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Historical Trends in New York State Cold-Stunned Sea Turtle Stranding-to-Release: 1998–2019

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Abstract. – Long Island Sound and the Great Peconic Bay (New York) contain southern barrier lagoons and eastern bays and are known habitats for foraging juvenile populations of sea turtles during summer months. Every year, sea turtles strand throughout these areas due to climate-related cold snaps that typically occur in the late fall and lead to cold-stunning, a physiological temperature shock similar to hypothermia that renders turtles unable to swim and prone to wash up onto beaches. Cold-stunning events in this area tend to last longer than a few weeks and typically affect juvenile Kemp's ridley (*Lepidochelys kempii*), juvenile green (*Chelonia mydas*) and subadult loggerhead (*Caretta caretta*) sea turtles. The New York Marine Rescue Center, formally known as the Riverhead Foundation for Marine Research and Preservation, is the sole rehabilitation facility for cold-stunned sea turtles in New York and responds to the second-largest number of cold stuns in the Greater Atlantic Region, which encompasses marine ecosystems from Maine to North Carolina. Since 1998, a total of 510 sea turtles have been recovered from New York state waters or beaches between the months of October and February. Of these 510 cases, 5 individuals restranded under similar conditions following rehabilitation and release, resulting in 505 distinct sea turtles stranding due to cold-stunning. These 505 cold-stunned sea turtles were composed of 3 different species: 281 *L. kempii* (56.0%), 174 *C. mydas* (31.3%), 48 *C. caretta* (9.5%), and 2 hybrids (0.4%). Over the course of 22 yrs, stranding frequency varied from 3 to 85 turtles per season, with an average of 23. However, a large increase in stranding numbers began in 2007; average stranding numbers from 1998 to 2006 were 7 per season, increasing to 34 per season from 2007 to 2019. Multiple factors are likely contributing to the increase in stranding/rescue frequency such as the gradual warming of northern waters (which may entice turtles farther north and prevent their timely southern migration), development of a free public outreach program targeted at educating patrons about local sea turtle populations, and implementation of an effective beach patrolling system. More efficient management of patrolling efforts has contributed to the quick response time and resulting increase in live turtle rescues. In addition, modification and enhancement of in-house treatment protocols have contributed to the upward trend of successfully rehabilitated cold-stunned turtles. Understanding historical cold-stun trends will allow local and national organizations to identify needs and allocate funding for conservation initiatives of endangered Atlantic sea turtle populations.

Key Words. – sea turtle; rescue; rehabilitation; cold-stunning; New York; Long Island

Every year, sea turtles strand throughout the United States and parts of Europe due to cold-stunning, a phenomenon similar to hypothermia (Witherington and Ehrhart 1989; Shaver 1990; Burke et al. 1991; Morreale et al. 1992; Bentivegna et al. 2000; Gerle et al. 2000; Still et al. 2002, 2005; Foley et al. 2007, 2012; Mettee 2010; Velez-Rubio et al. 2013; Roberts et al. 2014; Innis and Staggs 2017). Cold-stunning events are observed once surface waters have dropped below 10°C and death can occur at 5°C–6°C (Schwartz 1978). It is thought that the sudden and rapid decrease of water temperatures incapacitates these turtles and prevents them from migrating to warmer waters. Prolonged exposure to cold water results in turtles becoming lethargic and debilitated, and they are often observed floating at the surface (Morreale et al. 1992). Although all species of sea turtles are physiologically susceptible to cold-stunning, Kemp's ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), and loggerhead (*Caretta caretta*) sea turtles are observed to strand more frequently (Turnbull et al. 2000). Cold-stunning events can be classified as either acute or chronic and can be correlated with stranding location. Acute events

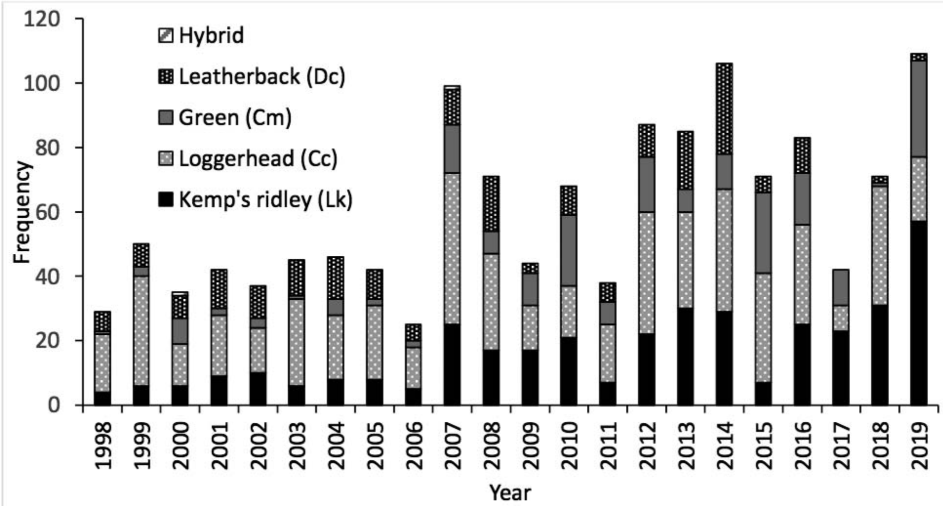

Figure 1. Yearly distribution of all sea turtle strandings 1998–2019 (n = 1325) recovered in New York. Species composition is indicated by the stacked bars: black (Kemp's ridley, Lk), gray (green, Cm), spotted gray (loggerhead, Cc), spotted black (leatherback, Dc), and diagonally striped (Hybrid).

are known to occur in lower latitudes (e.g., southern United States) due to abnormal cold weather over a short period of time, while chronic cases occur in higher latitudes (e.g., Massachusetts and New York), occurring annually in late autumn (Burke et al. 1991; Morreale et al. 1992; Gerle et al. 2000; Still et al. 2005; Dodge et al. 2007; Innis and Staggs 2017).

New York's waters are frequently used by 4 species of sea turtle: Kemp's ridley, green, loggerhead, and leatherback (*Dermochelys coriacea*) (Engelhardt 1913; Murphy 1916; Babcock 1919; DeSola 1931; Brongersma 1972; Morreale et al. 1992; Morreale and Standora 2005). A single hawksbill sea turtle (*Eretmochelys imbricata*) was documented in 1938 (Morreale et al. 1989, 1992), but additional sightings have not been reported. These resident species have been known to inhabit local waters throughout the summer months, foraging within the Long Island Sound, Great and Little Peconic bays, Great South Bay, and numerous nearby bays and lagoons. All 4 species of sea turtles are listed as threatened or endangered (International Union for Conservation of Nature 2021), which is directly correlated to human interference (Lutcavage et al. 1997). Throughout the Greater Atlantic Region, sea turtles strand for various reasons including vessel interaction, entanglement in fishing gear, ingestion of marine debris, and cold-stunning. Information gathered from these stranded sea turtles can provide insight on age, size composition, diet, reproductive status, health, population trends, and cause of mortality (Limpus and Reed 1985; Bjorndal et al. 1994; Caillouet et al. 1996; Boulon 2000; Schwartz 2000; Bugoni et al. 2001; Zug et al. 2002; Work et al. 2004; Foley et al. 2005; Chaloupka et al. 2008). The New York Marine Rescue Center (NYMRC; formerly known as Riverhead Foundation for Marine Research and Preservation) is the primary response team for sea turtles and maintains the only facility permitted to rehabilitate sea turtles in New York State. Since the 1980 inception, this organization has responded to over 2000 stranded sea turtles along the entire New York shoreline with 1325 strandings documented from 1998 to 2019 (Fig. 1). Of these, nearly 40% of turtles had stranded as a result of cold-stunning. In support of these numbers, Gerle and DiGiovanni (1998) reported that cold-stunning was the leading cause for stranding and mortalities of sea turtles in New York waters.

The NYMRC responds to the second-largest number of cold stuns in the Greater Atlantic Region (second only to Cape Cod Bay, Massachusetts). Cold-stun stranding events in New York have been documented as early as 1924 (Latham 1969; Meylan and Sadove 1986; Burke et al. 1991) where 103 turtles stranded on 3 miles of beach on Long Island. However, the cold-stunning of sea turtles was not fully understood until 1987 when it was acknowledged to be an annual event cued by cold temperatures (Burke et al. 1991). Typically, in New York, cold-stunning occurs from November through January, yet events have occurred as early as October with strandings occurring as late as February (Gerle et al. 2000). Three species of sea turtles are known to strand due to cold-stunning: Kemp's ridleys, greens, and loggerheads. Leatherbacks have stranded in New York during cold-stun season; however, there has not been a documented cold-stunned leatherback due to their physiological ability to maintain higher internal temperatures (Frair et al. 1972; Innis and Staggs 2017). The typical cause of death for leatherbacks in New York has been linked to entanglement or vessel interaction (Gerle and DiGiovanni 1998).

Stranding locations of cold-stunned sea turtles in New York vary by year, and timing is often unpredictable. The NYMRC is responsible for 1850 miles of coastline. Stranding location of sea turtles can be difficult to predict and varies yearly due to the large size of Long Island's waterways (Burke et al. 1991). It is believed that multiple factors play a role in where and how these turtles strand, which include geographic, oceanographic, and meteorological conditions (Still et al. 2005; Roberts et al. 2014; Innis and Staggs 2017). Increase in overall stranding frequency has been correlated to an increase of sea surface temperature (SST; Griffin et al. 2019). Kemp's ridley, green, and loggerhead sea turtles generally strand on Long Island throughout north-facing beaches with Long Island Sound and Great Peconic Bay exposure. Survival rate rests heavily on response and rescue time of these critical species (Witherington and Ehrhart 1989). Often more than 50% of these stranded sea turtles succumb due to cold-stunning (Bentivengna et al. 2000; Gerle et al. 2000; Turnbull et al. 2000; Innis et al. 2007; Stacy et al. 2013). For New York, all cold-stunned sea turtles were found by NYMRC staff, members of the public, or trained volunteers, and brought to NYMRC in Riverhead, New York, for immediate care. Patrolling efforts have increased over the years with the implementation of initiatives such as the Citizen Scientist Training Program and ongoing recruitment of volunteers (Montello and McFarlane 2019).

Rehabilitation efforts and in-house protocols for cold-stunned sea turtles fluctuate yearly based on staffing, funding, volunteer support, and resource availability. Ongoing assessment of protocols ensures that all patients receive high-quality care and survival rates for critical patients are maximized. Mass stranding events can be difficult as patients are not able to receive individual attention and animals are triaged and grouped together based on current status (Innis and Staggs 2017). Due to the smaller scale of stranding numbers in New York, NYMRC can provide individual, focused care on each admitted patient. Over the years, in-house rehabilitation procedures have been modified and improved over the time period analyzed in this study. For example, previous studies have demonstrated that a gradual increase of temperature over the course of several days as well as treatment for dehydration, pneumonia, traumatic injuries, and acid-base and electrolyte imbalances lead to greater survival in cold stuns (Wyneken et al. 2006; Keller et al. 2012). In addition, swim trials have been introduced to relatively stable patients, which improves activity, breathing, and heart rate (Innis and Staggs 2017), and can also diminish prolonged stress response (Hunt et al. 2012). NYMRC has implemented these best practice approaches with all cold stuns.

The objective of this study was to review historical trends of cold stun-related strandings from 1998 to 2019 to determine if the incidence of cold-stunning is increasing in New York waters, to assess which factors may be responsible for strandings, and lastly, to reflect on the rescue and rehabilitative efforts that lead to successful releases of these endangered species back to their natural habitats. Together, these efforts contribute to collaborative conservation efforts for endangered Atlantic sea turtle populations.

METHODS

Patrolling and Stranding Response. — Cold-stunned sea turtles were collected from beaches on Long Island, New York, between 1998 and 2019. Sightings of stranded sea turtles were reported to NYMRC by the general public or by trained volunteers/staff members. Patrolling and response were performed in accordance with NYMRC Institutional Animal Care and Use Committee (IACUC) protocol RESP001. In 2017, the cold-stun patrolling program was revitalized, modeled after the successful volunteer patrolling effort managed by Massachusetts Audubon, to expand and optimize patrolling efforts and increase the number of cold stuns recovered. Global positioning system (GPS) coordinates and photos of turtles were taken at each stranding site. Stranding locations in water were animals reported by boaters, with GPS coordinates obtained from the initial sighting location. With guidance, these animals were often brought to land by reporting patrons or local marine authority personnel who assisted NYMRC with in-water response and rescue. Most of the cold stuns were transported from the stranding site to NYMRC's facility by staff or qualified volunteers. A small percentage (less than 5%) of the turtles collected during this study period were brought to the facility by concerned members of the public aware of the stranding program and organization location in Riverhead, New York.

Intake and Evaluation. — Clinical care of cold-stunned sea turtles was performed according to NYMRC IACUC protocols MED003 and MED004. All animals admitted were provided an identification number that was marked on the carapace with permanent paint. Turtles received a complete physical and blood analysis that included pH, partial pressure of carbon dioxide (pCO_2), bicarbonate (HCO_3), total carbon dioxide (tCO_2), partial pressure of oxygen (PO_2), total hemoglobin (tHb), sulfur dioxide (SO_2), sodium (NA^+), potassium (K^+), chloride (Cl^-), and complete blood count. In addition, species, date, morphometrics, location, and cause of stranding were identified upon arrival and recorded on data sheets provided by the Sea Turtle Stranding and Salvage Network. Age class of individuals was based on categories described for each species: Kemp's ridley (Carr 1956, 1957, 1980; Carr and Caldwell 1958; Lazell 1980; Henwood and Ogren 1987), green (Henwood and Ogren 1987; Shaver 1998, 2000; Metz and Landry 2013), and loggerhead (Mendonca and Ehrhart 1982; Ruckdeschel and Zug 1982; Lutcavage and Musick 1985) sea turtles. When necessary, confirmation of potential hybridization of species was through genetic analysis by colleagues at the Southwest Fisheries Science Center (SWFSC; La Jolla, CA).

Data collected over the past 2 decades by the NYMRC were compiled for this study in order to analyze historical trends. From these data, stranding frequency, species composition, morphometrics, and rehabilitation success rate were compared. All turtles that were brought into NYMRC's facility and not showing signs of decomposition were treated as alive. Admitted animals were assigned a class level based on their condition (Class I through Class IV as reported in Sandove et al. 1998). Classes I and II were more responsive compared with Class III and Class IV. Class III and Class IV were patients requiring critical care and attention by attending veterinarians. Evaluation of health included blood sampling, morphometrics, and documentation of external injuries. Internal temperature (°C) was measured using a cloacal probe (HDE Max-Min Thermo Hygro TA318) and heart rate was detected using a fetal Doppler (Facelake JPD-100B) and ultrasound transducer (Sonoscape SS1-1000). Turtles were brought to full temperature (~ 24°C) before a final disposition was determined. Individuals that arrived partially decomposed or not exhibiting signs of life were declared dead, while individuals that exhibited signs of life (detectable heartbeat, response to touch, respiration) but did not survive the warming process or rehabilitation were declared dead in house (DIH).

Rehabilitation. — Preceding 2016, the warming protocol was more rapid with use of warm enemas, heat blankets, and heat lamps to raise the body temperature 2°C–3°C every 15 min. Following recent studies showing higher success rates with slow warming in cold stuns (Wyneken et al. 2006; Innis and Staggs 2017), a more gradual increase in temperature was adopted in 2017. The methods described below represent current in-house procedures.

Depending on the incoming temperature, turtles were allocated to temperature-controlled rooms, and the warming regime (5°C/d) continued until an ideal temperature between 25°C and 30°C had been achieved. Supervised swimming was introduced to stronger individuals within hours (1–4 hrs) of admission, and duration (5–60 min) was dependent on stability of the individual and reassessed every 12–24 hrs. This type of early swimming therapy has previously been shown to improve breathing, heart rate, and circulation (Innis and Staggs 2017). Emergency medicines were prescribed by veterinarians on an individual basis; these included atropine sulfate at 0.04–0.2 mg/kg (Elkin-Sinn Cherry Hill, NJ) to help with poor cardiac response and doxapram hydrochloride at 5–10 $mg \cdot kg^{-1} \cdot min^{-1}$ (Dopram®-V, Boehringer Ingelheim Vetmedica, INC, MO) to stimulate respiration (Pisciotta et al. 1995; Sandove et al. 1998; Turnbull et al. 2000; Wyneken et al. 2006; Innis and Staggs 2017). If necessary, individuals were intubated to support breathing. All individuals were also provided subcutaneous administration fluids daily during warming process (1 part lactated Ringer's solution to 1 part sodium chloride). For more severe dehydration cases, individuals were provided fluids intravenously instead of subcutaneously.

Once live individuals completed the warming process and reached optimal temperature (25°C), they were introduced to indoor temperature-controlled pools with full filtration. These pools held from 1–10 individuals depending on species, size, and in-house numbers. After animals were introduced to new pools, they were offered small amounts of food. Individuals with regular defecation observed were offered larger meals at 2%–3% body weight depending on individual condition. Many turtles began feeding once offered and anorexic turtles received an injection of vitamin B complex 0.1–0.3 ml/kg intramuscularly once a week and until the condition was resolved (Wyneken et al. 2006; Innis et al. 2017).

All turtles received daily and weekly checkups from staff and senior veterinarians, and individualized treatments were administered. Daily care for all admitted patients included diet management, vitamin supplementation, fluid therapy, shell treatment, behavioral enrichment, and water quality. In addition, many turtles received antibiotics to treat secondary infections, which may have included conditions such as pneumonia and osteomyelitis. Duration of rehabilitation was based on recovery rate and health status at admission. Previous studies have noted that cold-stun patients admitted due to prolonged exposure to temperature drops (chronic cases) or showcasing eating and swimming issues typically require more intensive medical care and remain in rehabilitation for several months (Wyneken et al. 2006; Innis et al. 2009a, 2009b, 2014; Hunt et al. 2012; Keller et al. 2012; Stockham et al. 2013; Innis and Staggs 2017).

Release. — More than 70% of the animals that survived the warming process within this study were released off the coast of New York after long-term rehabilitation (7–9 mo). However, the remaining 30% of individuals were ready for release sooner than the local water conditions allowed and were released in southern locations preapproved by the National Oceanic and Atmospheric Administration (NOAA). To help aid in future identification, all individuals greater than 30-cm straight carapace length (SCL) received metallic Inconel 681 flipper tags, and some turtles 20–30 cm SCL were provided 1005 series flipper tags (2018–2019). All turtles released that were under 20-cm SCL were not provided flipper tags due to their size. Turtles over 16-cm SCL received a passive integrated transponder of either 10-mm (> 16-cm SCL) or 12-mm (> 30-cm SCL) size. All tags were provided to NYMRC by NOAA Fisheries Greater Atlantic Regional Fisheries Office, and tagging protocols followed US Fish and Wildlife Services' Standard Conditions for Care and Maintenance of Captive Sea Turtles (US Department of the Interior 2019). To monitor postrelease movement pattern of released individuals (as in Mestre et al. 2014; Flint et al. 2017; Robinson et al. 2017, 2020), each year between 0 and 6 rehabilitated turtles received a satellite or acoustic tag, for a total of 36 tags over the 22-yr study period.

Correlating Cold-Stun Frequency with SST. — In an effort to correlate yearly cold-stun frequency with maximum and minimum SST, data were obtained through the NOAA-deployed monitoring station 44039, a moored

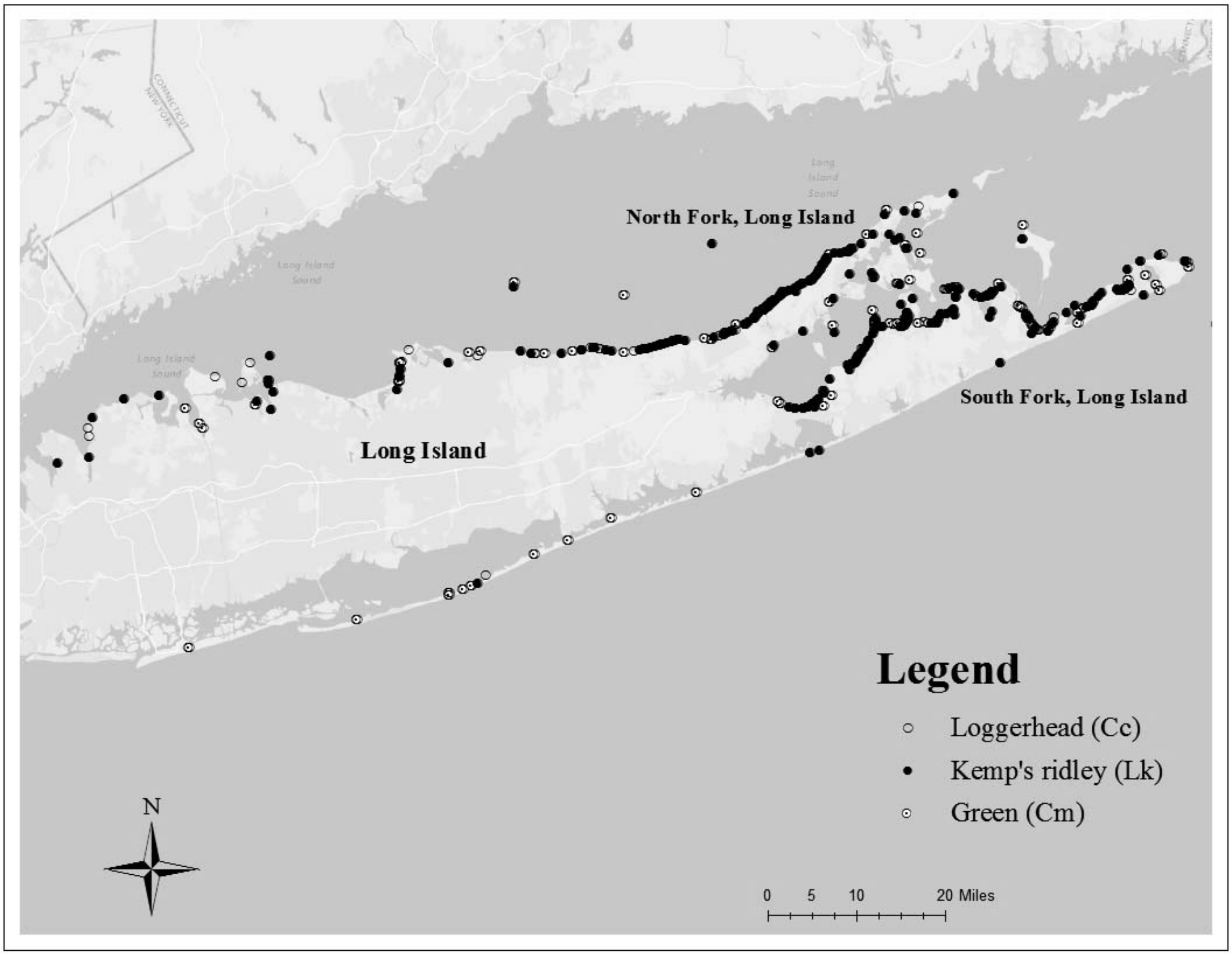

Figure 2. Map of Long Island, New York, showing the locations of the 510 cold-stunned sea turtle strandings during the cold-stun season (October–January) from 1998 to 2019. The North Fork and South Fork of Long Island are labeled as most strandings occurred along the northern shores of these peninsulas. Gray circle, loggerhead (Cc); black circle, Kemp's ridley (Lk); gray circle with dot, green (Cm).

buoy in central Long Island Sound (41°8′16.8″N, 72°39′18″W) that is owned and maintained by University of Connecticut, Department of Marine Sciences (National Data Buoy Center 2021). SSTs were measured from 2004 to 2019, at approximately 15-min intervals, 1 m below water surface. Data were isolated for cold-stunning months, October through January. Any data that were not measured, indicating equipment had been removed from the water, or temperature recorded as 999 (indicating equipment error) were excluded from analysis. The minimum and maximum SSTs were calculated for all active cold-stun stranding months (1 October–31 January).

RESULTS

New York Stranding Locations. — The total number of stranded turtles from 1998 to 2019 was 510. Cold-stunned sea turtles have been found as early as October and live strandings have occurred as late as February with higher frequency being documented in November and December (97.6%). Stranding locations for all species were observed primarily on north-facing beaches along the eastern end of Long Island Sound and Peconic Bay (Fig. 2). The highest frequency of strandings occurred on Long Island's North Fork as well as north-facing beaches on the South Fork. Yet, turtles were also found on all Long Island coastlines with some stranding sites along the southern coastline of Long Island and farther west along beaches of Long Island Sound (Fig. 2). There were no obvious trends observed when comparing species and location of stranding.

Species Demographics of Annual Strandings. — Of the 510 cold-stunned sea turtles that were recovered from New York State waters or beaches, 5 of these individuals restranded after being rehabilitated and released. This resulted in in 505 distinct turtles that stranded in New York due to cold-stunning over the 22-yr period. These 505 turtles were 3 different species: 279 Kemp's ridley, 176 green, 48 loggerhead, and 2 green–loggerhead hybrids (Fig. 3). In 2019, 85 sea turtles were recovered, which is the largest number ever documented in a single cold-stun season in New York since the inception of the New York

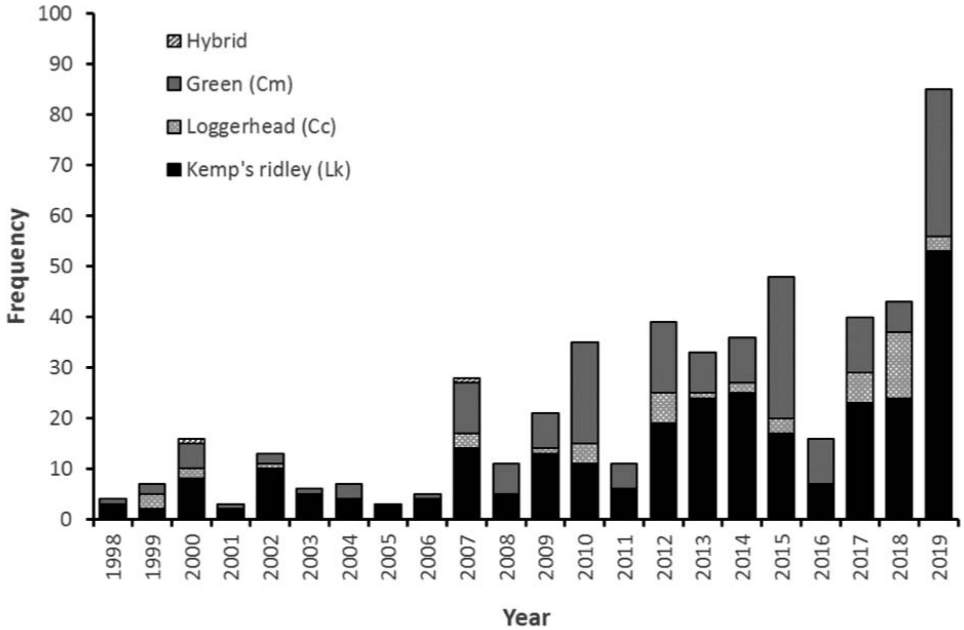

Figure 3. Yearly distribution of cold-stunned sea turtles (n = 505) recovered on Long Island, New York, during the cold-stun season (October–January) over the 22-yr study period (1998–2019). Species composition is indicated by the stacked bars: black (Kemp's ridley, Lk), gray (green, Cm), dotted (loggerhead, Cc), and diagonally striped (hybrid).

State Marine Mammal and Sea Turtle Stranding program in 1980. The previous highest number of strandings was 77, documented during the 1995 cold-stun season (Gerle et al. 2000). Over the course of 22 yrs, stranding frequency varied from 3 to 85 turtles per season, with an average of 23 per season. However, a large increase in documented strandings was observed starting in 2007, coinciding with a greater effort in public outreach and education. Average stranding numbers from 1998 to 2006 were 7 per winter season, increasing to 34 per winter season from 2007 to 2019 (Fig. 3).

Historical Species Composition. — Over 50% of the total animals stranding between 1998 and 2019 were the critically endangered Kemp's ridley sea turtles with the highest frequency documented in 2019 (n = 53; Figs. 3 and 4). Kemp's ridley consistently represented the most frequently stranded species (55.3%) throughout the period of study. The second most frequently documented species was the green sea turtle (34.9%; Figs. 3 and 4). Green sea turtles have increased in numbers over the study period, ranging from 0 (2003 and 2005) to 29 (2019; Fig. 3). Loggerhead sea turtles represented 9.4% of documented winter strandings (Fig. 4). Loggerheads were observed less frequently than the other 2 species and there were several years where none were rescued. Interestingly, loggerheads stranded consistently during cold-stun season for the last 3 yrs of the study (2017–2019; Fig. 3). The remaining 0.4% of winter strandings can be attributed to 2 unique turtles that were identified as hybrids (by SWFSC). In 2000, a cold-stunned green–loggerhead hybrid stranded live and another hybrid stranded dead in 2007 (Fig. 3). These 2 cases were not included in the success rate and the remainder of the analysis focuses on trends observed for Kemp's ridley, green, and loggerhead sea turtles.

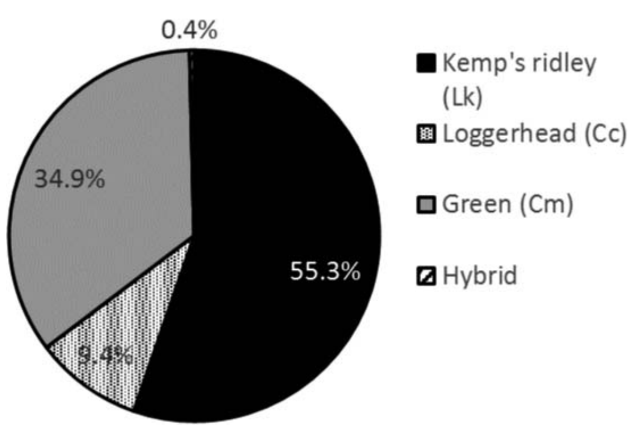

Figure 4. Species composition of cold-stunned sea turtles (n = 505) recovered from Long Island, New York, beaches 1998–2019. Kemp's ridley (Lk; n = 279) indicated in black, green (Cm; n = 176) indicated in gray, loggerhead (Cc; n = 48) in dotted pattern, and hybrids (n = 2) indicated with diagonal stripes.

Morphometrics by Species. — All turtles that stranded from 1998 to 2019 were mainly juvenile; however, subadult and adult sea turtles were documented during this study. As such, there was variation in morphometrics across the species. The mean SCL for Kemp's ridley was 27.79 cm (range = 20.7–45.5 cm) with a mean weight of 3.0 kg (range = 1.1–11.5 kg; Fig. 5). For greens, the mean SCL was 28.63 cm (range = 20.9–43.4 cm) with a mean weight of 2.79 kg (range = 1.0–9.4 kg), and for loggerheads the mean SCL was 55.09 cm (range = 42.8–73.5 cm) with a mean weight of 26.8 kg (range = 10.6–59.5 kg; Fig. 5).

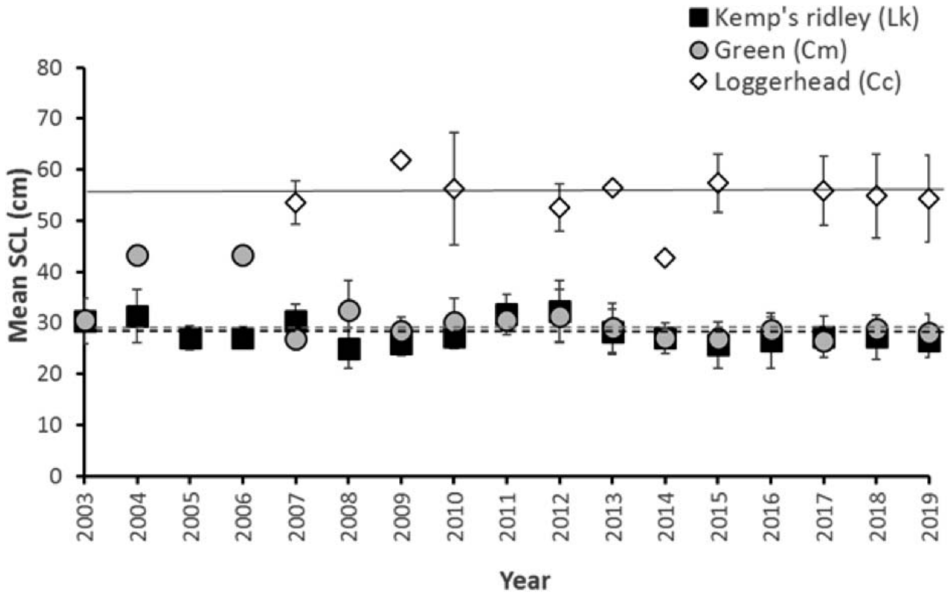

Figure 5. Average yearly SCL (in cm) of 3 species of cold-stunned sea turtles recovered on Long Island during the cold-stun season (October–January) from 1998 to 2019. Black circles are Kemp's ridley (Lk), gray circles are green (Cm), and open circles are loggerhead (Cc) sea turtles. Values are means ± standard errors of the mean (SEM).

Rehabilitation Success. — Of the 503 recovered turtles (2 hybrids not included), 281 (55.9%) stranded dead and 222 (44.1%) stranded alive (Fig. 6). Many of the recovered dead turtles appeared recently deceased. These individuals may have stranded alive and were not found immediately, and then died from exposure. Nearly half of the live stranded turtles (18.1% of total recovered) did not survive rehabilitation. These animals were typically individuals that did not survive the initial warming process once admitted and died either soon after admittance or within 72 hrs (DIH; Fig. 6). Of the animals that were admitted alive, more than half (26% of total recovered) survived and were released after either short- or long-term rehabilitation (Fig. 6).

When examining the species, disposition varied slightly for each. Kemp's ridley sea turtles were found dead at a rate of 59.9% (Fig. 7a). More than 20% ($n = 57$) of total stranded Kemp's ridleys died within the first 24–72

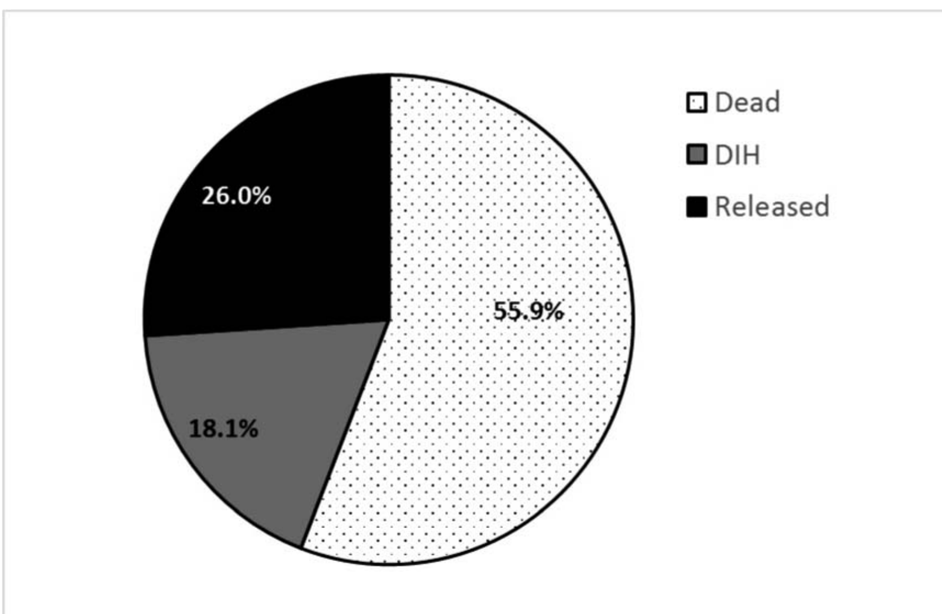

Figure 6. Final disposition of all stranded cold-stunned sea turtles ($n = 503$) recovered from Long Island, New York, beaches during the cold-stun season (October–January) from 1998 to 2019. Dotted section represents the percentage of turtles that were recovered dead (dead; $n = 281$), gray section represents the percentage of turtles that were recovered alive but died within 72 hrs of admittance (DIH; $n = 91$), and the black section represents the percentage of turtles that were recovered alive, successfully rehabilitated, and released (released; $n = 131$).

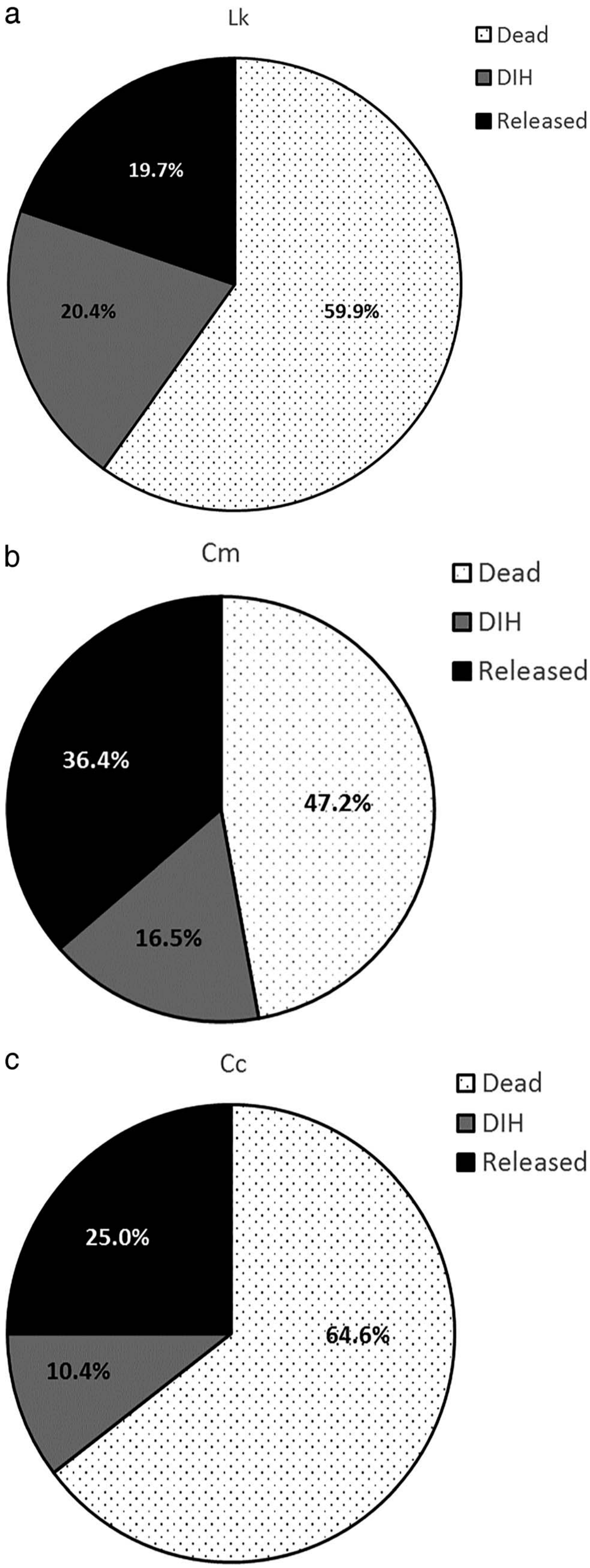

Figure 7. Final disposition of recovered cold-stunned sea turtles that stranded on New York beaches during the cold-stun seasons between 1998 and 2019, organized by species: (a) Kemp's ridley (Lk), (b) green (Cm), and (c) loggerhead (Cc). Dotted section represents the percentage of turtles that were recovered dead (dead), gray section represents the percentage of turtles that were recovered alive but died within 72 hrs of admittance (DIH), and the black section represents the percentage of turtles that were recovered alive, successfully rehabilitated, and released (released).

hrs and the remaining 19.7% (n = 55) survived and were released (Fig. 7a). Green sea turtles had lower mortality percentage at 47.2% and overall a higher release success of 36.4% (Fig. 7b). Loggerhead sea turtles were most often found dead at stranding compared with the other 2 species (Fig. 7c). However, live loggerheads responded well to rehabilitation with a 25% success rate.

Release. — In addition to variation in stranding numbers, there was yearly variation in success rate for release ranging from 0 to 32 turtles (0%–80%) between 1998 and 2019 (Fig. 8). It is important to note that there were years of 100% success rate calculated from only 1–2 live turtles being admitted and released (1998, 1999, 2002, 2003, and 2005; Fig. 8). Higher success rate observed during these years may be correlated to smaller stranding numbers allowing more individualized care and resources as compared with years with greater numbers of stranding. Of the 222 cold stuns that stranded alive, 131 (59%) were released due to successful rehabilitation efforts. Only 5 (0.9%) of the 505 turtles stranded a second time during a cold-stun season; this included 1 Kemp's ridley and 4 greens. All 5 sea turtles stranded dead during the next cold-stun season, 2–5 mo after their release. In addition to these 5 individuals, 6 other sea turtles that stranded during cold-stun season and were released the following year also stranded outside of cold-stun season (n = 3) or out of state (n = 3), which included Rhode Island, North Carolina, and Georgia. These restranded individuals represent 8% of all released turtles from 1998 to 2019.

SST by Year. — When average maximum and minimum SSTs (over the months of October–January) were illustrated by year, the maximum SST illustrated an upward trend, with an R^2 of 0.2632 (Fig. 9). This suggests that over a portion of the historical period examined (2004–2019), there was an increasing trend in coastal water temperatures around New York. By comparison, the minimum SST from October through January did not appear to change, showing an R^2 of only 0.0224 (Fig. 9). These correlations suggest that minimum temperatures have changed less than maximum temperatures over the past 2 decades.

DISCUSSION

Our historical data analysis demonstrates that New York's cold-stun season typically lasts 6–8 wks from November until the end of December with a majority of live strandings occurring in the early weeks of the season. However, cold stuns have been observed stranding as early as October and as late as February. Schwartz (1978) attributed cold-stunning to the tendency for surface currents in this area to travel in an east to west direction in the fall and winter. Furthermore, Burke et al. (1991) suggested that prevailing wind direction could determine the overall cold-stunning magnitude each year in New York due to the east–west orientation of Long Island. We demonstrate a clear increasing trend in the total number of

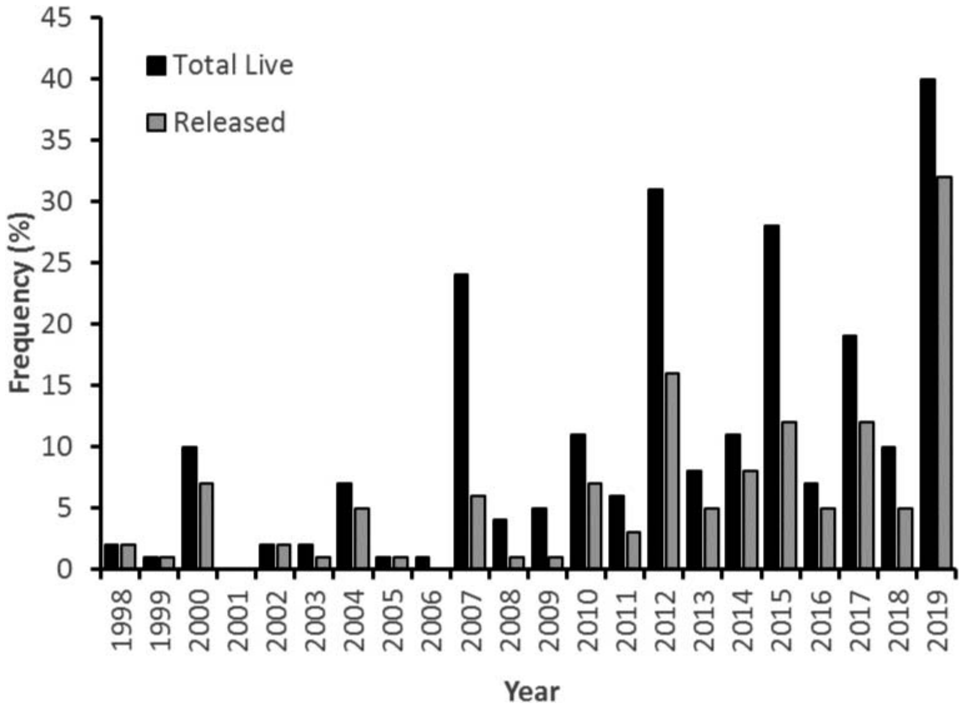

Figure 8. Total number of successfully rehabilitated cold-stunned sea turtles that stranded on New York beaches during peak cold-stun months (October–January) from 1998 to 2019. Black bars are the total number of live recovered cold-stunned sea turtles and gray bars are the number of turtles that were released each year following cold-stun rehabilitation.

turtles stranding over our 22-year study period with an average of 23 strandings per year with a dramatic increase in yearly strandings documented in 2007. Average strandings from 1998 to 2006 was 7 per year; however, in the last 12 yrs (2007–2019), the average has increased to 34 turtles per year. Previous work, summarizing New York stranding data from 1982 to 1997, documented 290 sea turtles stranding over the course of 17 yrs with peaks in

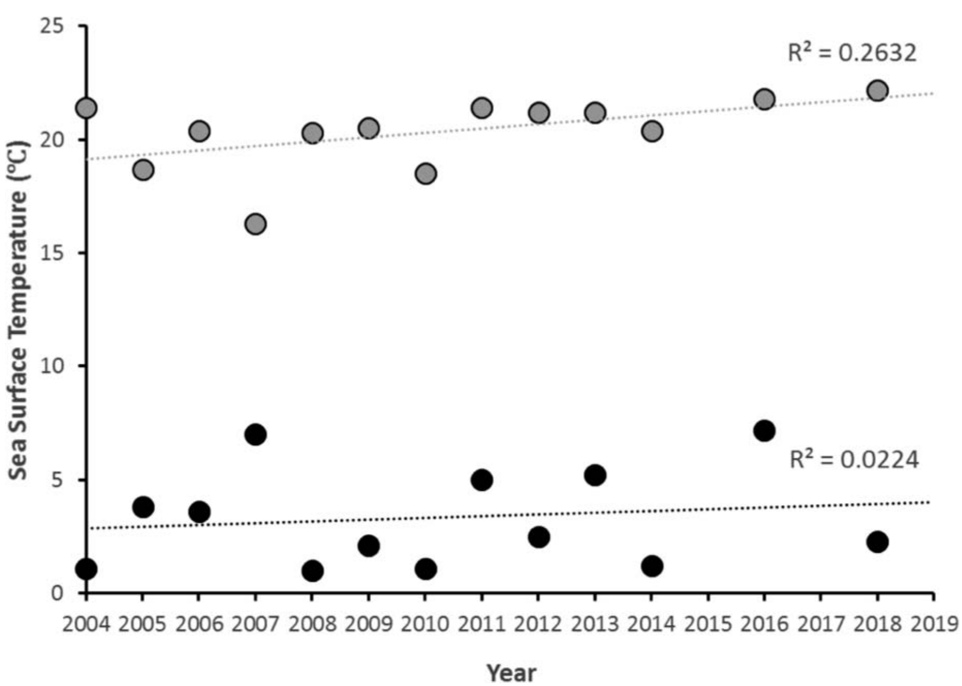

Figure 9. Minimum and maximum SSTs in the central Long Island Sound during the peak cold-stun season months (October–January) over the 22-yr study period (1998–2019). Gray symbols are maximum SST and black are minimum SST. Years that show missing data indicate equipment failure or equipment removal from the water for repairs (2015, 2017, 2019). Dotted lines represent the linear regression of the SST during the cold-stun season. R^2 values represent the goodness of fit of the linear regression model to the maximum and minimum SST values.

1985–1987 and 1995 and a stranding average of 12 turtles per season (Morreale et al. 1992; Gerle et al. 2000). A variety of causes can be linked to more numerous strandings, including environmental factors, education and outreach, and patrolling effort (Montello and McFarlane 2019). More public awareness through an increase in educational programming has brought more people actively looking for turtles and therefore more turtles being found on beaches. When average SSTs in New York waters from 2004 to 2019 were observed, there was a gradual increase in maximum temperatures over the cold-stun season, even though minimum average temperatures appeared consistent. This gradual warming trend over time may be linked to a greater number of Kemp's ridleys, greens, and loggerheads using northern habitats around Long Island Sound and Peconic Bay in New York later in the year.

Increasing survival numbers have previously been linked to enhanced recovery and rehabilitation effort (Innis et al 2009b; Innis and Staggs 2017). Data analyzed from this study indicated a lower mortality rate (73.9%) of cold stuns compared with greater than 80% as reported in previous studies (Morreale et al. 1992; Gerle et al. 2000). Indeed, immediate rescue leads to higher survival of stranded individuals (Innis and Staggs 2017), and our improvement in community education and outreach, alongside greater patrolling efforts over New York's extensive beaches are likely contributing to the increase in survival rate. As NYMRC has encouraged local communities to watch for turtles on beaches and use the hotline for reporting, this has undoubtedly led to a decrease in the time that turtles spend on the beach prior to rescue. Additional educational programming has been offered monthly, discussing sea turtle species affected by cold-stunning, and best practices for handling a stranded turtle. The NYMRC has targeted local beach walkers and provided training opportunities. In addition, more public awareness has come from media outlets such as local news coverage, and social media posts.

Our historical data from 1998 to 2019 demonstrates that species demographics may be changing. We have noted an increase in green sea turtle strandings, with 34.9% of cold stuns from this species compared with 4% and 6% from previous studies (Morreale et al. 1992; Gerle et al. 2000). Between 1985 and 1988, green sea turtles were not documented stranding during cold-stun season in New York, and a total of 119 cold-stunned Kemp's ridley ($n = 94$) and loggerhead ($n = 25$) sea turtles were recovered (Burke et al. 1991). Kemp's ridleys remain the most prevalent species with 55.3% of total strandings ($n = 282$). Lastly, loggerheads remain less frequent at 9.4% ($n = 48$) and exhibit high variability from year to year. Although no loggerheads were documented during the winter in some years, they have been observed with greater frequency since 2017. Cold-stunning exhibits temporal species trends with greens stranding when water temperature falls below 10°C, Kemp's ridleys at 7°C–10°C, and loggerheads stranding at 5°C–9°C (Morreale et al. 1992; Still et al. 2005; Robinson et al. 2020). Loggerhead seasonality and variability is most likely due to their size and capability to handle cooler temperatures compared with the smaller juvenile species, as noted by Still et al. (2005) in reference to Cape Cod Bay, Massachusetts. Perhaps a milder winter allows larger turtles, such as loggerheads, to migrate out of the water prior to cold-stunning. Although stranding frequency for each species has differed throughout the years, there has been less variability in species morphometrics historically. Minor variation in morphometrics was documented when comparing smaller sea turtle species (Kemp's ridley and green) and larger loggerhead sea turtles with strandings from previous studies (Morreale et al. 1992; Gerle et al. 2000). Together, these data show that similar age classes are using New York waters on a yearly basis, but our study demonstrates an increasing frequency in the past 22 yrs.

This analysis has demonstrated that the overall survival rate of rehabilitated cold-stunned turtles has increased over time with nearly 60% ($n = 131$) of all animals stranding alive ($n = 222$) released back into the wild. Data collected 1982–1997 showed a success rate of 56.8% ($n = 54$), yet fewer strandings were documented during this time with 290 total strandings and 95 stranding alive (32.7%). Although this success rate increase is gradual, overall live stranding numbers have almost tripled for New York State since 1998. This greater rehabilitation success can be attributed to faster rescue response and more targeted veterinary interventions for critical patients. Furthermore, survival rate can be linked to environmental conditions that turtles were exposed to. For example, seasons with severe drop in water temperatures (ranging 5.0°C–6.5°C; Schwartz 1978) typically lead to more deceased turtles washing up on shore or very weak individuals, which are classified as Classes III and IV. These animals are often nonresponsive, unable to breath on their own, and in need of emergency intervention. Typically, these cases have a higher chance of survival with the use of atropine sulfate to help with poor cardiac response and doxapram hydrochloride to stimulate respiration (Pisciotta et al. 1995; Turnbull et al. 2000; Wyneken et al. 2006; Innis and Staggs 2017). Previous admission methods involving faster warming regimes were later altered to a slower rate of temperature (2°C–4°C) increase. Rapid warming of cold-stunned sea turtles has been linked to acidosis and hyperkalemia (Kraus and Jackson 1980; Lutz et al. 1989; Innis and Staggs 2017) and is no longer recommended. Implementation of swim trials have proven to increase recovery for critical patients by improving breathing, heart rate, and overall activity (Innis and Staggs 2017). In addition, further in-house blood analysis has been implemented to monitor incoming turtles as they are gradually warmed up. Extensive blood analysis is monitored closely as studies have shown that pH, pCO_2, and K^+ can be used as predictors for survival rate (Keller et al. 2012; Stacy et al. 2013; Innis and Staggs 2017).

Patients are provided additional supportive care such as fluid therapy and vitamin supplementation. Lastly, turtles are not offered food until they have reached optimal temperature and have remained in a holding pool for 24 hrs. In the past, animals were force-fed immediately if they showed no interest in food. However, new in-house protocols involve the use of vitamin B complex on a weekly basis or until the animal eats (Wyneken et al 2018). Currently, assisted feeding is species-specific and limited to those who have exhibited prolonged lack of feeding and are experiencing weight loss (anorexia). Force-feeding is performed minimally throughout the week to keep stress response low. It has been noted that due to their strong response to stress, sea turtles fare better with less human contact and fewer stimuli during this early rehabilitation period (Hunt et al. 2012; Innis and Staggs 2017). Continued improvements to in-house protocols support the increase in successful rehabilitation of stranded sea turtles at NYMRC.

CONCLUSIONS

Strandings of cold-stunned sea turtles have been increasing in New York over the last 40 yrs. Our analysis suggests that more frequent strandings may be attributed to environmental factors such as warming of SSTs as well as increasing efforts toward rescue and rehabilitation. Yet, cold-stun stranding numbers may only represent a small percentage of total turtles using local New York waters (Burke et al. 1991), and further information is needed to fully understand New York's sea turtle populations. Recommendations for future studies include in-water capturing of sea turtles during summer foraging months to look at nonstranded individuals and placing acoustic tags on individuals to further understand habitat use in Peconic Bay and Long Island Sound. Species composition continues to be dominated by critically endangered Kemp's ridley sea turtles. The increase in stranding events is not just occurring on a local level, but also on regional and national levels (Roberts et al. 2014; Shaver et al. 2017; Griffin et al. 2019). It has been predicted that over 2000 Kemp's ridley sea turtles will strand yearly in Cape Cod Bay by 2031 (Griffin et al. 2019). With this Atlantic increase, stranding organizations will need to respond with elevated rescue and rehabilitation efforts in addition to enhanced rehabilitation space.

Over the years, in-house veterinary intervention continues to be modified and improved by rehabilitation facilities (Caillouet et al. 2016; Manire et al. 2017; Innis et al. 2019). More turtles survive the rehabilitation process and are released, which directly affects conservation of these species (NMFS et al. 2011; Innis et al. 2019). To date, several studies have shown that rehabilitated sea turtles are able to demonstrate normal behavior postrehabilitation (Cardona et al. 2012; Mestre et al. 2014; Flint et al. 2017; Robinson et al. 2017; Innis et al. 2019; Robinson et al. 2020) including successful nesting behavior (Nutter et al. 2000; Innis et al. 2019). Although restranding cases represented a very small percentage (8%) in our study, more information is needed to understand the etiology of restranding. Future projects will investigate sea turtles' use of local waters, encompassing telemetry studies for rehabilitated cases to analyze their postrelease movement patterns. Together, these studies will support the mission of the NYMRC to conserve threatened and endangered sea turtle species in New York and will allow NYMRC to contribute to broader conversation initiatives for sea turtles.

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