under Migration, *e.g.*, Burger *et al.* 2018) and in the Supplemental Listing Document (Service 2014, pp. 63-67), optimal nonbreeding habitat for rufa red knots is typically associated with wide tidal flats and channel inlets.

<u>U.S. Shoreline Stabilization and Coastal Development</u>: Rice (2017, p. 138) assessed sandy oceanfront beaches from Maine to North Carolina and found that, as of 2015, a substantial proportion of the sandy beaches along this section of the U.S. coast had been developed (44 percent), armored (at least 27 percent), filled with sediment (at least 23 percent), fenced (14 percent), and scraped (4 percent). Across this same section of U.S. coast, Rice (2016, p. 5) found that 68 percent of the 412 inlets open as of 2015 had been modified by human activities, including 59 percent stabilized with hard structures and 44 percent dredged.

Miselis *et al.* (2021) presented a comprehensive review of the effects of sediment removal and placement in coastal barrier island systems. Beach nourishment can lead to improved shorebird habitat by widening severely eroded beaches, but can adversely affect shorebirds through impacts to the invertebrate prey base. Most studies to date have looked at the effects of a single beach nourishment event—results have been inconsistent and cumulative effects of multiple events are not well studied. As summarized in this report, a few studies suggest that nourishment may be helpful in reducing erosion under future sea level rise. However, artificially high, nourished dunes may reduce overwash and deprive back-barrier environments of the deposition needed to keep pace with sea-level rise. The effects of sediment removal, such as downdrift shoreline erosion and reduced sediment supply, may be worsened by sea level rise (Miselis *et al.* 2021, pp. 4-5). These landscape-level changes to coastal habitats from sediment removal and placement, which generally result in more stabilized shorelines, have important effects on rufa red knot habitat quality and quantity because optimal Atlantic coast habitats for this subspecies typically include dynamic and ephemeral features such as sand spits, islets, shoals, and sandbars, especially at inlets (Service 2014, p. 67).

Smith *et al.* (2017b, p. 33) found that more than half of the tidal marsh on the New Jersey side of Delaware Bay had been historically impounded for agriculture, and that marsh elevation of current and formerly impounded areas is significantly lower than the elevation of marsh areas that were never impounded. In cases where impoundment boundaries coincided with the bay shoreline, these losses also include the sandy beaches that rest upon the bay's fringing salt marshes. Of these beaches, 2.3 km have been lost to open water where low elevations behind the beach berm caused the beach to disintegrate, dispersing sand across the intertidal area after dikes were breached (Smith *et al.* 2017b, p. 37).

Guilfoyle *et al.* (2019, entire) developed best management practices for coastal engineering to benefit shoreline species. This document exemplifies a range of work emerging around living shorelines, “engineering with nature,” and beneficial use of dredged materials. Such approaches to coastal management have been promoted through state and regional coastal resiliency efforts, disaster recovery efforts (*e.g.*, following major storms or oil spills), through the Act’s Section 7(a)(1) conservation planning process, and through large-scale partnerships such as the National Estuary Programs, the Atlantic Coast Joint Venture, and the Atlantic Flyway Shorebird Initiative (AFSI). Most progress to date has been in the arenas of managing habitats and responding to sea level rise, *in situ*, with less progress in the areas of human retreat from the coasts and facilitated landward migration of coastal ecosystem habitat complexes. As part of the Recovery Strategy, the draft Recovery Plan includes not just habitat protection and restoration, but also facilitated migration of certain beaches or tidal flats, as well as restoring the natural coastal processes that create and maintain rufa red knot habitat.

<u>Aquaculture</u>: In 2016, the Service issued a Programmatic Biological Opinion (PBO) on the effects of structural aquaculture along a 6.5-mile-long stretch of tidal flats on the New Jersey side of Delaware Bay. The assessment in the PBO found that rufa red knots are likely to be disturbed and/or displaced by human activities related to aquaculture, and that presence of aquaculture gear on the tidal flats precludes foraging (Service 2016, entire). Maslo *et al.* (2020, p. 1) studied rufa red knots and several other shorebird species in and around aquaculture farms within the PBO action area, and found that human activity associated with aquaculture reduced the probability of shorebird presence by 1 to 7 percent, whereas untended aquaculture structures had no detectable impact on shorebird presence. Foraging rates were mostly influenced by environmental conditions, and none of the focal species substantially altered their time budget or foraging rates in the presence of tended or untended aquaculture (Maslo *et al.* 2020, p. 1). In trapping experiments and spatial modeling, Smith (2019b, entire) found avoidance of aquaculture farms by horseshoe crabs, which could suggest possible impacts on rufa red knot food supplies if horseshoe crabs are deterred from spawning landward of the farms. However, in tank and sonar studies, Munroe *et al.* (2020, p. 81) found that horseshoe crabs can successfully traverse rack-and-bag farms to reach spawning beaches, that crabs do not differentially use farm

versus non-farm areas, and that crab behavior is relatively unaltered by farm gear. Since the listing, intertidal aquaculture has also emerged as a potential threat to rufa red knots in New England (vonOettingen pers. comm. 2021). In light of this new information since listing, we classified aquaculture as a moderate threat in the SSA report, indicating a threat that causes additive mortality and/or negative synergistic effects but is not driving the threatened status of the rufa red knot (Service 2020, pp. 17-18).

Breeding Habitat Loss and Ecosystem Change: The SSA report presents new information since the final listing rule regarding vegetative and other ecosystem changes being driven by climate change in the Arctic (Service 2020, pp. 33, 37). 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. Potential impacts of changing arctic conditions on rufa red knots have not been studied to date.

Modeling results by Lathrop *et al.* (2018, p. 650) suggested it is highly unlikely that the availability of breeding habitat currently limits the population size of the rufa red knot. However, habitat modeling by Lathrop *et al.* (undated) predicted a wholesale decrease in predicted habitat suitability in the southern portion of the rufa red knot breeding range by 2070 under moderate and “worst case” warming scenarios (RCP 4.5 and 8.5). Some model results also suggested increasing habitat suitability in selected locations in the central portion of the breeding range under future climate change. But areas that may potentially become suitable with climate change appear insufficient to offset the loss of areas that are projected to become unsuitable, and are located father north requiring birds to make a longer migration (Lathrop *et al.* undated).

One authority on arctic ecology and breeding rufa red knots has reported observing rapid environmental changes in the Arctic, but to date has not noted dramatic shrub encroachment in tundra areas such as those that support rufa red knots (Smith pers. comm. 2019). Smith (pers. comm. 2019) concludes that tundra degradation from overabundant light geese (*Chen* spp.), especially in the eastern Arctic, is a more pressing problem. Goose-driven habitat degradation is a threat that was not considered at the time of listing, but was considered briefly in the SSA. On Bylot Island, Canada (outside the modeled rufa red knot breeding range but within the *Calidris canutus islandica* range to the north), Lamarre *et al.* (2017) found that a goose colony had a strong influence on the spatial distribution of nest predators and nesting shorebirds (American golden-plover (*Pluvialis dominica*)). Occurrence of predators decreased, while occurrence of nesting shorebirds increased with distance from the goose colony. The strength of these effects was influenced by lemming density, the preferred prey for predators. Shorebird nest predation risk also decreased with distance from the colony (Lamarre *et al.* 2017, p. 1). After accounting for regional variation, Flemming *et al* (2019) found that densities of most cover-nesting shorebirds (including several *Calidris* species, but not *C. canutus*) were depressed in the vicinity of light goose colonies. These authors suggested that these trends are the results of the combined effects of goose-induced changes in habitat and predator-prey interactions. These direct and indirect effects of light geese could be contributing to the declines experienced by some tundra-nesting bird populations in parts of their range (Flemming *et al.* 2019, pp. 1, 5). Potential impacts of increased goose breeding populations specifically on breeding rufa red knots have not been studied to date.

Overabundant geese are also identified as a threat at one of the northernmost rufa red knot migration stopover sites, the Nelson River Delta on Canada's Hudson Bay. McKellar *et al.* (2015, p. 209) observed huge flocks of geese grazing in the salt marshes during shorebird ground surveys in this area. Goose herbivory may result in a habitat degradation and/or changes in predation pressure, with potential to impact migrating rufa red knots at this important stopover site.

Factor A Summary: High severity threats to habitat that were identified in the rufa red knot listing and SSA (sea level rise, coastal engineering, coastal development, and Arctic ecosystem change) and moderate threats (invasive vegetation and aquaculture) have increased since listing. Sea level rise has continued to accelerate since the time of listing, and is projected to continue accelerating into the future (see also Service 2020, pp. 32-39). New studies have quantified the extent of stabilization along the U.S. coast, modification of inlets, effects of sediment removal and placement, and historic modifications to tidal marshes. Conflicts with aquaculture have proven to be more widespread, and potentially more impactful to rufa red knots, than was appreciated at the time of listing. Rapid warming continues to result in ecosystem changes in the Arctic. In addition, a new threat (not considered at the time of listing) has emerged—that of arctic habitat damage caused by overabundant goose populations. Newer and more environmentally sensitive approaches to coastal engineering are beginning to emerge in some areas, and a number of local and regional habitat protection and restoration projects have been carried out across the rufa red knot nonbreeding range. However, these efforts have been insufficient to counteract ongoing habitat loss and degradation across the range (both breeding and nonbreeding), which remains a major threat to the rufa red knot.

Factor B: Overutilization for Commercial, Recreational, Scientific or Educational Purposes

Hunting: The rufa red knot is now legally protected in all French overseas territories including Guadeloupe, Martinique, and French Guyana (Levesque pers. comm. 2020). Andres (2017, entire) summarized a number of harvest policy and management changes across North America, the Caribbean, and southern South America since 2012—changes largely aimed at limiting harvest and protecting shorebird populations. The AFSI Harvest Working Group has been working to address illegal and unsustainable shorebird harvest across multiple countries. This group recently released a new action plan for 2020 through 2025 (AFSI 2020, entire). In light of this new information since listing, we classified sport hunting as a low threat in the SSA report, indicating a minor or potential threat. We classified subsistence hunting as a moderate threat, indicating a threat that causes additive mortality and/or negative synergistic effects but is not driving the threatened status of the rufa red knot (Service 2020, pp. 17-18).

Scientific Study: Despite extensive personnel training and precautions, rufa red knots are occasionally injured or killed as a result of scientific study. Cannon netting in Delaware Bay has resulted in a rufa red knot mortality approximately every 1 to 3 years, typically as a result of stochastic, unavoidable circumstances (*e.g.*, a bird randomly struck by the ropes or projectiles).

A highly unusual event in 2018 resulted in mortality of 10 rufa red knots as a result of stochastic factors as well as human error; a careful analysis was conducted after the fact and lessons learned have been shared and adopted (Breese *et al.* 2018, entire). Personnel conducting scientific research are required to obtain federal and/or state permits to ensure they are qualified, trained, and using appropriate methodologies to minimize the risk of harm to individual birds.

Factor B Summary: Direct human-caused mortality of rufa red knot continues. In the SSA report (Service 2020, p. 18), we characterized these threats as low (sport hunting, research) or moderate (subsistence hunting) severity. This characterization remains valid in light of the new information summarized above.

Factor C: Disease or Predation

Predation—Nonbreeding Areas: Watts and Truitt (2021, p. 1) evaluated the relationship between distance to active peregrine falcon (*Falco peregrinus*) nests and a beach's rufa red knot density using data collected from 2006 to 2009 at the Virginia spring stopover area. Total use of beaches throughout the season by rufa red knots was significantly influenced by proximity of the beach to an active falcon nest. Compared to beaches that were within 3 km of an active falcon nest, mean rufa red knot density was more than 6 times greater on beaches more than 6 km away from a falcon nest. Whether or not a falcon nest was used in a given year had a significant influence on the use of associated close (0 to 3 km) beaches by rufa red knots. From 6.5 to 64 times more rufa red knots used beaches when associated falcon nests were inactive compared to when they were active. Until human introduction efforts to introduce peregrine falcons into coastal areas in the 1970s and 1980s, migratory shorebirds would have experienced a peregrine-free zone within this important stopover area (Watts and Truitt 2021, p. 1).

Dey (pers. comm. 2021) observed increases in interactions between peregrine falcons and rufa red knots in Delaware Bay in 2020 and 2021, and has suggested this as a possible causal factor for the low 2021 peak shorebird abundances as recorded by the baywide aerial survey. Duijns *et al.* (2019 pp. 1) showed that greater airspeeds of rufa red knots and other shorebirds during fall migration precede a wave of avian predators, which could suggest that migrant shorebirds show predation-minimizing behavior during the post-breeding season.

Predation—Breeding Areas: Based on patterns detected in data on lemmings and shorebirds, including other subspecies of red knots, Aharon-Rotman *et al.* (2015, p. 861) argued that diminishing of lemming population cycles in some parts of the Arctic are causing decreasing periodicity in shorebird breeding success along the East Atlantic and East Asian-Australasian Flyways. These authors concluded that changes on the breeding grounds have not yet resulted in any marked changing trends in breeding success across years, and declining numbers of shorebirds in these flyways are therefore more likely a result of changing conditions at stopover and wintering sites. Applicability of these findings to the rufa red knot is unclear. Ehrich *et al.* (2019) presented an overview of recent trends in lemming abundance across the circumpolar Arctic. There was no evidence that lemming populations were decreasing in general, although a negative trend was detected for low arctic populations sympatric with voles. However, these authors noted that high arctic Canada is underrepresented in lemming monitoring, and that natural variability in lemming dynamics makes population trends inherently difficult to detect, so their trend analysis needs to be considered cautiously (Ehrich *et al.* 2019, pp. 1, 13). Ehrich *et al.*

(2019) did not present any conclusions regarding lemming cycles within the rufa red knot breeding range.

Factor C Summary: New information regarding predation is consistent with the assessment and conclusions in the Supplemental Listing Document (Service 2014, pp. 194-202), characterized in the SSA (Service 2020) as severe in breeding areas and moderate in the rufa red knot wintering and migration range. Predation pressures likely exacerbate other threats in some nonbreeding areas, likely more through displacement from preferred habitats than through direct mortality. Natural cycles of high predation rates on the breeding grounds are not considered a threat to rufa red knot populations, but disruption of these cycles from climate change, which may lead to prolonged periods of low productivity, may be an emerging threat to the rufa red knot.

Factor D: Inadequacy of Existing Regulatory Mechanisms

In 2020, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2020, pp. 3-5) updated the Designated Status level for three "Designatable Units" of rufa red knot. The Southeastern USA / Gulf of Mexico / Caribbean wintering population and the Tierra del Fuego / Patagonia wintering population were designated endangered, while the Northeastern South America wintering population was designated special concern. To date, these COSEWIC designations have not yet been formalized under the Canadian Species at Risk Act and thus do not currently create any changes in protections or conservation actions. Please refer to the discussion of subsistence and sport hunting regulations under Factor B, above. Notwithstanding the rufa red knot's status as a threatened species under the Act, regulatory mechanisms are not adequate to address threats such as coastal development or shoreline stabilization. Further, many important global climate threats are not amenable to direct regulatory amelioration.

Factor E: Other Natural or Manmade Factors Affecting Its Continued Existence

Reduced Food Availability – Marine Ecosystem Change: In a comprehensive meta-analysis of 228 studies examining biological response to ocean acidification, Kroeker *et al*. (2013, p. 1884) found decreased survival, calcification, growth, development and abundance in response to acidification when the broad range of marine organisms is pooled together; however, the magnitude of these responses varies among taxonomic groups. The results also reveal an enhanced sensitivity of mollusk larvae in some groups. Species responses varied when exposed to acidification in multi-species assemblages, and sensitivity to acidification was typically enhanced when taxa are concurrently exposed to elevated seawater temperature (Kroeker *et al*. 2013, p. 1884). Using an ecosystem model for the Northeast U.S. continental shelf, Fay *et al.* (2017, p. 1) found generally detrimental effects to shelled invertebrates from ocean acidification, with food web consequences that can extend beyond groups thought most vulnerable.

Gobler and Baumann (2016, entire) reviewed evidence from published literature to evaluate the combined effects of low pH and low oxygen across a broad spectrum of marine taxa. Additive negative effects of combined low pH and low oxygen appear to be most common, but synergistic negative effects have also been observed. Neither the occurrence nor the strength of these synergistic impacts is currently predictable, and therefore, the true threat of concurrent acidification and hypoxia to marine food webs is still not fully understood (Gobler and Baumann 2016, p. 1). Stevens and Gobler (2018, p. 143) investigated the individual and interactive effects of coastal and climate change stressors (elevated temperatures, acidification, and hypoxia) on four North Atlantic bivalves, including the rufa red knot prey species blue mussel (*Mytilus edulis*). Elevated temperatures most consistently altered the performance of the bivalves, with both positive and negative physiological consequences. Low levels of dissolved oxygen and pH individually reduced the survival, shell growth, and/or tissue weight of each bivalve. Blue mussels displayed size-dependent vulnerability to acidification, with smaller individuals being more susceptible. The climate change stressors interacted in various ways, producing outcomes that could not be predicted from the responses to individual stressors (Gobler 2018, p. 143).

Heller (2020, pp. iii-iv) found that blue mussel abundance declined in the rufa red knot's Virginia (spring) stopover. Chemical analysis suggested that Virginia's blue mussels originated from ocean populations in more saline and/or colder water than that within Virginia's intertidal zone. Blue mussel shell chemistry suggested that Virginia's blue mussels originated in ocean waters between Delaware and Virginia. However, the mussels may have originated as far north as New York in some years, potentially decreasing the risk of this prey species being completely extirpated from Virginia in the near future (Heller 2020, p. iv).

A 130,000-square-mile hotspot off the coasts of Uruguay and Argentina, shorelines that support important concentrations of nonbreeding rufa red knots, has warmed over 2 degrees Celsius over the past century, making it one of the fastest-warming areas of the ocean and causing mass clam die-offs and algal blooms. The Gulf of Maine and the Gulf of St. Lawrence, which include major rufa red knot fall stopovers, also warmed by more than 2 degrees Celsius comparing the period 2014 to 2018 with the period 1880 to 1899 (Mooney and Muyskens 2018, entire).

Reduced Food Availability – Sediment Placement: Peterson and Bishop (2014, p. 481) found that beach nourishment involving placement of coarse, shelly sediments that differed from the native beach sands resulted in suppressed densities of two infaunal invertebrates (including *Donax* spp.) 3 to 4 years after the nourishment event. The overall impact to invertebrates of nourishment was matched by multi-year reductions in abundances of their predators, including shorebirds. Monitoring a New Jersey habitat enhancement project involving sediment transfer, Tsipoura (2018, p. 9) found lower invertebrate mass in sediment source areas than in control plots, particularly in bivalves mainly *Donax variabilis*, an important rufa red knot prey species. Amphipods and annelids, secondary rufa red knot prey, also were lower in plots affected by the restoration activities, and there was no evidence of recovery of annelids during the two years of this study. In a review paper of the effects of beach nourishment on invertebrates, Rosov *et al.* (2016, p. 3-5) underscored the important effects of seasonal timing, recovery periods between nourishment cycles, and the degree of similarity between the native beach sand and the placed sediment.

Reduced Food Availability – Horseshoe Crab Eggs: Nonbreeding rufa red knots are specialized molluscivores; thus, in most wintering and migration habitats mollusks such as clams, mussels, and snails are the primary prey. However, in several localized areas along the Atlantic coast, horseshoe crab eggs are a preferred food for rufa red knots and may be an important component of the spring diet. In Delaware Bay, rufa red knots eat horseshoe crab eggs almost exclusively, and a superabundance of eggs in this bay fuels rapid weight gain that is necessary for the birds to complete their migrations (Service 2014, p. 74). Carmichael *et al.* (2015, entire) presented a comprehensive review of horseshoe crab research, ecology, assessment, threats, conservation, and management, including numerous chapters relevant to the rufa red knot.

As discussed in the Supplemental Listing Document, the body mass of rufa red knots leaving the Delaware Bay stopover has been linked to both the availability of horseshoe crab eggs and to the birds' subsequent survival rates (Service 2014, pp. 240-247). A new study by Duijns *et al.* (2017) adds to the body of evidence for these ecological linkages. Duijns *et al.* (2017 pp. 1, 4) examined the effects of body condition using data from 302 rufa red knots fitted with nanotags in Delaware Bay in the springs of 2014 to 2016, and subsequently detected by the Motus network of stationary receivers. These authors found that rufa red knots with a higher relative body condition (measured as relative mass) left Delaware Bay later than birds in lower condition, yet still arrived earlier to their arctic breeding grounds compared to birds in lower relative body condition. They accomplished this by selecting more favorable winds at departure, thereby flying faster and making shorter stops en route. Individuals with a higher relative body condition in spring migrated south up to a month later than individuals in lower condition, suggesting that individuals in better condition were more likely to have bred successfully. Moreover, individuals with a lower relative body condition in spring had a lower probability of being detected in autumn, suggestive of increased mortality (Duijns *et al.* 2017 pp. 1, 4).

Abundance of spawning horseshoe crabs is tied to rufa red knot weight gain not only because more spawning crabs deposit more eggs, but also because the nesting activity of multiple females across many weeks moves previously buried egg clusters to the surface where they are available to shorebirds. Smith and Robinson (2015, p. 1) assessed standardized surveys of spawning horseshoe crabs in Delaware Bay from 1999 to 2013 to estimate trends in female and male spawning densities at the beach level. For females, there was no overall trend and no single explanation applied to the temporal and spatial patterns in their densities. Individual beaches that initially had higher densities tended to experience a decrease, while beaches that initially had lower densities tended to experience an increase. As a result, densities of spawning females at the end of the study period were relatively similar among beaches, suggesting a redistribution of females among the beaches over the study period. For males, there was a positive overall trend in spawning abundance from 1999 to 2013, and this increase occurred broadly among beaches. Moreover, the beaches with below-average initial male density tended to have the greatest increases. Possible explanations for these patterns include harvest reduction, sampling artifact, habitat change, density-dependent habitat selection, or mate selection.

A recent ASMFC benchmark stock assessment evaluated four regional populations of horseshoe crab using Autoregressive Integrated Moving Average models fit to survey data for stock status determination, relative to abundance in 1998. Examination of results from multiple surveys within individual regions was necessary. Stock status was based on the proportion of surveys above or below their 1998 reference point when coastwide management began. Stock status was considered poor if 33 percent of the surveys were below their reference point, good if 66 percent were above their reference point, with a neutral condition in between. Horseshoe crab relative abundance in the Northeast and Delaware Bay regions were found to be in a neutral condition, New York in a poor condition, and the Southeast in a good condition. Across the entire U.S. Atlantic coast, horseshoe crab relative abundance is likely in a neutral condition (ASMFC 2019, p. 1). A separate status assessment by Smith *et al.* (2016, entire) found that horseshoe crabs are vulnerable to local extirpation, with the Gulf of Maine, New England, Northeast Gulf of Mexico, and Yucatán Peninsula regional populations at elevated risk.

In addition to the bait harvest, which is regulated by the ASMFC, horseshoe crabs are also harvested along the U.S. Atlantic coast for biomedical uses. The primary biomedical use of horseshoe crabs involves using an extract of crab blood, called Limulus amebocyte lysate (LAL), to screen medicines and medical devices for bacterial contamination. From 2010 through 2019, biomedical mortality was estimated at roughly 50,000 to 100,000 crabs per year; coastwide bait landings are much higher, averaging about 750,000 crabs per year over this same time period (ASMFC 2020, pp. 5-7). However, uncertainty around biomedical mortality estimates is high, and biomedical harvests may cause localized impacts that are not yet fully documented. Demonstrating the risk of local extirpation (*e.g.*, as highlighted by Smith *et al.* 2016), Chaplin (pers. comm. 2021) reported that there has been no horseshoe crab spawning on Turtle Island, South Carolina following intensive biomedical collections there in 2019.

Building on previous laboratory studies showing sublethal effects of biomedical bleeding, Owings *et al.* (2019, p. 1) found behavioral differences between 14 bled crabs versus 14 control crabs fitted with acoustic transmitters and released back into the wild. Although bled versus control animals displayed overall similar seasonal movements, bled animals approached mating beaches less than control animals during the first week after release, with the greatest differences among females. Sublethal effects are not currently considered by the ASFMC, but the results of Owings *et al.* (2019) suggest that such effects (*e.g.*, on behavior) could impact spawning and therefore rufa red knot food supplies.

Concerns have been raised about a potential spike in horseshoe crab harvest due to the COVID-19 pandemic (Wittenberg 2021). Because horseshoe crab landings data for 2020-2021 are not yet available, we do not yet know if the biomedical harvest recently increased in order to test COVID-19 vaccines. A synthetic compound has been developed that could replace LAL but has seen limited adoption to date by the U.S. pharmaceutical industry (Wittenberg 2021). Although the ASMFC has not directly regulated the biomedical harvest to date, it is working on updated scientific modeling that will account for biomedical mortality levels when setting bait harvest quotas, though only in Delaware Bay. In addition to biomedical harvest along the Atlantic coast, concerns have also been raised regarding the emergence of a biomedical fishery in the Gulf of Mexico (Shin and Botton 2015, entire).

Asynchronies During the Annual Cycle: Studying timing mismatches between peak food availability and chick rearing among six shorebird species (including four *Calidris* species, but not *C. canutus*) across a large latitudinal and longitudinal gradient of the North American Arctic, Kwon *et al.* (2019, p. 15) found a linear relationship between recent climate-driven shifts in snow phenology and the birds' current extent of phenological mismatches. These authors also found that shorebird populations are experiencing greater trophic mismatches at higher latitudes and more easterly longitudes, which may be contributing to regional population declines.

The Supplemental Listing Document (Service 2014, pp. 253-254) summarizes several papers that suggest that the reduced rufa red knot survival rates noted between 1998 and 2002 were likely exacerbated by birds arriving late in Delaware Bay, and not caused solely by insufficient horseshoe crab egg availability alone. However, based on new information and re-analysis, some researchers (including most of those involved in the original research from the mid-2000s) now conclude that late arrivals did not actually play a role in declining apparent survival rates during this period. Updated analysis now in progress shows that the apparent variation in low-weight late birds arose not because there were more or less late arrivals, but instead reflects the proportion of birds that were caught in Mispillion Harbor, Delaware, where late-arriving birds are now known to congregate (Sitters pers. comm. 2019).

Looking at 22 years of data from Delaware Bay, Tucker *et al.* (2019, p. 1) found that, in years with cooler water temperatures, horseshoe crabs spawned later, which was associated with later and faster mass gain for rufa red knots that feed almost exclusively on crab eggs at this stopover. In contrast, ruddy turnstones (*Arenaria interpres*) exhibited less inter-annual variation in the timing and rate of mass gain than rufa red knots, and these authors found no relationship between mass gain dynamics and the availability of horseshoe crab eggs for this more generalist-feeding species. This supports earlier work indicating the rufa red knot's high vulnerability to timing mismatches due to several aspects of its biology and life history (Service 2014, pp. 249-253; Thurman *et al*. 2020, p. 525).

<u>Human Disturbance</u>: In a study of human disturbance from Nova Scotia to Florida across a number of shorebird species, Hunt *et al.* (2018, pp. 18–19) found rufa red knots to be particularly reactive to the presence of humans. Although variable among the species, most shorebirds were rarely observed near an area if there were more than 15 people within 200 meters. For all species, the point counts with the largest numbers of shorebirds were generally associated with areas where the observers were the only humans nearby (Hunt *et al.* 2018, p. 19). Based on the distance at which various species flew in response to approaching humans, Koch and Paton (2014, p. 64) also found rufa red knots to be among the more sensitive shorebirds and recommended affording the birds a buffer of 124 meters to avoid disturbance.

Based on surveys of the North Carolina coast, Watts (2017, p. 66) found that the average rufa knot density was four times higher on government-owned lands compared to private lands, while human density was ten times higher on private lands. More than 80 percent of all rufa red knots used beaches with human densities below five people per km, with these conditions being primarily found on government lands resulting from beach closures. Migrating rufa red knots appear to benefit incidentally from seasonal beach closures implemented to protect nesting piping plovers and sea turtles along the North Carolina coast (Watts 2017, p. 66).

Studying eight nonbreeding areas in the Southeastern U.S. from 2012 to 2016, Gibson *et al*. (2018, p. 566) found that piping plovers (*Charadrius melodus*) at disturbed sites were 7 percent lighter (in body mass) compared to those at less disturbed sites. True annual survival was lower in more disturbed areas. Site fidelity was less influenced by disturbance than were body mass and survival. Movements away from specific nonbreeding areas were uncommon, regardless of disturbance regime, but individuals that moved to new wintering locations had higher probabilities of annual survival (Gibson *et al*. 2018, p. 566). These findings underscore the effects of disturbance in nonbreeding areas on the body condition, survival, and habitat use of a migratory shorebird, important considerations for rufa red knot conservation.

Mengak (2019, entire) developed best practices for evaluating and managing human disturbances to migrating shorebirds in the Northeast U.S. Recommendations were based on a literature review as well as systematic expert elicitation.

Harmful Algal Blooms: Harmful algal blooms, classified as a moderate threat in the SSA (Service 2020), are a continuing threat. Red tide events affected moderate numbers of rufa red knots in Florida in 2017, 2018, and 2021. Several red knots became sick and some died in Florida in 2020 from unknown causes, which could have included red tide. Newstead (pers. comm. 2019) reported that harmful algal blooms may be seriously affecting rufa red knot survival rates through illness and direct mortality.

Oil Spills and Leaks: Oil spills, classified as a moderate threat in the SSA (Service 2020), are a continuing threat. In 2019 and early 2020, oil contamination from an unknown source was documented along about 4,000 km of Brazil's northeast shoreline (Law 2020), potentially overlapping the core rufa red knot wintering area and likely overlapping the eastern peripheral area. Any impacts to red knots from this oil contamination event are not yet known. Biological and ecological effects of oil spills (*e.g.*, to shorebirds and their prey species) are discussed in the Supplemental Listing Document (Service 2014, pp. 282-283).

Wind Energy Development: The first offshore wind farm in the U.S., Block Island Wind Farm, began operation in 2016 and includes 5 turbines off the coast of Rhode Island (Orsted undated). The Bureau of Ocean Energy Management (BOEM), which oversees wind development in Federal waters, has 16 active commercial wind energy leases off the Atlantic coast as of March 2021. The Departments of Energy and Commerce have established a target to deploy 30 gigawatts of offshore wind by 2030 (BOEM 2021). Loring (*et al.* 2018, p. ii) used nanotag data to assess rufa red knot movement though wind energy areas in the Atlantic Outer Continental Shelf. Of 388 tagged birds, 8 percent were detected passing through one or more wind energy areas, and 75 percent of those crossings were within the altitude of the rotor swept zone of a (potential future) turbine. However, error around estimated flight heights was large and offshore data were limited by detection range of tracking stations (typically less than 20 km), so occurrence estimates in lease areas represent minimum estimates. Loring *et al.*(2021, pp. 43, 55) also deployed nanotags on rufa red knots along the U.S. Atlantic coast, and estimated that 81 percent of the tagged individuals were tracked in Federal waters (where BOEM is entering into offshore wind energy leases) in fall versus 26 percent in spring. These data were also limited by the locations and detection ranges of the tracking stations. More detailed information is needed to fully assess offshore occurrence in Federal waters and lease areas. In Brazil, offshore areas near red knot wintering areas are currently under consideration for development (Energy Research Office 2020), and many onshore facilities are in operation along the coast of South America.

Conservation Efforts: The Atlantic Flyway Shorebird Initiative (AFSI) was formed to address declines in shorebirds. The Atlantic Flyway Shorebird Business Plan represents the full suite of strategies and actions needed to conserve 15 Atlantic Flyway shorebird focal species, including the rufa red knot (AFSI 2015, entire). Efforts are now underway to develop a similar framework for the inland portions of South and North America, known as the Midcontinent Shorebird Conservation Initiative.

Factor E Summary: Since the time of listing, new research has continued to show that multiple aspects of climate change, primarily warming and acidifying coastal waters, are poised to broadly impact mollusk species, some of which rufa red knots depend on for food across most of their nonbreeding range. Likewise, new information continues to support our previous conclusions regarding the effects of sediment placement on rufa red knot prey species. New studies underscore the vulnerability of rufa red knots to insufficient horseshoe crab egg supplies in Delaware Bay, but present mixed findings about the conditions of regional crab populations along the Atlantic coast. Available information continues to highlight the vulnerability of rufa red knots to timing mismatches. However, an updated assessment concluded that late arrivals in Delaware Bay were not actually a factor in declining rufa red knot survival rates in the early and mid-2000s, as had been previously believed. New information supports the conclusion that, among shorebirds, rufa red knots are particularly sensitive to human disturbance. Harmful algal blooms and oil spills continue contributing to rufa red knot mortality, and the risk of a catastrophic spill impact remains due to the extensive overlap of petroleum extraction and transport with numerous key rufa red knot habitats. Offshore wind energy development is likely to make at least modest additional contributions to mortality in the coming decades. Watts *et al.* (2015, pp. 37, 40) found that rufa red knots have notably low limits of sustainable mortality from anthropogenic causes, such as hunting, oil spills, and wind turbine collisions.

Synthesis

Rufa red knot abundance remains depleted. A notably low peak count in Delaware Bay in spring 2021 warrants further investigation, pending results of the total passage population estimate later this year. Since the time of listing, genetic, stable isotope, tracking, and modeling efforts have produced important new insights into rufa red knot distribution, migration, phenology, and population structure. Less progress has been made in estimating key demographic rates and in studying birds on the breeding grounds, but new modeling efforts and tracking technologies (particularly satellite transmitters) are expected to facilitate advances in these areas. Tracking and resighting work has largely confirmed our previous understanding of the migratory habits of rufa red knots wintering in Argentina/Chile, northern Brazil, and across the Southeastern U.S., underscoring the connectivity among nonbreeding sites and the need for rufa red knots to be able to shift among them across multiple geographic and temporal scales. Many new insights have been revealed in recent years about birds wintering in Texas and Louisiana, but the migration of these birds remains less clear than those of the other three wintering populations. Even more questions remain about the *Calidris canutus* that winter in Central America and along the Pacific coast from Mexico (south of Las Garzas) to Chile, at least some of which are known to be rufa red knots.

The threats classification and "3 Rs" assessment presented in the SSA (Service 2020, pp. 15-32) remain valid and continue to be supported by the new information presented above. The magnitude and imminence of the primary (high severity) threats to the rufa red knot (sea level rise, coastal engineering/development, arctic ecosystem change, reduced food availability, and timing asynchronies) are increasing. Only one secondary threat (subsistence hunting) has decreased since listing, while all other secondary threats (invasive vegetation, aquaculture, predation in nonbreeding areas, human disturbance, wind energy development, harmful algal blooms, and oil spills) are continuing and increasing in magnitude, singly and cumulatively adding to reduced rufa red knot survival. One new threat has been identified that was not considered at the time of listing, namely arctic habitat damage caused by overabundant goose populations. At this time, we consider goose overpopulation a secondary threat, but recognize high uncertainty around how geese may be impacting rufa red knot reproductive rates, and if/how those effects may be interacting with climate-driven habitat and ecosystem changes. The new information above provides additional context and insights into this suite of threats, and fundamentally reinforces our understanding at the time of listing of how these threats are affecting the rufa red knot and its classification as a threatened species.

RESULTS

Recommended Classification:

____ Downlist to Threatened
____ Uplist to Endangered
    ____ Delist (*Indicate reasons for delisting per 50 CFR 424.11):*
    ____ *Extinction*
    ____ *Recovery*
    ____ *Original data for classification in error*
__X_ No change is needed

New Recovery Priority Number: No change

Brief Rationale: The Recovery Outline presents the Service’s rationale for assigning a recovery priority number of 12C (Service 2019, p. 10). The information presented in the Recovery Outline remains current, relevant, and valid; thus, no change is proposed to the recovery priority number.

RECOMMENDATIONS FOR FUTURE ACTIONS

The approved Recovery Outline includes a preliminary action plan with 12 high priority conservation tasks. Progress has been made in several of these areas, and the Service recommends continued efforts on these tasks while the Recovery Plan is being finalized.

With feedback from numerous partners across the range of the rufa red knot, the Service has begun work on a Recovery Implementation Strategy (RIS). The RIS will be released after conclusion of the public comment period on the draft Recovery Plan, and will provide a detailed, prioritized list of tasks needed to step down and implement the Recovery Actions identified in the Plan. The RIS will be kept current through regular updates. The Service defers any further recommendations for future actions (beyond those included in the Recovery Outline) until release of the RIS.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW OF RUFA RED KNOT (*Calidris canutus rufa*)

Current Classification: threatened

Recommendation resulting from the 5-Year Review:

____ Downlist to Threatened

____ Uplist to Endangered

____ Delist (Indicate reasons for delisting per 50 CFR 424.11):
    ____ Extinction
    ____ Recovery
    ____ Original data for classification in error

_X_ No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: Not applicable

Review conducted by: Wendy Walsh, Senior Endangered Species Biologist, New Jersey Field Office.

REGIONAL OFFICE APPROVAL:

Approve SHARON MARINO Digitally signed by SHARON MARINO Date: 2021.12.06 17:07:48 -05'00' Date _________

Assistant Regional Director, Ecological Services, North Atlantic-Appalachian Region