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Habitat risk: Use of intertidal flats by foraging red knots (*Calidris canutus rufa*), ruddy turnstones, (*Arenaria interpres*), semipalmated sandpipers (*Calidris pusilla*), and sanderling (*Calidris alba*) on Delaware Bay beaches

Joanna Burger[a,*], Lawrence Niles[b], Christian Jeitner[a], Michael Gochfeld[c]

[a] Division of Life Sciences, Rutgers University, 604 Allison Road, Piscataway, NJ 08854-8082, USA
[b] Niles and Associates and Conserve Wildlife Foundation of New Jersey, 109 Market land, Greenwich, NJ 08323, USA
[c] Rutgers Robert Wood Johnson Medical School, Piscataway, NJ 08854, USA

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ABSTRACT

Shorebirds usually forage on intertidal flats that are exposed during low tide, and roost on higher areas when the tidal flats are covered with water. During spring migration on Delaware Bay (New Jersey) shorebirds mainly forage on horseshoe crab (*Limulus polyphemus*) eggs that are concentrated at the high tide line. However, they also use other habitats for foraging. We examined habitat use of 4 species of shorebirds (with declining populations) at five Delaware Bay beaches to determine their use of the intertidal habitat (2015, 2016). We observed birds in three sections at different distances from the mean high tideline (< 100 m, 101–200 m, and 201–300 m) ne. We examined the presence of red knots (*Calidris canutus rufa*), ruddy turnstones (*Arenaria interpres*), semipalmated sandpipers (*Calidris pusilla*), and sanderling (*Calidris alba*) as a function of date, tide cycle, section shorebirds foraged from the mean high tide line, and presence of other shorebird species. Understanding how these species use the intertidal flats is important because these habitats are at risk from coastal development, sea level rise, and decreases in intertidal space, including the possible expansion of intertidal oyster culture. Overall, knots were present in the intertidal on 67% of the surveys, turnstones were present on 86% of the surveys, semipalmated sandpipers were present on 77% of the surveys, and sanderling were present on 86% of the surveys. Use of the intertidal flats varied among beaches. Peak and mean numbers of shorebirds/ decreased in each census section, as distance to mean high tideline increased. In general, shorebirds foraged at the waters' edge during high tide, and then moved out onto the intertidal flats. The strongest interspecific associations were between red knots and ruddy turnstones, and the lowest associations were between sanderling and semipalmated sandpipers. Variations in numbers of each species in 2016 were mainly explained by the number of other species, section (distance from the mean high tide line), location (one of 5 beaches), and date for all species (and minutes to low tide for sanderling). These data indicate that these 4 species use intertidal flats as they become available, and that the mean number in each newly exposed census section of the flats may be lower than in the previous one, partly as a result of some birds remaining in each previously-exposed section. We discuss the management and regulatory implications of shorebird use of the intertidal flats, which include protection of high quality intertidal for foraging by shorebirds.

1. Introduction

Many Western Hemisphere species of shorebirds undergo long migrations from high latitude breeding grounds to wintering grounds in South America, and back. Some of these species spend a quarter of their life at migration stopover sites where they refuel for the next leg of their journey (Morrison, 1984; Klaassen et al., 2001; Conklin et al., 2010). Stopover sites are critical for shorebirds on both northbound and southbound migrations. Similar migration and stopover patterns occur in the Eastern Hemisphere (Tomkovich et al., 2013). Because several species of shorebirds are declining (Morrison et al., 2001, 2007; IWSG, 2003; Andres et al., 2013), examining the threats facing shorebirds at coastal stopover sites is important for management of both shorebird populations and human activities. Migrating and wintering shorebirds normally feed on intertidal flats at low tide, and are forced to higher places to roost as the tide covers the flats. (Pitelka, 1979; Connors et al., 1981; Warnock et al., 2002; Burger and Niles, 2014). During migration, shorebirds face prey depletion, severe storms, and disruptions from

* Corresponding author.
E-mail address: burger@biology.rutgers.edu (J. Burger).

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human and predator activities (Piersma et al., 2001; Baker et al., 2004, 2013; Burger et al., 2004, 2007; Niles et al., 2008, 2009; Harrington et al., 2010; Burger and Niles, 2013a, 2013b). They face a severe ecological constraint in securing enough food to undertake long distance migrations (Piersma et al., 2005; Mizrahi et al., 2012; Hua et al., 2013), and body condition may explain success of long-distance migrants (Duijns et al., 2017).

Given that shorebirds often stop for only short periods of time to refuel before their next long-distance migration flights, the availability of suitable foraging space and sufficient prey is critical (Baker et al., 2004; Hua et al., 2013; Duijns et al., 2017). Examining the factors that determine availability and suitability of foraging habitat can contribute not only to understanding migration behavior, but to conservation and the maintenance of stable shorebird population (Dolman and Sutherland, 1995; Piersma et al., 2006; Burger et al., 2017). Habitat loss due to development and human disturbance is well documented in many places, and available exposed mudflat for shorebirds is expected to decline due to global climate change and sea level rise (Piersma et al., 1993, 2001; Galbraith et al., 2002, 2014; Burger and Gochfeld, 2016; Burger, 2018). Thus, it is critical to gather data on how different species of shorebirds use intertidal habitats, and to identify potential risks from loss of these habitats due to human activities.

Foraging difficulties have been identified as a partial cause of shorebird population declines, particularly on Delaware Bay, New Jersey, USA (Burger et al., 1997; Baker et al., 2004; Niles et al., 2008, 2009), as well as along the mid-Atlantic coast (Conklin et al., 2010). Shorebirds are attracted to Delaware Bay because of the abundance of horseshoe crab (*Limulus polyphemus*) eggs concentrated at the high tide line. Northbound shorebirds stop at Delaware Bay only during May to refuel for further northward migration, and they forage almost exclusively on horseshoe crab eggs (Tsipoura and Burger, 1999). Declines in the number of spawning horseshoe crabs, caused by overfishing, has led to decreased availability of eggs, the subsequent decline in weight gain of Red Knots, and declines in knot populations (*Calidris canutus rufa*)(ASMFC, 1998; Baker et al., 2004, 2013; Niles et al., 2009). At low tide, some eggs are scattered over the mudflat with the receding tide, food is more spread out and the birds, in turn, spread out over the flats, feeding on eggs. Delaware Bay is a good case study of habitat use, and the risks from expanding human activities, because it is the major stopover site in the U.S. for several shorebird species that have declined (Andres et al., 2013; Niles et al., 2009; Mizrahi et al., 2012; Lyons et al., 2017).

In this paper we examine the use of intertidal flats by 4 species of shorebirds as a function of date, tide cycle, and location on the intertidal flats during spring migration on Delaware Bay, New Jersey. In 2015 and 2016 observations were made on red knot, ruddy turnstone (*Arenaria interpres*), semipalmated sandpiper (*Calidris pusilla*), and sanderling (*Calidris alba*) at five high-use beaches along New Jersey's Delaware Bay coast. We recorded the number of foraging shorebirds (by species) in each of three sections (0–100 m, 101–200 m, and 201–300 m from the high tideline). Our overall goal was to understand if the intertidal area (out to 300 m) is important for foraging shorebirds. We test the null hypothesis that there are no differences in the numbers of each of the 4 species of shorebirds/census as a function of date, beach (5 beaches), tide stage, location on the intertidal, and presence of other shorebirds. We predicted that there would be differences as a function of date and tide based on previous work on Delaware Bay (Niles et al., 2008; Dey et al., 2016, 2017 [and other years of NJ state reports]), and that these may vary by species. Delaware Bay is a "bottleneck migration stopover site" for the shorebirds (see references above). However, other migration stopover sites are also located along coasts where shorebirds forage on exposed tidal flats, moving with the receding or rising tides (Lyons et al., 2017).

The risks foraging shorebirds face on their spring stopover in New Jersey are from human disturbance, low density of crab eggs, and the potential of expanding aquaculture, among other factors (Burger et al., 2015; Burger and Niles, 2017a, 2017b). Most of the beaches examined are protected from human disturbance because the beaches are closed to recreationists during May by the NJ Department of Environmental Protection, and most beaches have signs and wardens. The Atlantic State Marine Fisheries Commission manages the commercial horseshoe crab take so that there are sufficient eggs for migrant shorebirds (ASMFC, 1998), although this has not been as successful as planned (Niles et al., 2009). Permits for placing rack-and-bag aquaculture in the intertidal of New Jersey are issued by NJ Department of Environmental Protection and the U.S. Army Corps of Engineers (Burger and Niles, 2017a). Currently, there is a strong desire to expand structural oyster aquaculture in the intertidal, which could pose a risk to foraging shorebirds (Burger et al., 2015; Gittings and O'Donoghue, 2016; Burger and Niles, 2017a, 2017b).

Traditional oyster harvesting in New Jersey occurred along natural reefs, and was an important component of Delaware Bay culture (Niles et al., 2013). Rack-and-bag oyster culture started in the 1990s in the Bay, and will aid restoration and economic development along Delaware Bay (Munroe and Calvo, 2015). Although aquaculture is usually viewed as an ecologically-friendly industry (Shumway et al., 2003), it has the potential to decrease intertidal foraging space for shorebirds and subtidal foraging and resting places for horseshoe crabs (Zydelis et al., 2009; Godet et al., 2009; Burger et al., 2015; Burger and Niles, 2017a, 2017b). It may also inhibit foraging on the high tide, either because of disturbance or because of lowered egg density. Shorebirds concentrate along Delaware Bay beaches at the high tide line in direct proportion to the abundance of horseshoe crab eggs (Botton et al., 1994, 2003), but the intertidal flats may also be very important for foraging.

2. Methods

Our protocol was to census the number of shorebirds as a function of time in the tide cycle and distance from mean high tide in 2015 and 2016. We observed shorebirds on all the beaches from Villas to Reeds Beach North in 2015, and at only 5 of these beaches in 2016 that each had at least 300 m of intertidal flats at very low tides (Fig. 1). For this paper we present data ONLY on the birds recorded at the same 5 beaches in both years. Results from the full 2015 data set are presented elsewhere, with an emphasis on red knots (Burger and Niles, 2017a, 2017b, 2018), as well as results on habitat use of shorebirds on an experimental array with oyster racks, reefs, and controls (Burger et al., 2015; Burger, 2017).

We recorded the number of each species of shorebirds in a census section that was 300 m along the shoreline, at three distances from mean high tide (0–100 m, 101–200 m, and 201–300 m). Data were not recorded for the 15 min before and after high tide as the birds were concentrated at the tidal edge where crabs were spawning on the sandy beaches, and were not on intertidal flats. The data reported in this paper are based on 81 censuses in 2015, and 676 censuses in 2016 at different tide times. In 2015 the number of censuses was not evenly distributed among beaches; there were more censuses at Dias Creek where oyster racks were deployed. Oyster racks were also deployed at Rutgers beach and at Pierces beach.

We recorded the time of day, and the number of each species present, by location for red knot, ruddy turnstone, semipalmated sandpiper, and sanderling. Later, using tide charts we assigned the tide time. The census area for each beach was 300 m along the beach, and 300 m out into the intertidal (stakes were placed to designate 100 m sections of the 3 × 3 grid). Any census taken from 1 h before low tide to low tide was assigned − 1; a census taken the time of low tide to 1 h after was assigned to the + 1 h group; a census taken from 1 h after low tide to 2 h after low tide was assigned + 2, and so on. In 2015, 8 people recorded the number of birds present by tide time, recording the data whenever they checked the beaches to determine where along this stretch of Delaware Bay birds were present. In 2016, each observer (N = 3) was present all day at one of the 5 key beaches, shifting among