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Update to the STATUS OF THE RED KNOT (*CALIDRIS CANUTUS RUFA)* IN THE WESTERN HEMISPHERE

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Findings:

- The National Fish and Wildlife Foundation (NFWF) funded development of metrics to track red knot recovery (Appendix I). The document was developed by a team of red knot experts in the US and Canada, with review by a wider group, convened in April 2018 in Washington DC. These metrics will form the basis for a NFWF shorebird business plan (in review).

- Tierra del Fuego winter count - The abundance of red knots, on the main wintering area in Tierra del Fuego, has followed a trajectory of overall decline: rapid decline 2000 to 2005 (51,255 to 17,653), a period of apparent stability 2006-2009 (17,211 – 17,780) and subsequent decline 2010 – 2020 (15,512 – 11,895), (Figure 1).

- Delaware Bay Peak Count - Peak stopover abundance of red knots in Delaware Bay (aerial/ground counts) had been low and stable for much of the last decade, 2009 to 2016 (24,000 to 21,128); (Figure 1). Peak abundance declined in 2017 (17,969); resightings of marked red knots (NY, MA) indicate some birds left the Bay early to seek food elsewhere due to low egg resources. This departure was also captured in estimates of time-specific stopover population size by Lyons (2017). In 2018 and 2019, peak numbers of red knots were higher (32,930 and 30,880, respectively) as more birds remained in the bay to take advantage of greater, and more widely distributed, egg resources. The aerial survey does not account for turnover; (the total number of knots moving through Delaware Bay stopover, May 1 to June 7).

- Superpopulation Estimate for Red Knot – The superpopulation estimate for red knots in the Delaware Bay stopover was 45,113 in 2019 (95% CI: 42,269-48,393); this figure is commensurate with estimates of previous years; (Table 1). The superpopulation estimate accounts for turnover.

- Red Knot Distribution from Aerial Survey - Since 2009, there has been an apparent shift in red knot distribution toward use of NJ Bayshore beaches (Figure 2). This is due, in part, to the change from weekly aerial counts (5 to 6 during May 1 to June 7), which captured seasonal shifts in bay-wide distribution, to fewer counts conducted during peak shorebird numbers (~May 18 - 28). Given equal or greater egg resources on DE beaches historically (2005-2013, Dey et al. 2012) and in 2019 (21,613 eggs/m^2, n=4 sites, Table 2), food availability does not readily explain the observed red knot distribution. Likewise, proximity of high-tide roost sites does not explain this red knot distribution. High tide roosts (day, night) are present in DE and NJ, and red knots readily commute to DE from NJ spring-tide roosts (Stone Harbor, Egg Island), (Sitters Unpublished Radio Telemetry Reports). New Jersey bay beaches and wide creek-mouth shoals may have become more attractive to crab spawning/shorebird foraging since the 2013 addition of sand (post Hurricane Sandy). New Jersey restricts pedestrian access on important shorebird foraging areas (since 2003) and leaves some portion open to human use. This provides for needs of shorebirds, residents and visitors. The extent of disturbance on DE beaches, and its influence on red knot use, is unknown. A review of management activities is necessary as long-distance red knot migrants are most time constrained (10-12 days) and most reliant on egg resources for large, rapid weight gain near the end of the May stopover when the Memorial Day holiday occurs. It is this group of red knots that suffered large population declines and are highly vulnerable to reduced egg resources, disturbance, and the combination of these, near the end of May and just prior to Arctic breeding (see also Appendix I, pg. 18-19)

- Red Knot Weight Gain – Red knot weights are statistically linked to Horseshoe Crab surface egg density (eggs/m^2 in top 5 cm of sand), (Figure 3). Sufficient weight gain on Delaware Bay is statistically linked to adult survival (Baker et al. 1994) and Arctic productivity, (Duijns et al. 2017).

- Horseshoe crab eggs on NJ beaches – Surface egg density (eggs/m^2 in top 5 cm of sand) have not shown substantive or sustained increases over the 20-year survey period (2000 to 2019) and remain well below historic densities observed prior to crab overharvest; (~50,000 eggs/m^2 in 1991); (Botton et al. 1994); (Figure 4). The lack of increase in egg resources is consistent with a lack of substantive and sustained increases in mature female horseshoe crabs during the same period (see below); (Hata and Hallerman 2019). We estimate 50,000 eggs/m^2 on 50 percent of suitable spawning beaches is the minimum necessary to begin red knot recovery (Niles et al. 2009).

- The proportion of red knots reaching 180 grams (P180) at time of normal departure (May 26-28) – P180 is useful as an index of foraging conditions (Figure 5). In 2018 and 2019, the proportion of red knots reaching ≥180 grams were 0.46 and 0.43, respectively, up from 0.28 in 2017. Since 2005, P180 has varied widely and has not shown substantive or sustained improvement. In 1997 and 1998, when shorebird studies began, the stopover population was larger, and a majority of red knots departed with sufficient weight. We estimate a P180 of 0.80, achieved year-on-year, is necessary to restore and maintain a recovered red knot population (80,000 individuals). We wish to note that Mispillion Harbor capture data were not included in P180 estimates. Lower-weight birds tend to be captured in Mispillion Harbor, versus other sites in DE and NJ, and thus reduce the estimate. An analysis of capture weights is in prep. by J. Clark and H. Sitters for the Delaware Bay Volume (Wader Studies). Mispillon Harbor is a highly important, protected foraging area in the Delaware Bay.

- Virginia Tech Atlantic Coast Benthic Trawl Survey (September – October) – The Virginia Tech trawl is designed to sample horseshoe crabs for assessment of population size and trend. The survey covers the non-breeding range of Delaware Bay Origin (DBO) horseshoe crabs (Atlantic City NJ to Chincoteague VA, the "Delaware Bay Survey Area") in September-

October when spawning is complete and mature crabs have moved to the Atlantic Coast to overwinter; (Figure 6).

- The mean catch-per-tow of mature crabs (males and females) appears to be increasing over the time series (Males $r = 0.729$, P = 0.005; Females $r = 0.599$, P = 0.031); males were less abundant in 2018 than in 2016 and 2017 (Figure 7). Mean catch-per-tow of Mature horseshoe crabs may be related to water temperature. The observed positive trend in Mature crabs may be due to warmer water temperatures in the last 4 years of survey; (Hata and Hallerman 2019, Figure 7).
- Mean catch-per-tow of Newly Mature and Immature crabs have been variable since 2002 with no trend; (Figure 7).
- The lack of substantive and sustained increases in female crabs (Mature and Newly mature) since 2002 is unexplained given cessation of female bait harvest in 2006 (NJ, DE) and 2013 (MD, VA). This suggests management of bait harvest alone is not sufficient, and other sources of female mortality (bycatch, biomedical collection and bleeding, unregulated harvest in federal waters, illegal harvest) should be accounted in management of the Delaware Bay crab population.

- Consistent with goals and objectives in the 1998 Horseshoe Crab Management Plan (ASFMC 1998, pgs. 19-20), the Atlantic States Marine Fisheries Commission (ASMFC), and individual states, initiated bait harvest reductions aimed primarily at increasing breeding-age female horseshoe crabs and crab eggs for shorebirds, (Figure 8, Table 3). This includes the voluntary cessation of female bait harvest in 2006 (NJ, DE), moratoriums on bait harvest in SC (1998) and NJ (2008), the 2013 implementation of the Adaptive Resource Management (ARM) model, which has so far limited DE, MD and VA to male-only bait harvest. Outside of the Mid-Atlantic Region, New York and Massachusetts voluntarily reduced annual bait landings, however females are still taken for bait. Since 1998, 94 percent of coastwide bait harvest (Avg. ~1 million crabs/year) is taken by the above states -- five states in the Mid-Atlantic Region: NJ, DE, MD, VA (59 percent), New York (20 percent), and Massachusetts (15 Percent) in the New England Region. The remainder of bait crabs (both sexes) are landed in the Southeast Region (3 percent) primarily North Carolina and Florida, and New England Region (3 percent) primarily Connecticut and Rhode Island.

- In 2016, the Adaptive Resource Management (ARM) Model Subcommittee recommended inclusion of 15 percent biomedical mortality in the ARM Model (used to set bait harvest quotas). The ASMFC Horseshoe Crab Management Board delayed this recommendation until completion of the 2019 Benchmark Stock Assessment. The ARM Model will hereafter include Biomedical and Bycatch (Discard) mortality in determining annual quotas for Mid-Atlantic bait harvests (M. Schmidtke, Pers. Comm.). In 2020, the ARM Model will undergo a major review per the framework for adaptive management (ASFMC 2009).

- Benchmark Stock Assessment 2019 –
  - Detailed models and analyses were focused primarily on the Delaware Bay horseshoe crab population as significantly more information is available for the Mid-Atlantic Region. These analyses used population estimates, derived from the Virginia Tech (VT)

Atlantic Coast Trawl Survey, which are comprised of crabs that breed in Delaware Bay (Delaware Bay Origin) and elsewhere (Non-DBO). The Stock Assessment Subcommittee (SAS) did not adjust population estimates downward to more accurately reflect the smaller DBO population size. Inflated estimates for the Delaware Bay population, used by Stock Assessment and ARM Subcommittees, will influence trend assessment, management decisions, and may lead to an unwarranted increase in DBO bait harvests.

- Bycatch (Discard) mortality of horseshoe crabs, primarily from trawl and dredge fisheries, were estimated for the first time using available data from the National Marine Fisheries Service Observer Program (ASFMC 2019, Pg. 42-45). Data on horseshoe crab bycatch were variable in Mid-Atlantic states (more data in NJ, VA; less in DE, MD); there were differences in expert opinion on the percent mortality by gear type (trawl v. dredge). Bycatch mortality estimates will be influenced by the percent mortality assigned to gear type and prevalence of gear types used in the Mid-Atlantic region.
- Biomedical mortality (bled crabs) was reviewed, as in past Stock Assessments, based on extant studies. The estimate of biomedical mortality for bled crabs was held at 15 percent given a lack of new studies to suggest otherwise. Unbled crabs (collected but rejected at bleeding labs due to injury, slow movement, small size) are not assessed in mortality figures and range in number from 13,000 to 45,000 (mean 23,700) per year; (ASMFC Annual Fishery Management Plan Updates 2004-2018). Unlike the bait industry, the biomedical industry is not restricted in the number or sex of crabs they may collect for annual biomedical use.
- Biomedical collection and mortality data, used in various Stock Assessment analyses, were available only to the ASFMC Stock Assessment Subcommittee (SAS) and Peer Reviewers. Results were redacted from the final Stock Assessment document and are unavailable for review by ASFMC technical committees or the public due to confidentiality provisions in the Magnuson-Stevens Act. This precludes an assessment of biomedical-use impact on the Delaware Bay crab population, per written request to the ASFMC, via Former NJ Division of Fish and Wildlife Director Larry Herrighty, by the NJ Endangered and Nongame Species Advisory Committee (ENSAC) in 2018. In accordance with N.J.S.A. 23:2B-21, which codifies New Jersey's legislated moratorium on taking of horseshoe crabs, ENSAC is charged with determining if the recovery of red knots, and implementation of measures to ensure adequate supply of horseshoe crab eggs for red knots, have been sufficient to allow a limited harvest of horseshoe crabs in New Jersey waters.

- Delaware 30-Foot Trawl Survey (April – July) – The Delaware trawl is conducted within the Delaware Bay year-round. Data presented here were collected during the spring and summer when adult crabs migrate into Delaware Bay to spawn. Adult males and females (>160 mm prosomal width) show an apparent increasing trend since 2015; (Figures 9 and 10). The DE Division of Fish and Wildlife did not provide trend statistics.

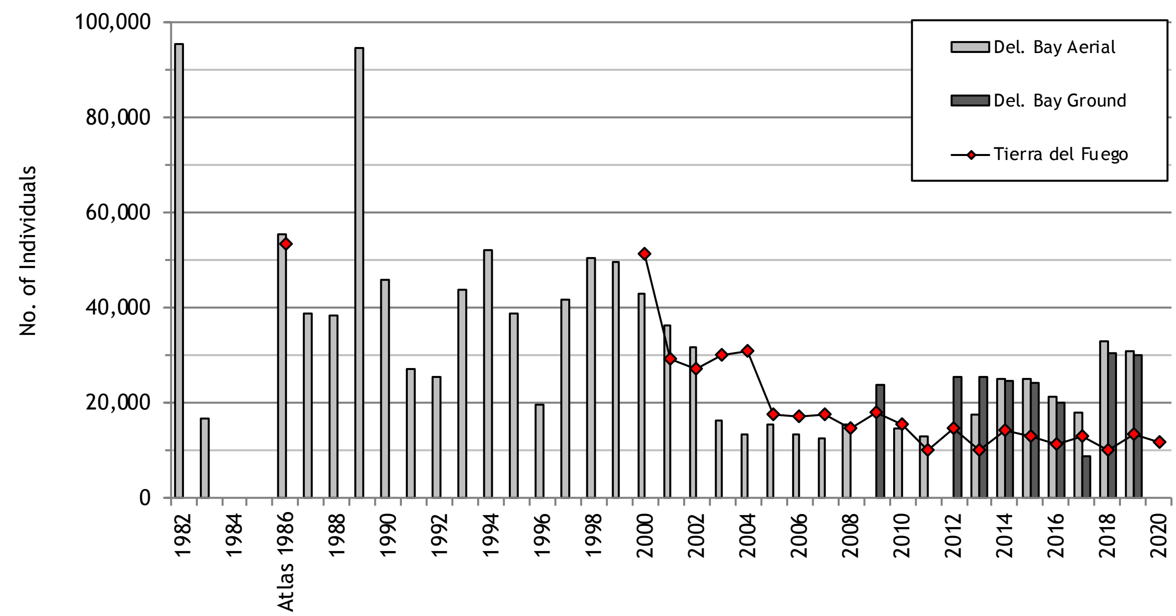
- Delaware Bay Spawning Crab Survey (May-June) – Baywide Male spawning activity 1999 to 2018 showed no significant trend though the slope was positive (Slope = 0.04, P=0.15); (Figure 11). Trend in Male spawning activity was slightly positive in DE and NJ; the trend in NJ was positive and significant (Slope = 0.06, SE = 0.04, P = 0.09). Baywide female spawning activity 1999 to 2018 showed no significant trend and slope was slightly negative (Slope = -

0.01, SE = 0.01, P= 0.11); (Figure 12). Trend in Female spawning activity was slightly negative in DE and NJ; the trend in DE was negative and significant (Slope = -0.01, SE = 0.004, P = 0.03); (Zimmerman et al. 2019).

Red Knot Trend:

Peak Counts in Delaware Bay (NJ & DE) – Aerial and Ground 1986 – 2019

Winter Counts in Tierra del Fuego, Chile – Aerial Count 1986, 2000 – 2020



Aerial Counts: K Clark 1986-2008; W Pitts 2010; H Sitters 2011; L Niles 2013; M Peck 2014-2015, RIG Morrison 2016-2017. Peak aerial counts in 2009 and 2012 not conducted or not available, respectively. Tierra del Fuego RIG Morrison, K. Ross.

Figure 1. Peak aerial count of Red Knots in Delaware Bay during spring stopover, 1982-2019; aerial count from Tierra del Fuego (major wintering area) are included for comparison, 1986-2020. Delaware Bay aerial counts in 1982-1983 were conducted by New Jersey Audubon; no aerial counts were conducted in 1984-1985. Aerial counts from 1986-present were conducted by New Jersey Division of Fish & Wildlife, Delaware Division of Fish & Wildlife and various individuals after 2008, (see above). Aerial counts of in 2009 and 2012 were not conducted or not available, respectively; peak values for these years are from ground counts. Beginning in 2009 with a change of long-term observers, ground and boat counts were conducted simultaneously with aerial survey to help validate aerial abundances, particularly in Mispillion Harbor, DE, where birds can be missed by aerial observers, and Egg Island, NJ, where large numbers of birds stage and may be undercounted. Ground surveys are presented for years when comprehensive ground/boat surveys were conducted in NJ and DE. Source: Atlas 1986, Morrison, R. I. G. and R. K. Ross. 1989. Atlas of Nearctic shorebirds on the coast of South America. 2 vols. Special Publication, Canadian Wildlife Service, Ottawa, Ontario. 325 pp.

Delaware Bay Foraging Conditions

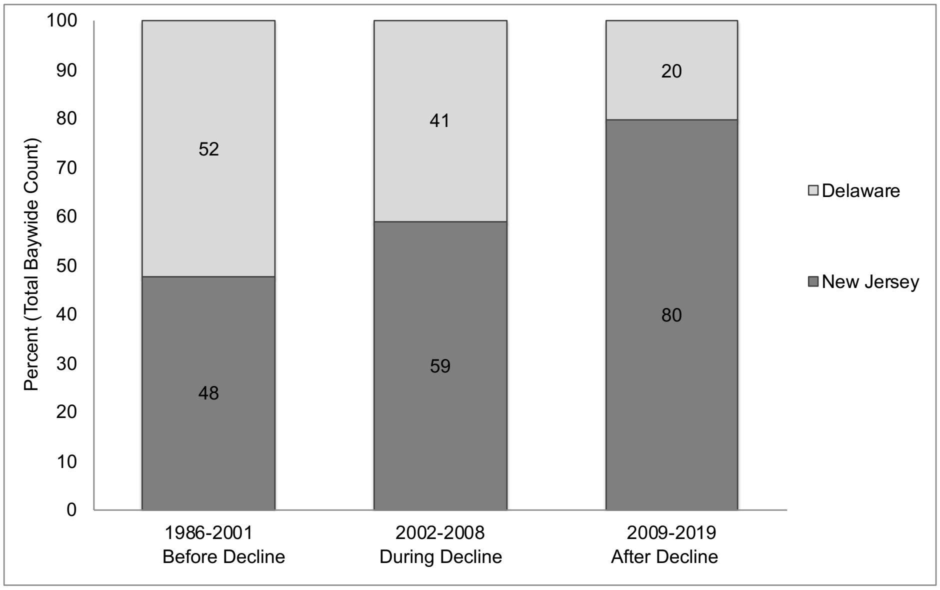


Figure 2. Percent of total annual count by State. In 2019, 99 percent of red knots counted during peak stopover period (May 22 & 25) were on NJ beaches. Note: Starting in 2009, 2-3 aerial surveys were conducted during the peak shorebird abundance (May 18-28). Prior to 2009, weekly aerial surveys (5-6 flights) through May and early June were conducted which captured seasonal shifts in bay-wide bird distribution over the entire stopover period.

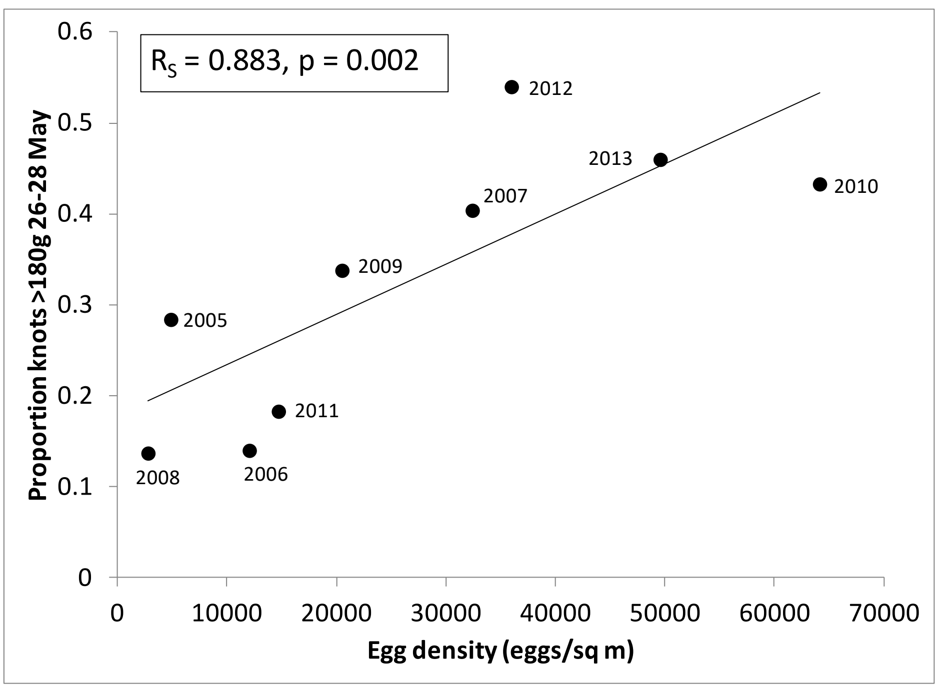


Figure 3. Proportion of Red Knots in the >180 g body-mass category in Delaware Bay during 26-28 May plotted against the median horseshoe crab egg density during 14-27 May 2005-2013 for Delaware and New Jersey (R_s = 0.883, p = 0.002). DE ceased egg surveys after 2013. Source: Delaware Division of Fish and Wildlife and New Jersey Division of Fish and Wildlife.

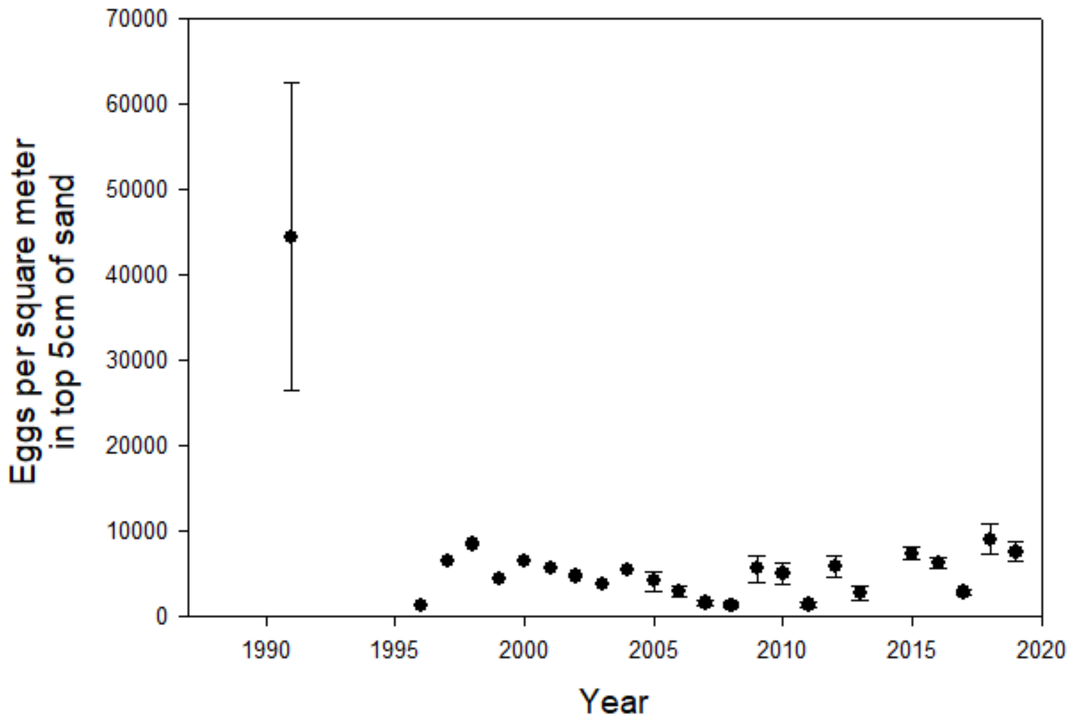


Figure 4. Surface egg densities on New Jersey beaches: historic 1990-1991 (Botton et al. 1994), unpublished report to NJDEP 1996-1999 (Botton and Loveland), NJDFW unpublished data 2000-2019. NJ Division of Fish and Wildlife.

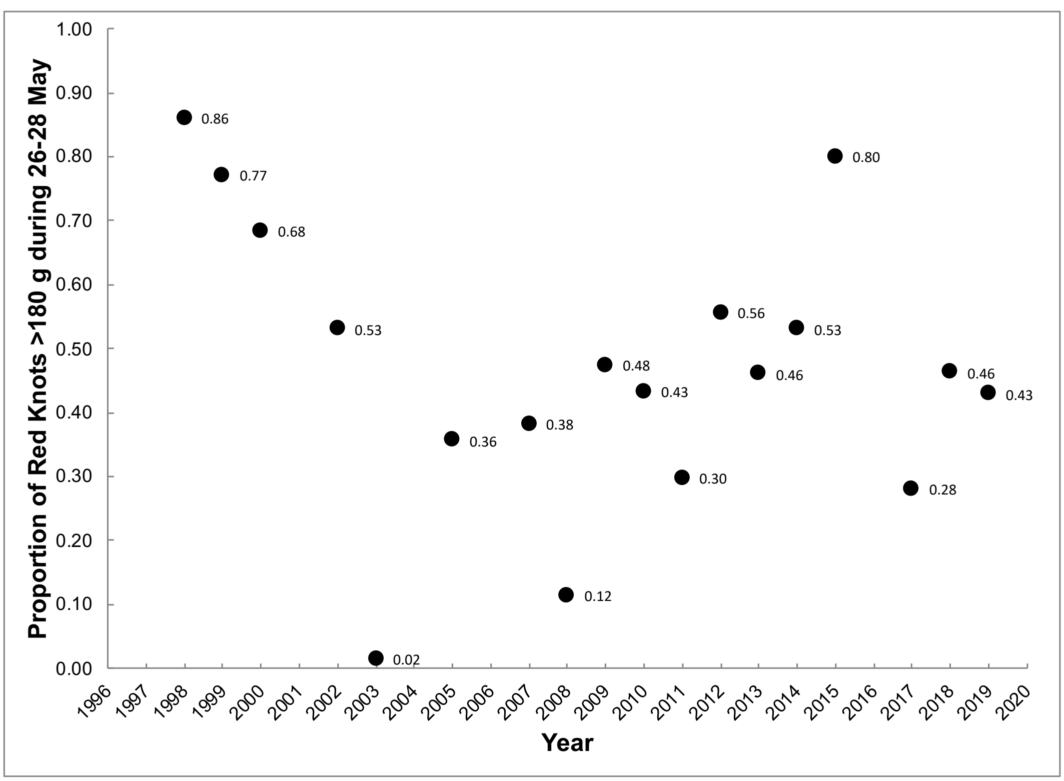


Figure 5. The proportion of red knots reaching ≥180 grams (P180) at time of departure from Delaware Bay (May 26-28) excluding capture data from Mispillion Harbor, DE.

Trawl and Spawning Crab Data

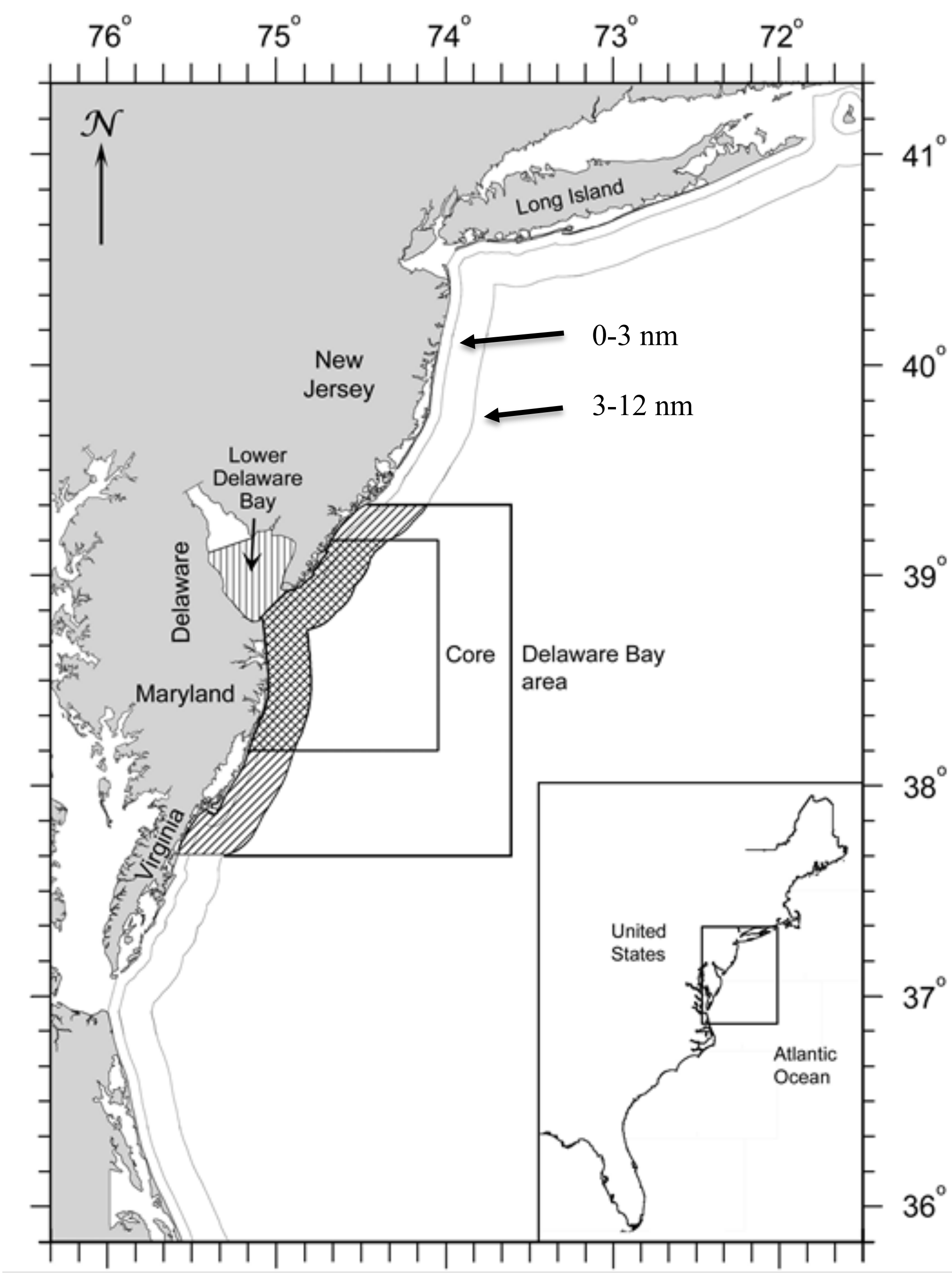


Figure 6. Fall 2017 horseshoe crab trawl survey sampling area. The coastal Delaware Bay area (DBA) and Lower Delaware Bay (LDB) survey areas are indicated. Mean catches among years were compared using stations within the shaded portions of the survey areas. Source: Hata and Hallerman 2019 (Fig. 1). Virginia Tech, Horseshoe Crab Research Center.

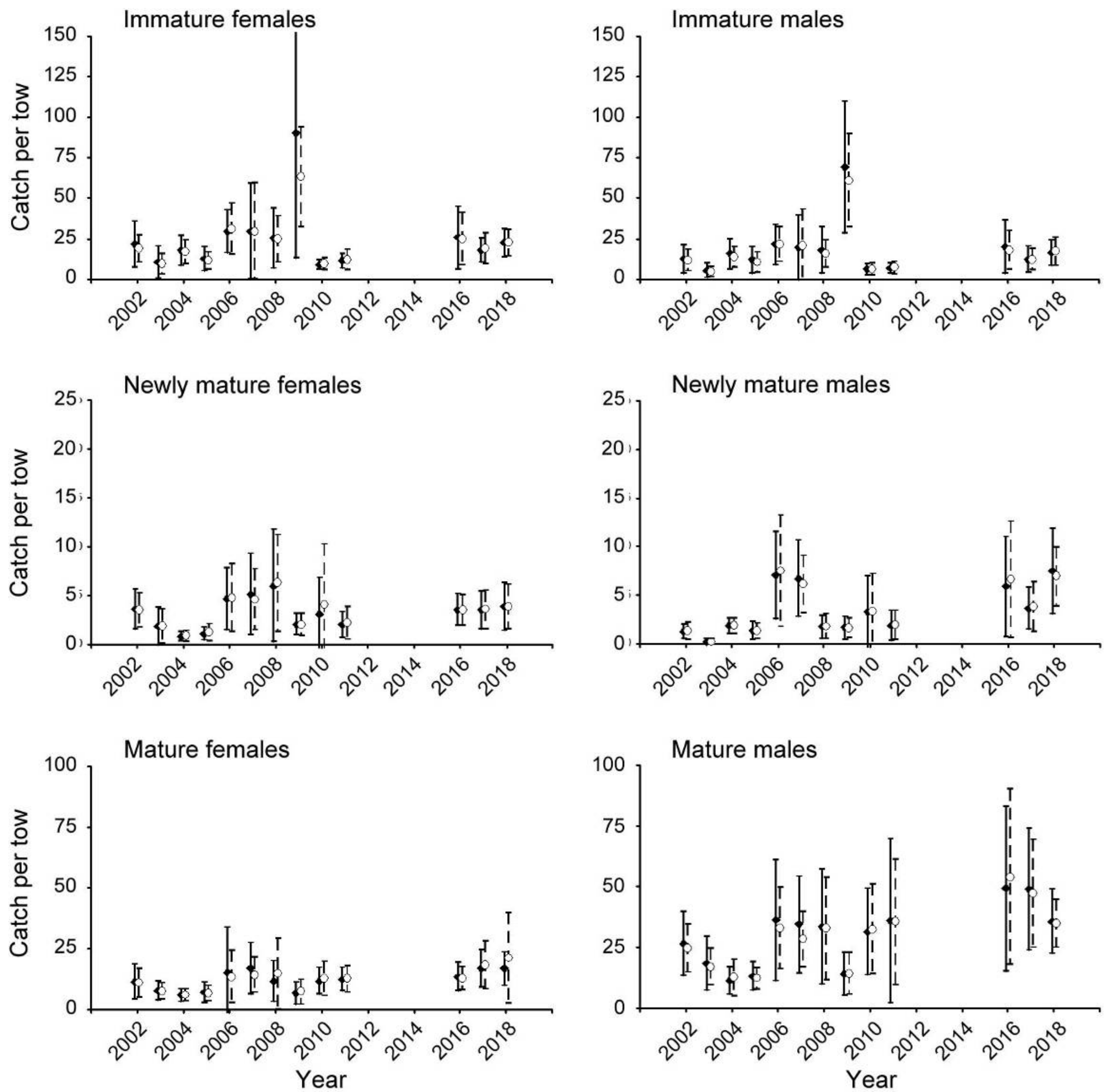


Figure 7. Plots of stratified mean catches per tow of horseshoe crabs in the coastal Delaware Bay Area by demographic group. Vertical lines indicate 95% confidence limits. Solid symbols and lines indicate the **delta distribution model**. Open symbols and dashed lines indicate the **normal distribution model**. Data are from Tables 1 and 2 in Hata and Hallerman, 2019. Note differences in y-axis scales. Source: D. Hata & E. Hallerman, (Fig. 2), Virginia Tech, Horseshoe Crab Research Center.

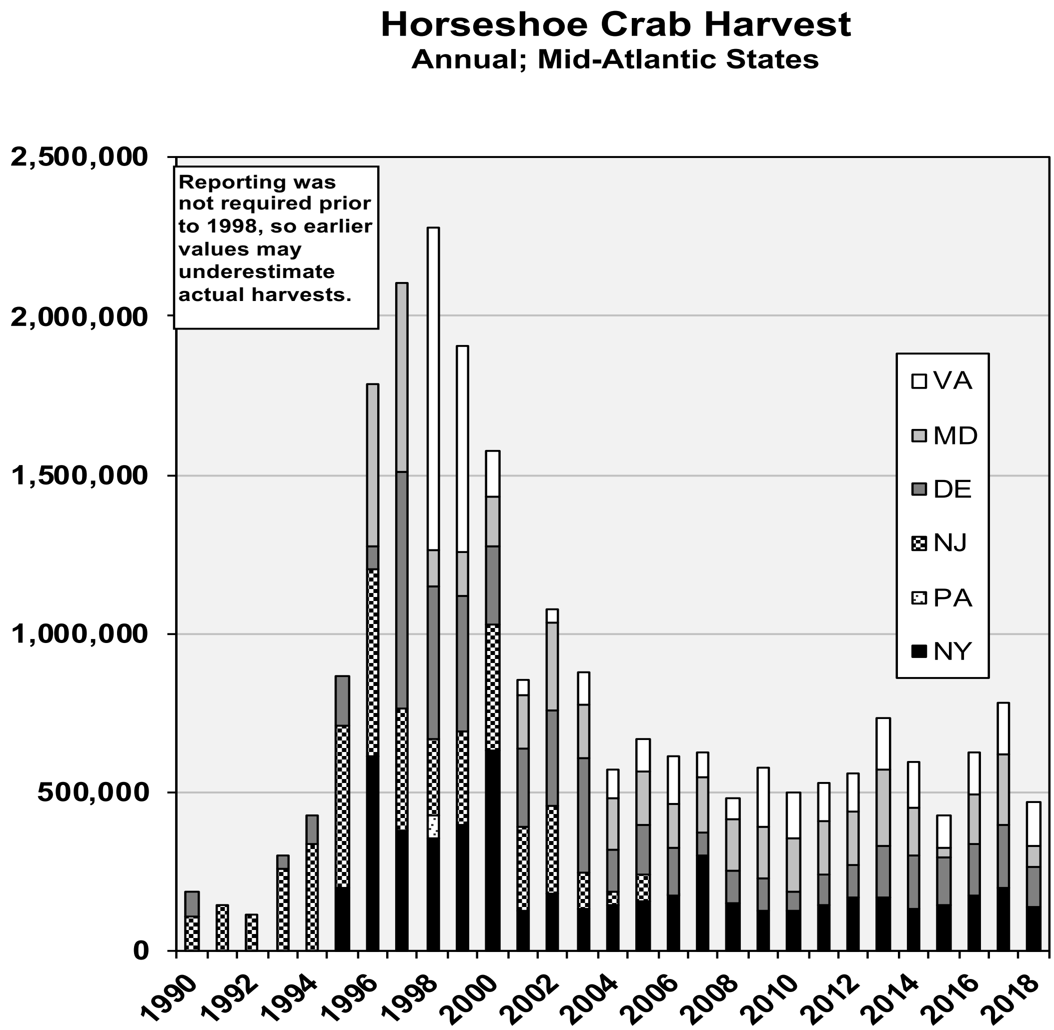


Figure 8. Reported horseshoe crab harvest 1990-2018 for Mid-Atlantic states; reporting was not compulsory until 1998, so earlier figures from NOAA data may underestimate the true harvest. Note: <=40% of the VA annual harvest above is taken East of COLREGS (i.e., on the Atlantic Coast). Source: ASMFC 2019 Fishery Management Plan for Horseshoe Crab (www.asmfc.org).

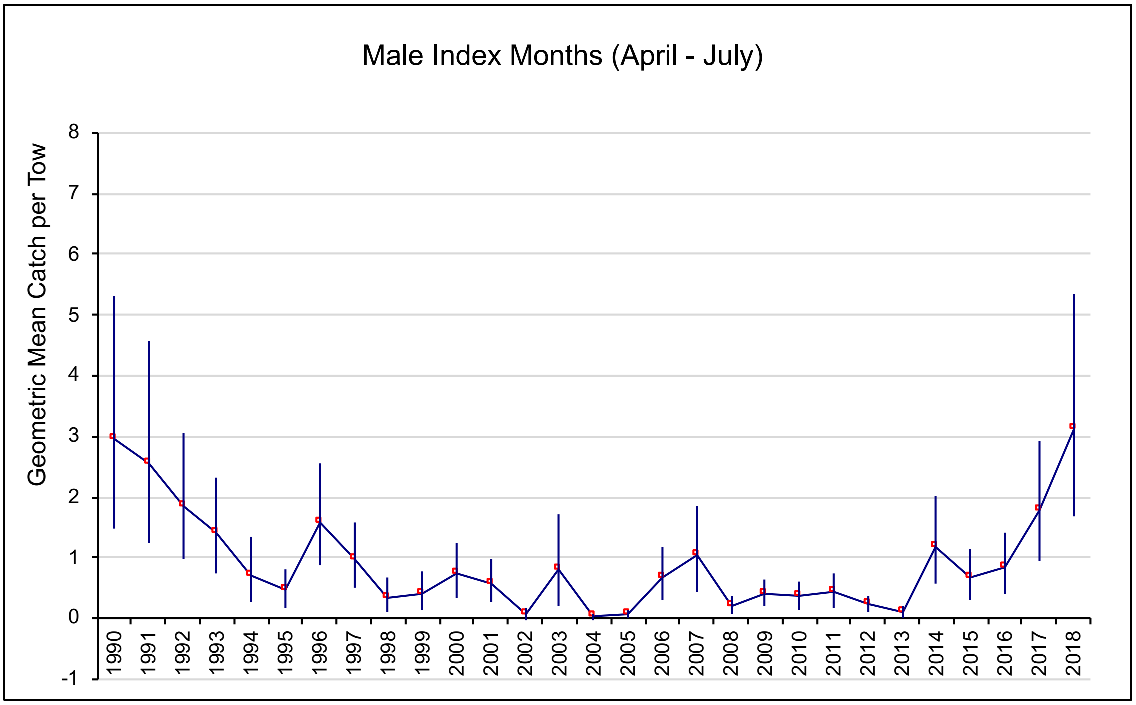


Figure 9. Delaware 30-foot trawl survey (Apr. – July 2019). Source: Delaware Natural Resources and Environmental Control, Division of Fish and Wildlife

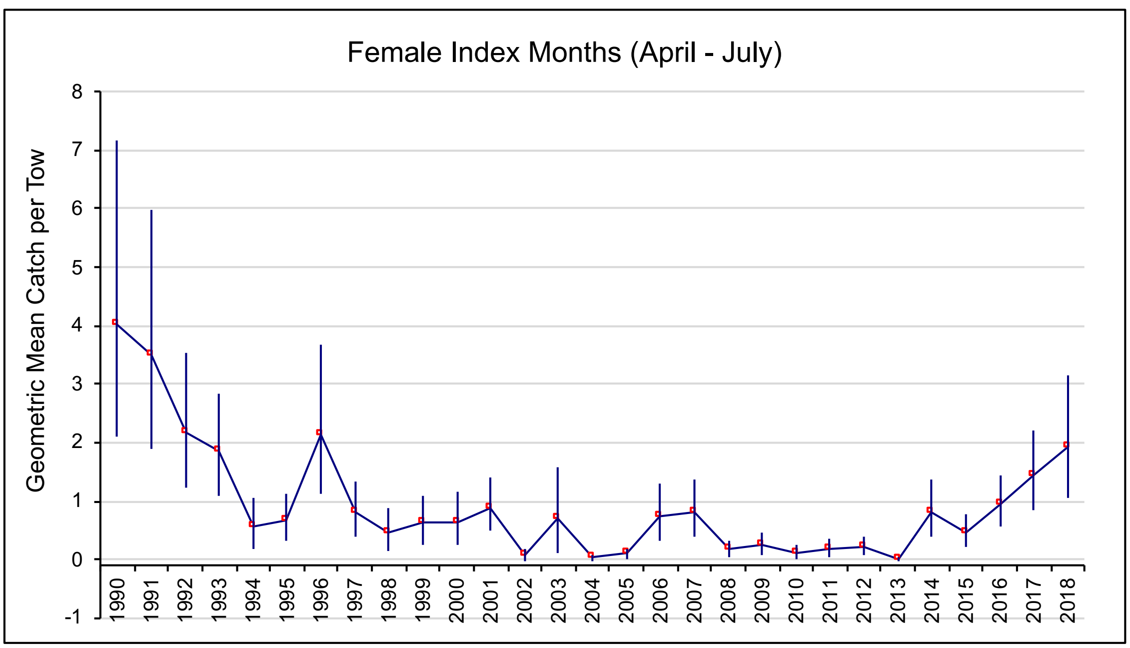


Figure 10. Delaware 30-Ft. Trawl Survey (April – July 2019). Source: Delaware Natural Resources and Environmental Control, Division of Fish and Wildlife

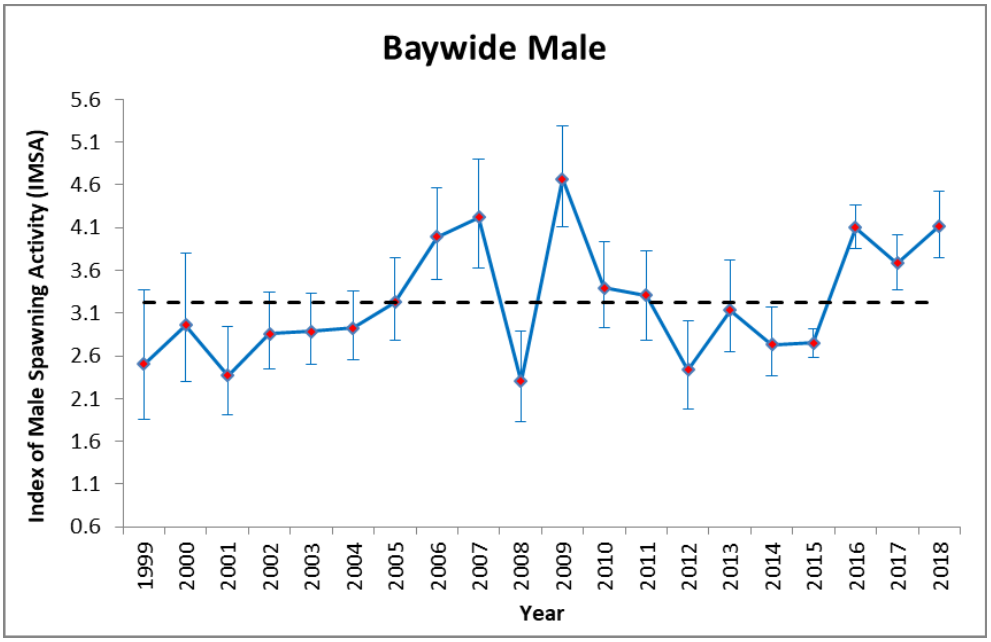


Figure 11. Index of male horseshoe crab spawning activity for the Delaware Bay, 1999-2018. Error Bars are 90% confidence intervals. Dashed line is mean value for the time series. Source: Zimmerman et al. 2019.

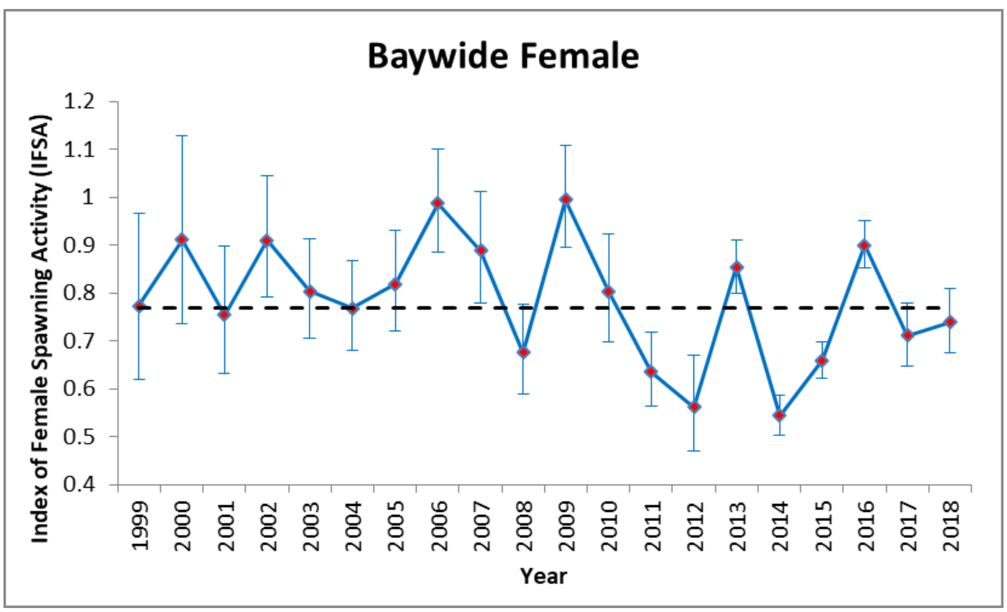


Figure 12. Index of female horseshoe crab spawning activity for Delaware Bay from 1999 to 2018. Error bars are 90% confidence intervals. Dashed line is mean value for the time series. Source: Zimmerman et al. 2019.

Table 1. Superpopulation Estimate (Mark-Resighting method). Source: Lyons 2019, Table 4.

Stopover (passage) population estimate using mark-resight methods compared to peak-count index using aerial- or ground-survey methods. The mark-resight estimate of stopover (passage) population accounts for population turnover during migration; peak-count index, a single count on a single day, does not account for turnover.

Year	Stopover population[a] (mark-resight *N**)	95% CI Stopover population *N**	Peak-count index [aerial (A) or ground (G)]
2011	43,570	(40,880–46,570)	12,804 (A)[b]
2012	44,100	(41,860–46,790)	25,458 (G)[c]
2013	48,955	(39,119–63,130)	25,596 (A)[d]
2014	44,010	(41,900–46,310)	24,980 (A)[c]
2015	60,727	(55,568–68,732)	24,890 (A)[c]
2016	47,254	(44,873–50,574)	21,128 (A)[b]
2017	49,405[e]	(46,368–53,109)	17,969 (A)[f]
2018	45,221	(42,568–49,508)	32,930 (A)[b]
2019	45,133	(42,269–48,393)	30,880 (A)[g]

[a] passage population estimate for entire season, including population turnover
[b] 23 May
[c] 24 May
[d] 28 May
[e] Data management procedures to reduce bias from recording errors in the field; data from observers with greater than average misread rate were not included in the analysis
[f] 26 May
[g] 22 May

Table 2. Horseshoe crab egg density (2019) on DE and NJ Beaches, May 23 – June 7. NJ total season count is provided for comparison. Note: eggs were counted by hand. Source: J. A. M. Smith, Unpublished Data.

				Density (Eggs/m^2)		
State	Type	Sites (N)	Sampling Period	Samples (n)	Mean	SE
DE*	Beach	4	May 23, 24 & Jun 6, 7	359	21,613	2,971
NJ	Beach	17	May 23 - Jun 7	980	7,199	1,341
NJ	Shoal	9	May 23 - Jun 7	115	4,678	1,202
NJ	Beach	17	May 6 - Jun 14	2,557	8,593	830
NJ	Shoal	10	May 6 - Jun 14	347	6,081	1,039

* Kitts Hummock, South Bowers, Big Stone, Pickering.

Table 3. Annual Horseshoe Crab bait harvest landings, actions by states and Atlantic States Marine Fisheries Commission (ASFMC) Addenda (1997-2017). Note: Bait landings are taken from the 2019 Benchmark Stock Assessment for Horseshoe Crab (Table 1, Pg. 102). www.asmfc.org.

Year	Bait Harvest Coastwide (in Millions)	Bait Harvest NJ, DE, MD, VA (in Millions)	Addendumenda/Action
1997*	3.00	1.90	Gov. Whitman imposes one-year harvest moratorium in NJ
1998	1.90	1.09	Fisheries Mgmt. Plan for Horseshoe Crab published (Dec 1998); recommended a variety of measures including harvest caps
1999	2.60	1.53	
2000	1.68	0.72	Addendum I (Apr. 2000) - set a 25% reduction in state harvest quotas (25% below each state's reference period landings of 1995-1997); implemented May 2000
2001	0.79	0.50	Addendum II (May 2001 no change to quotas) - to alleviate bait shortages via voluntary quota transfers between states with review and oversight by HSC Management Board and HSC Technical Committee.
2002	1.27	0.90	
2003	1.05	0.74	
2004	0.66	0.40	Addendum III (May 2004) - (NJ/DE 150,000 crabs/year/state, MD 170,653, VA 150,495) --harvest restricted betw. May 1 - June 7. NJ, DE, MD held to listed quotas, all other states kept quota from Addendumendum I. Monitoring porgram for horseshoe crabs established (required and recommended metrics). MA establishes a protocol to purchase bait crabs from other states.
2005	0.75	0.48	
2006	0.84	0.44	Addendum IV - (June 2006) NJ & DE: Prohibits harvest of all crabs Jan 1 - Jun 7, prohibits harvest of female crabs from June 8 - Dec 31 (NJ and DE go to male-only harvest); NJ has voluntary moratorium for 2 years starting in 2006MD; prohibits harvest from Jan 1 - Jun 7; VA: prohibits harvest from fed waters Jan 1 - Jun 7, <=40% shall come from east of COLREGS, min. male:female harvest ratio of 2:1.
2007	0.83	0.34	Per Addendum. IV, 40% of VA harvests reported in FMP are East of COLREGS (Delware Bay Origin).
2008	0.71	0.33	Addendum V (Sept. 2008) - carries over quotas from Addendum. IV for one year. NJ enacts legislated moratorium until adequate food (horseshoe crab eggs) are available for a recovered red knot population.
2009	0.83	0.47	
2010	0.68	0.37	Addendum VI (Aug. 2010) - NJ & DE: prohibits directed harvest and landing of all HSC in NJ and DE from Jan 1 - Jun 7, and female HSC in NJ and DE from Jun 8 - Dec 31 (NJ & DE harvest limit 100K males per state). MD: Del Bay origin crabs are protected by Addendum VI by prohibiting direct harvest and landing of crabs in MD from Jan 1-Jun7. VA: Prohibits landing of HSC in VA from Federal waters from Jan 1-Jun 7. Addendum VI mandates <= 40% of VA's quota may be harvested east of Colregs and requires that crabs harvested east of colregs and landed in VA must be min 2:1 male female.
2011	0.75	0.40	
2012	0.86	0.42	Note: Atlantic States Marine Fisheries Commission (ASMFC) stops reporting state bait landings by sex. Starting in 2013, Mid-Atlantic bait landings are Male-only (ARM Model); all other states land both sexes but sex is reported "Unknown".
2013	1.02	0.56	Addendum VII (Apr. 2013) - Adaptive Resource Management (ARM) Model harvests are implemented in 2013. Percent Delaware Bay Origin (DBO) in bait landings is based primarily on genetic samples from two MD bait trawls (July 2005, July 2006): NJ, DE (100% DBO), MD (51% DBO), VA (35% DBO). ARM Quota is 500,000 males; MD & VA receive offset allowance of two males for every female disallowed. ARM Quota: NJ 162,136 DBO males; DE 162,136 DBO males; MD 141,112 DBO Males + 114,868 Non-DBO males; VA 34,615 DBO Males + 46,716 Non-DBO Males (total VA ARM quota 81,331 E. of COLREGS). VA harvests both sexes West of COLREGS in Chesapeake Bay, (not part of ARM). See annual Fisheries Management Plan Reviews for harvest figures; www.asmfc.org
2014	0.87	0.46	Sept. 2014 - Atlantic Coast Benthic trawl is defunded after 2012 trawl is conducted. No female crab population data are available to generate ARM model harvest quotes. Horseshoe Crab Tech. Committee carries over 2013 harvest quotas to 2014 (one year only); ARM group attempts to find extant trawl data to produce a population estimate. Various efforts in progress to find permanent funding for Atlantic Coast Benthic Trawl (conducted by Virginia Tech).
2015	0.68	0.28	
2016	0.83	0.40	
2017	1.01	0.60	American Eel classified as "Depleted Stock" (2018 Am. Fisheries Soc. Meeting, Atlantic City, NJ; http://www.asmfc.org/home/2018-afs-eel-symposium). The Conch fishery has no management plan.
2018	0.65	0.33	Preliminary landing figures.

* 1997 bait landings are from Fisheries Management Plan updates (www.asmfc.org)

Acknowledgements

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Appendix I.

Developing A System for Tracking Recovery of Red Knots on the Atlantic Flyway.

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Introduction

The goal of this project is to develop a system for tracking progress in the recovery of red knots as a result of investments from National Fish and Wildlife Foundation and other donors. We proposed a dashboard of metrics that can be tracked in the intermediate and long term periods. We made the following assumptions about tracking metrics

1. The intermediate recovery metrics must be responsive in at least a three-year period so recovery actions can be evaluated for performance independent of performance measures of the project itself. If the project produces no positive results than funding can be shifted to more productive actions.
2. The metrics should come from existing work to connect with long term studies and to target funding to existing projects.
3. Long term metrics should provide interim assessment of the recovery's overall progress
4. Metrics must be suited to the strategy of restoration specific to the red knot.

This metrics document was initially developed at a workshop on the Conservation of Delaware Bay Shorebirds conducted in May 2017. From this discussion a draft document was developed and reviewed by staff of Environment Canada and the US Fish and Wildlife Service. This became the focus of a two-day workshop that took place in National Fish and Wildlife Foundation Headquarters in Washington held on April 5-6, 2018. The list of participants is provided as an appendix to the report. The group provided valuable insights and suggested revisions that were subsequently included into this report.

The Primary Reason for the Decline of Red Knots

The USFWS listed the *rufa* Red Knot as "Threatened" based on a series of significant declines in the number of birds observed at the critical stopover site of Delaware Bay, and the principal wintering areas in Tierra del Fuego, including Bahía Lomas, Chile, and Rio Grande, Argentina (Niles et al. 2008). The decline of Red Knots was first observed in Delaware Bay where numbers estimated by aerial survey peaked at 91,000 (Clark et al. 1993) and fell to less than 50,000 by 2001 then finally to a low in 2005 of 15,000 (Niles et al. 2008). Morrison and Ross (1989) surveyed Red Knot wintering areas in early 1980 and found 56,000 Red Knots, with 70% of this total in South America. During these surveys, approximately 49,000 Red Knots were found at Bahía Lomas. In subsequent surveys conducted from 2000 to the present, numbers at Bahía Lomas fell to a low of 12,000 in 2004 (Morrison et al. 2005). Numbers of other species that do not migrate through Delaware Bay, such as the Hudsonian Godwit

(*Limosa haemastica*) and White-rumped Sandpiper (*Calidris fuscicollis*), did not decline in these surveys, suggesting that declines were not caused by unknown threats in the wintering area. Using band-resighting data, Baker et al. (2004) demonstrated that a decline in rates of mass gain in Delaware Bay was associated with a reduced apparent survival rate, potentially linking the population declines to failing foraging conditions in Delaware Bay (McGowan et al 2011). In a subsequent study, Duijns et al. (2017) used digital VHF telemetry to demonstrate that Red Knots leaving Delaware Bay with low body condition have reduced migratory performance, and potentially a lower likelihood of breeding and surviving through to fall migration.

This inability to gain sufficient weight before flights to Arctic breeding areas is linked to a dramatic decline in horseshoe crab (*Limulus polyphemus*) egg densities. In the 1990s, egg densities were estimated on most Delaware Bay beaches at over 100,000/m^2 (Botton et al. 1994). By 2000, densities had fallen to less than 5,000 egg/m^2 and have remained near that level to date (Smith et al. 2017). The decline in eggs was most likely a consequence of a dramatic increase in horseshoe crab harvest from around 100,000 in the early 1990s to 2.5 million by 1998 (Atlantic States Marine Fisheries Commission 2016). Although harvests have since been curtailed, the current population of horseshoe crabs is still only a third of carrying capacity (McGowan et al. 2015).

The impact of red knots leaving the Delaware Bay stopover in poor condition on survival and productivity has been verified repeatedly however we have little understanding of the impact of birds leaving in poor conditions in at least three other stopovers where knots build weight to similar levels as Delaware Bay: Lagoa do Peixe, Brazil, Maranhao/Para, Brazil, Mingan Island Quebec, Cape Cod, MA, and Stone Harbor/Bringantine NJ. In each place red knots build weight to make 4-7 days of continuous flying. Departure weights at less than optimal levels may result in impacts to survival although it is still unknown.

Other Factors Contributing to the Decline

Given its hemisphere-long migrations, numerous other factors may also have impacted the Red Knot populations. These include: shorebird hunting in the leeward islands of the Caribbean and northern South America (especially French Guiana and Brazil), disturbance in all southbound stopovers in the U.S. (Burger and Niles 2013) and northbound stopovers in South America (Federizzi 2008), and habitat loss in areas such as San Antonio Este and Rio Grande, Argentina (P. González pers comm), Florida's gulf coast (Niles et al. 2006), and Lagoa do Peixe, Brazil. However, because the population is currently only a fraction of its original size (i.e., leaving previously occupied habitat unused) it may be less susceptible to issues of habitat loss. Nevertheless, the losses of habitat, may impair species restoration.

With tropical wintering areas and Arctic breeding areas more than 10,000 km apart, asynchronies resulting from climate change are nearly inevitable. The impacts of any climate mismatches, however, remain unknown. Potential habitat shifts in Arctic breeding areas have been demonstrated by Lathrop et al. (2016), by modeling the impact of increasing temperature, decreasing snow amount and other habitat factors. Suitable habitat is predicted to move northward or decrease, pushing *rufa* breeding areas into those dominated currently by the Red Knot subspecies *islandica*, that migrates into the European flyway to winter. The impact that dynamics between the subspecies might have on *rufa* knots is unknown, as are the consequences of an increased distance between breeding areas and key stopovers like Delaware Bay. For example results for the first recovered geolocators attached to red knots included a new location, Nelson River on Hudson Bay that subsequent recoveries showed it to be an important stopover that was not reported (Mckellar et al 2015) . Did this stopover always exist or was it only recently established, and a consequence of changing conditions related to climate change?

A Draft Plan to Restore the Red Knot

A choice of metrics to track recovery depends on the strategy tracked. The Atlantic Flyway strategy blends the interests of both beach-nesting birds and Arctic nesting birds but the needs of these species are not always synonymous, even when they occupy the same sites. For example a strategy to decrease predation or seasonal disturbance across all sites may be the best action to increase beach nesting bird breeding success, this strategy will not necessarily improve conditions for Arctic nesting shorebirds that stopover and winter in such areas. Instead others threats determine carrying capacity, thus generalized strategies may waste valuable resources.

We propose to anchor the strategy to recover red knots on improving conditions in the stopovers on which knots depend to gain weight before embarking on long distance flights. Additionally we propose management actions in all other places that will maintain current conditions, especially including wintering areas where current numbers are far below current carrying capacity. This strategy prioritizes long distance red knots (those wintering in Patagonia) over short distance knots (those wintering in Southeast US and Caribbean) simply because all of the verified declines in knots have occurred among the long distance population. Short distance knots are not known to be in decline. The exception is the Gulf Coast wintering areas of Florida to Texas where extraordinary development and recreational use are destroying once important wintering sites threatening the stability of this short distance wintering population.

Red knot Metric Dashboard

Metrics that assess year-to-year progress towards recovery are urgently needed to ensure that limited funds are spent strategically. We propose a “dashboard” composed of five metrics, focused on the flyway-wide population of red knot with emphasis on key stopovers. The metrics are a mix of objective measurements from key locations that will characterize red knot productivity and survivorship as well as measures of habitat quality and conservation protections at individual sites. Although the metrics will provide objective year-to-year assessment of a conservation program, evaluation of the overall success of conservation actions will rest ultimately on a weight-of-evidence approach.

An annual measure of population size is the ultimate measure of population recovery. However, population size is a challenging metric to estimate for the following reasons:

a. The principal problem with using population size as a measure of response to conservation action is that imprecision in the estimate is so great that, in the short-term, any reasonably expected population response would be so small that it could not be reliably detected. For example, even sophisticated, regional estimation procedures like “superpopulation method” (Lyons et al. 2012) have confidence intervals of ±15% or more in some years, so that detecting an incremental annual population response would be challenging. Larger-scale estimates suffer from even greater imprecision, unless monitoring efforts are expanded to a level at which they are too costly to maintain.

Site-specific counts can be instructive, but they can be confounded by extraordinary variation from year to year and site to site, because only a handful of sites can be accurately counted. Stopover numbers vary because surveys might not coincide with peak numbers or may not be sufficiently robust to count all the birds as they variously move into and out of the stopover. Wintering area counts, as in northern Brazil or Tierra del Fuego are hampered by the vast extent of the areas and the propensity for birds to move around these large areas within the season.

Surveys of the breeding grounds, when birds are stationary, would address this issue of movement. However, Red Knots are poorly captured by the PRISM Arctic surveys because of their low densities, their secretive behavior and their use of barren upland habitats avoided by many other species (Bart and Johnson 2012, Lathrop et al. *in review*).

b. A second reason that population size can be misleading is that the population can decrease despite a positive effect of conservation actions. Shorebird populations are influenced by events throughout the annual cycle, some of which cannot be controlled by site-level management (e.g. red tide outbreaks and tropical storms). For long-distance migrants like red knots, the potential for such events to affect populations is compounded by the long-distance flights and their dependence on multiple stopover sites. Population fluctuations arising from these events obscure the relationships between conservation action and population response.

Thus, although a precise, fly-way wide estimate of population size would be the definitive metric of success, this may not be achievable. Instead, we suggest several complementary monitoring indices that provide metrics of abundance, metrics of demographic response, and metrics of the direct impacts of our interventions.

The metric dashboard will be based on the following:

- An estimate of flyway-wide population abundance, based on combined estimates from wintering areas and key stopovers
- Juvenile to adult ratios at stopovers and wintering sites
- Indices of habitat quality and birds' body condition from Delaware Bay (and other sites with a demonstrated connection between habitat quality and population-level impacts to red knot)
- Mark-recapture based estimates of adult survival, divided seasonally to the extent possible.

1. The first metric for assessing progress in the flyway is a year-to-year assessment of abundance, based on the combined estimates of numbers in stopovers and wintering areas. At present, quantitatively combining these various estimates is challenging because connectivity among the

areas is unknown. To address this, we suggest using a semi-quantitative "four-point" expert elicitation approach to assess annual population status.

A four-point estimate is comprised of a "best guess" population estimate, estimated upper and lower bounds around this estimate, and an estimate of the experts' confidence that the true value lies within the bounds (Martin et al 2012). Project leaders for each site included in this analysis will independently develop the four-point estimate for flyway-wide population size?, and these will be averaged across experts to arrive at the consensus estimate of annual status. Ongoing work to determine migratory connectivity among sites will improve these estimates (i.e., what fraction of Bahía Lomas birds are also at Delaware Bay), and may allow for a quantitative combination of site-specific estimates in the future.

Surveys included in the metric of abundance:

- ***Wintering Surveys:*** Red knots winter mainly in four areas, each representing a different migratory strategy: 1) The Tierra del Fuego wintering area, focused primarily in Bahía Lomas, once included 70% of all Atlantic Flyway red knots, numbering as high as 56,000 of the known number of 76,000 wintering knots (Morrison and Ross 1986). The population is now estimated at between 12,000 to 15,000 (Morrison et al 2004, Dey 2017). 2) The Northern Brazil population centered in the states of Maranhão and Para was estimated at about 10,000 (Morrison and Ross 1986) but recent surveys show over 15,000 (D. Mizrahi *pers comm*). 3) The SE US–Caribbean population once centered on the Gulf coast of Florida (Harrington et al 1982), with over 10,000 knots wintering along about 50 miles of coastline. The number has since fallen to less than 1000 (Niles et al 2006). Concurrently, however, numbers in coastal GA and other locations in the Caribbean suggest a regional wintering population over 10,000 still winter in the SE (Lyons et al 2012).4) NW Gulf of Mexico including Texas, Louisiana and north eastern Mexico. The area likely supports about 2000 rufa red knots, but is the flock is mixed with rosallarii both long and short distance. It unique mix deserves special monitoring.

  We suggest the use of three wintering area surveys, to capture these three segments of the wintering population. The only wintering area currently surveyed annually is Tierra del Fuego, and so should be included in a yearly assessment. Surveys have taken place continuously since 2000 (Morrison et al 2004, Dey 2017) The first survey occurred in 1986. We recommended restoring the aerial count of knots on the Florida Gulf coast which would provide a useful comparison with surveys conducted in 2000-2005 (Niles et al. 2006), and the first survey in 1981 (Harrington et al 1982). Restarting the survey would provide an important index of short distance migrant winterers while Tierra del Fuego provides a comparable number for long distance migrants. There have been only two counts in the northern Brazilian wintering area but ICMBio intends to continue them (D. Paludo pers com) and they would provide a useful assessment of this important wintering area. Surveys in the Caribbean Islands especially Cuba would help determine the full extent of the short distance population of red knots wintering in this vast area.

- ***Stopover Surveys:*** Red knots use many stopovers along the Atlantic Flyway, but many of these sites either have minimal survey effort or small populations of knots using them. Such sites are, at this point, not useful in a flyway wide assessment of progress. We suggest focusing on those sites with a history of surveys and relatively uniform coverage. Experts associated with each site will produce the 4 point estimate, as with wintering sites. We suggest including the following:
    i. James Bay (2012 to 2017)
    ii. Mingan Islands 2010-2017,
    iii. Cape Cod 2010-2017 with the first survey conducted in 1981, 2012-2017
    iv. Delaware Bay 1983- 2017 and a first survey in 1981, superpopulation estimate from 2012-2017)
    v. Lagoa do Peixe National Park, Brazil, (1981, 2006)
    vi. San Antonio Oeste, Argentina. (1996-2017)

2. The second method of assessing year-to-year progress toward population recovery is to use south bound juvenile to adult ratios in areas where ratios are possible to estimate and have been done repeatedly. We will rely on the same four-point estimation approach to derive a consensus estimate for flyway-wide juvenile production.

   Currently juvenile/adult ratios are estimated at the following staging sites: James Bay, Mingan Archipelago, Cape Cod and coastal NJ. Juvenile/adult ratios are available in at least two wintering areas: the Gulf coast of Florida and Tierra del Fuego, but there are no previous long term summaries of this metric.

   In addition to being a crucial demographic parameter, enhanced monitoring of juvenile production could allow us to resolve whether periodic breeding failure is contributing to the population declines (McGowan), and whether this failure relates to poor foraging conditions during migration in spring (Baker et al. 2004, Duijns et al. 2017) or poor conditions in the Arctic (Fraser et al. 2012), or some combination of the two.

3. The third method of assessing progress on the flyway is to rely on an assessment of conditions in vital stopovers known to influence productivity and survivorship. At present only Delaware Bay meets this qualification based on work by Allan Baker (Baker et al 2004) and more recent work by Dujins et al (2017). These studies have shown that knots must gain considerable weight quickly at the Delaware Bay stopover in order to survive and reproduce. Only one other area, Lagoa do Piexe has been found to have similar departure weight profiles as Delaware Bay (Harrington et al 1986), although some data suggest Mingan Islands, Cape Cod and Coastal NJ may play a similar role in knot survival during long distance south bound flights (Buiden et al 2012, Harrington et al 2010, Loring et al 2017).
    c. Choosing essential stopovers that could provide realistic information on the condition of the population are challenging for two reasons. First the data are not available to assess the role of most stopovers. Regular trapping only occurs in a few locations so year-to-year assessment is not possible. Even when trapping occurs, most areas present difficulties that make it nearly impossible to make regular repeated captures. Southeast northbound departure sites such as Deveaux Bank, SC are notable but have not yet been

the focus of repeated trapping. Secondly, even where repeated trapping results are available, as with San Antonio Oeste in Argentina, the data show no dramatic weight increases.

d. Currently no other site has shown a similar influence on survival and productivity as Delaware Bay so we propose to use horseshoe crab egg density and departure weights as key metrics. These metrics have been recorded for over 20 years and are sensitive to changes in resource (horseshoe crab eggs) availability and can predict survival rate and productivity as influenced by the Bay stopover. Survival of course can be influenced by many other factors once birds leave Delaware Bay, such as adverse winds, Arctic snow conditions and predation levels. But these cannot be influenced by direct conservation investment, unlike tested strategies in the Delaware Bay, including beach restoration or horseshoe crab harvest regulation. Consequently, these metrics have a second value in that they can measure actions that have a direct influence on survival and productivity.

4. The fourth method of assessing progress towards our conservation goals relates to adult survival. Given the longevity and low reproductive output of red knots, adult survival is the demographic parameter most likely to be driving the population declines (Charnov 1986, Hitchcock and Gratto-Trevor 1997). Monitoring adult survival through analysis of band-resighting data allows us to track the demographic responses that underlie population increase, and also could allow us to test our hypothesis about the importance of Delaware Bay as a limiting phase of the annual cycle.

   Annual demographic analyses are probably unfeasible, so we propose a periodic analysis of flyway wide band-resighting data to estimate apparent adult survival annually, and for several phases of the annual cycle independently using a multi-state mark-recapture framework. For example, a multi-state framework could allow us to estimate the survival from spring departure from Delaware Bay through to fall arrival at key southbound stopovers, and separately estimate the survival from fall migration through to spring arrival in Delaware Bay. Estimating and then tracking these rates over time could allow us to determine whether conditions at Delaware Bay are indeed limiting the population, and would provide a warning system for the emergence of unknown threats at other phases of the annual cycle.

   An analysis of this scale requires collaboration from banders throughout the flyway. Key data holders offered preliminary indications of support for a collaboration like this at the recent WHSG meeting in Paracas, Peru, and in subsequent discussions.

Implementing the Metric Dashboard

Four-point estimates will be submitted by respective manager/biologists and used to determine yearly trend for each metric. The dashboard will be used to assess if earlier funding produced the desired outcomes for each year and the outcome of this review will provide the fifth part of the dashboard. Along with the other metrics, this final assessment will provide a complete picture for policy makers, grantors and managers to help determine progress towards recovery.

We propose separating funding into three categories based on the three types of management necessary for restoration of red knots, (a) management to increase the survival of adults and increase production, (b) management to insure continued protection in stable areas, and (c) management to limit negative impact on population recovery in areas of declining habitat or protection.

a. Management to increase survival and reproduction - the most obvious opportunity where investment could directly translate to increased survival and reproduction is in the Delaware Bay. At present, there are insufficient horseshoe crabs and horseshoe crab eggs for all shorebirds including knots to leave the bay in good condition. Based on past studies, we hypothesize that actions that increase the number of birds leaving the Delaware Bay stopover in good condition will increase red knot survival and reproduction. Lagoa do Peixe may provide a similar opportunity if there is a means to maintain and increase stopover habitat quality there. Types of actions on Delaware Bay include: habitat restoration, increasing restrictions on bait harvest of horseshoe crabs, decreasing lysate bleeding kills of horseshoe crabs.
b. Management to insure continued protection - The basic strategy rests on the assumption that all shorebird species have declined and carrying capacity of these sites is greater than current populations including red knots. Money spent in this category aims to insure stability of current protection or improving capacity for protection but without any expectation of growth in knot population. Specific sites could fall into this category and the next category (damage control) depending on the size of the site (some portions remain in good condition, others sections damaged) Site-specific metrics will be developed to assess long term condition of the stopover. The areas falling into this category are: James Bay, Mingan Islands, South Eastern Cape Cod , NJ Atlantic coast –Stone Harbor and Brigantine, Virginia Barrier Islands, South Carolina Coastal Island south of Charleston and Cape Romain, Georgia Coastal Islands Altamaha Delta, Florida Gulf Coast from Marco Island to Anclotte Key, Northern Brazil Maranhoa / Para coast, Lagoa do Peixe area from Pinhal to Rio Grande, San Antonio Oeste, Tierra del Fuego Bahia Lomas. The types of action include: GIS Mapping to determine critical areas and threats, in particular at James Bay, Maranhao/Para, Tierra del Fuego and Lagoa de Peixe, outreach to federal, state and local government to ensure site area protections, outreach to WHRSN, Important Bird Areas, RAMSAR and other protection organizations to ensure proper boundary definition, develop regular aerial survey and surveillance of key metrics.
c. Management to Limit Damage – Funded action in this category aims only to prevent further decline of stopovers or wintering areas damaged for shorebirds for various reasons: disturbance in NJ AC coastal sites, industrial development in San Antonio Estes, housing development and disturbance in gulf coast of Florida. The goal is to determine the extent of damage to red knot resources and explore methods of reaching stable conditions but without any expectation of increasing numbers of red knots. Areas in this category include: Coastal NJ, San Antonio Este, Florida Gulf Coast, Rio Grande Argentina. The types of action would include: GIS projects determining areas of greatest damage or areas that can be saved, management actions to limit the impact of disturbance, habitat restoration that can restore resources to the site lost to development, partnerships with other restoration efforts to achieve costly work with minimal input from red knot based funding.

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