coasts

MDPI

Article

Changes in Eelgrass (*Zostera marina*) in the Little Narragansett Bay Estuary Between 2019 and 2022

Bryan A. Oakley [1,*], Emily Watling [1], Nina Musco [1], Michael Bradley [2], Alan Desbonnet [3], Peter V. August [2,4] and Daniel T. Cole [4]

[1] Environmental Earth Science Department, Eastern Connecticut State University, Willimantic, CT 06226, USA; watlinge@my.easternct.edu (E.W.)
[2] Environmental Data Center, University of Rhode Island, Kingston, RI 02881, USA; michael_bradley@uri.edu (M.B.); pete@edc.uri.edu (P.V.A.)
[3] Rhode Island Sea Grant, Narragansett, RI 02882, USA; alandesbonnet@gmail.com
[4] The Watch Hill Conservancy, Westerly, RI 02891, USA; daniel@thewatchhillconservancy.org
* Correspondence: oakleyb@easternct.edu

Abstract

Eelgrass (*Zostera marina*) is a native perennial marine angiosperm found in shallow bays and estuaries. Eelgrass beds are considered essential fish habitats and provide an important food source for marine organisms and waterfowl. This study examines changes in extent of the eelgrass beds in the southern portion of the Little Narragansett Bay Estuary, Rhode Island/Connecticut, USA, between 2019 and 2022. The primary dataset used to delineate eelgrass beds was side-scan sonar coupled with underwater video imagery. Previous studies showed a decline in the extent of eelgrass here between 2012 and 2016. Our results show an increase in eelgrass coverage from 0.52 km^2 in 2019 to 0.75 km^2 in 2022. This increase in the extent of eelgrass occurred against the trends of declining eelgrass coverage both globally and regionally.

Keywords: eelgrass; side-scan sonar; submerged aquatic vegetation; underwater video imagery

check for updates

Academic Editor: Philip Collins

Received: 18 July 2025
Revised: 20 August 2025
Accepted: 9 September 2025
Published: 14 September 2025

Citation: Oakley, B.A.; Watling, E.; Musco, N.; Bradley, M.; Desbonnet, A.; August, P.V.; Cole, D.T. Changes in Eelgrass (*Zostera marina*) in the Little Narragansett Bay Estuary Between 2019 and 2022. *Coasts* **2025**, *5*, 35. https://doi.org/10.3390/coasts5030035

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Eelgrass (*Zostera marina*) is a native perennial marine angiosperm that grows in shallow bays and estuaries as shoots or bundles of blades [1] and is an essential habitat for fish, epifauna, phytoplankton, and infauna, as well as a foraging habitat for migratory waterfowl [2]. Dense *Z. marina* beds and meadows also provide a breeding habitat for species such as pipefish and Atlantic Cod [3–5]. Eelgrass produces large quantities of oxygen through photosynthesis [6] and utilizes nitrogen, thus removing it from the water column and sediment [7]. Eelgrass is designated as an essential fish habitat (EFH), as well as a Habitat of Particular Concern under the Magnuson–Stevens Fishery Conservation and Management Act reauthorization in 1996 (16 U.S.C. §§ 1801 et seq). Seine surveys have identified dozens of fish species within Little Narragansett Bay, including recreationally and commercially important fin fish such as Winter Flounder (*Pseudopleuronectes americanus*), Atlantic Cod (*Gadus morhua*), Striped Bass (*Morone saxatilis*), Black Sea Bass (*Centropristis striata*), and Tautog (*Tautoga onitis*) [8,9], which utilize eelgrass habitat as juveniles [10,11]. Eelgrass is recognized as a critical marine resource and is protected by both federal (Clean Water Act 33 U.S.C. § 1321) and state regulations (Section 300.18 of the Rhode Island Coastal

Resources Management Program [12]). Anthropogenic and environmental stressors, including boat traffic (via propellor scarring), hurricane damage due to wave drag, changes in bed elevation due to sediment transport from storms, and degradation in water quality from high nutrient and pollution influx, have led to eelgrass declines (e.g., [13–15]).

Eelgrass habitat in Rhode Island (RI) coastal waters declined between 1930 and 1955 due to a wasting disease caused by the *Labyrinthula zosterae* fungus [16,17]. Water quality issues, primarily nutrient loading and rising water temperatures, further contributed to eelgrass decline [18–20]. This follows regional and global trends of seagrass meadows. The temperate North Atlantic coast of the US and Canada showed some recovery between the 1960s and 1990s, but the extent of seagrasses (including eelgrass) has declined in the last two decades [21]. The Chesapeake Bay Estuary has seen declines in eelgrass of 29% since 1991, with localized declines in coverage up to 80% in shallow areas, driven primarily by decreases in water clarity and increasing water temperatures [22]. Eelgrass beds in Rhode Island have been mapped and monitored using aerial photography [23–27], side-scan sonar [28,29], and underwater video with direct observation for ground truthing. This study focuses on mapping the eelgrass beds in the Little Narragansett Bay Estuary (LNB) at the southern border of Rhode Island and Connecticut (Figure 1) using side-scan sonar, underwater video, and direct (diver) observation. The increase in eelgrass coverage seen here goes against the trend seen globally and elsewhere in Rhode Island. The mapping approach used is not limited by visibility in aerial photographs and represents an approach that can be applied elsewhere to map eelgrass in similar depositional environments.

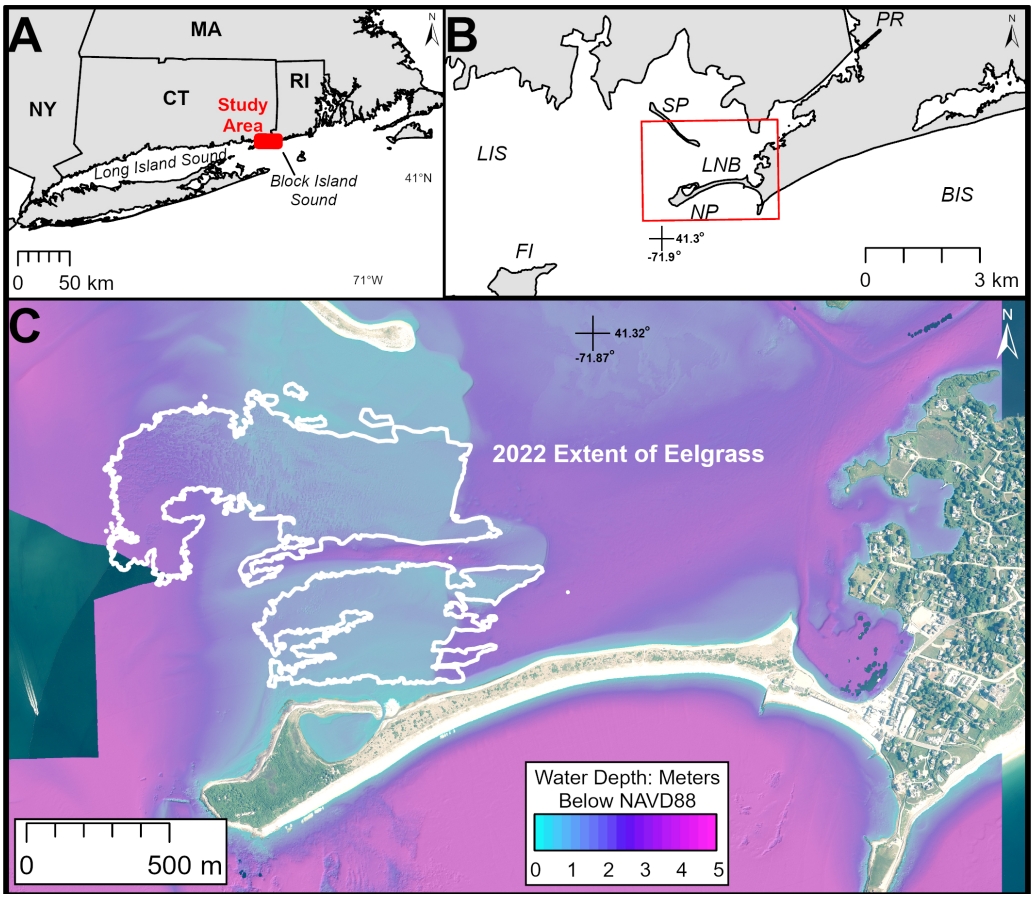

Figure 1. *Cont.*

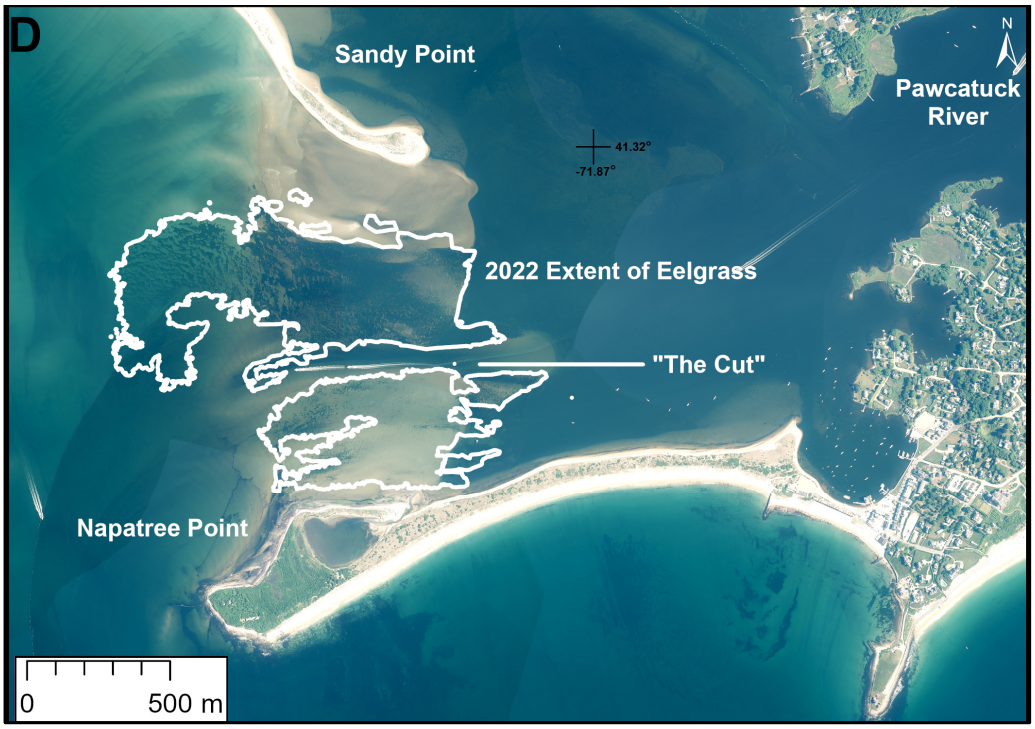

Figure 1. (**A**) Location map showing the study area in southwestern Rhode Island/southeastern Connecticut. (**B**) Key geographic features around the study area mentioned in the report. Long Island Sound (LIS), Block Island Sound (BIS), Napatree Point (NP), Sandy Point (SP), Fishers Island (FI) and the Pawcatuck River (PR). (**C**) 2018 USACE topobathy LiDAR digital elevation model [30] of the study area showing the water depth below NAVD88. (**D**) June 2021 digital orthoimagery [31] showing key geographic features discussed in the text. The white outline in both panels C and D shows the mapped extent of the eelgrass beds in 2022.

2. Materials and Methods

Side-scan sonar, underwater video imagery, and field-measured transects were used to map the extent of eelgrass beds in portions of Little Narragansett Bay (LNB) between 2019 and 2022. The area of focus was selected based on previous work mapping the extent of eelgrass in the estuary, and the area mapped represents the largest contiguous beds within the state of Rhode Island.

2.1. Study Area

Little Narragansett Bay is the seaward-most part of the Pawcatuck River estuary in southwestern Rhode Island, partially enclosed by the Napatree Point and Sandy Point Barriers (Figure 1). LNB is a microtidal estuary with a great diurnal tidal range of ~0.9 m based on water levels recorded since 2015 [32] and covers approximately 5 km^2 with an average depth of 2 m [33]. The eelgrass beds in LNB are situated on and near the former back barrier overwash deposits of the Sandy Point barrier, which was separated from Napatree Point during the 1938 Hurricane [34]. The substrate here is dominated by sand, with some pebble- to cobble-sized gravel. The southern and northern beds are divided by a tidal inlet known locally as 'The Cut' (Figure 1). Significant reductions in eelgrass extent in LNB began in the 1990s due to macroalgae mats [19], with some areas of the estuary observed to be fully covered with filamentous macroalgae [35]. Spring tidal currents in LNB range from approximately 0.3 to >0.7 m s^{-1} [36].

2.2. Previous Work

The extent of LNB eelgrass was previously mapped using digital four-band true color and infrared aerial photographs field checked with underwater video imagery and site visits in 2012, 2016, 2017, and 2021 (Figure 2) [23–27]. This method is intended for regional studies of eelgrass presence or absence [37]. The total acreage of eelgrass mapped in these surveys is reported in Table 1. The general extent of the beds as mapped via aerial imagery was similar between 2012 and 2021, particularly beds north of The Cut (Figure 1). The beds were more dynamic and saw a marked decrease in eelgrass coverage between 2012 and 2016 south of The Cut, followed by an increase between 2016 and 2021 [23,25–27]. One 0.24 km^2 (60 acre) bed mapped in 2012 contained no eelgrass in either 2016 or 2019–2022 (Figure 2). Upon further analysis, this area was likely a mat of macroalgae mistaken for eelgrass (Michael Bradley, personal observation). Such extensive mats of macroalgae are common in LNB [19]. This bed was not included in the eelgrass coverage reported in Table 1 and is shown in a stippled pattern in Figure 2.

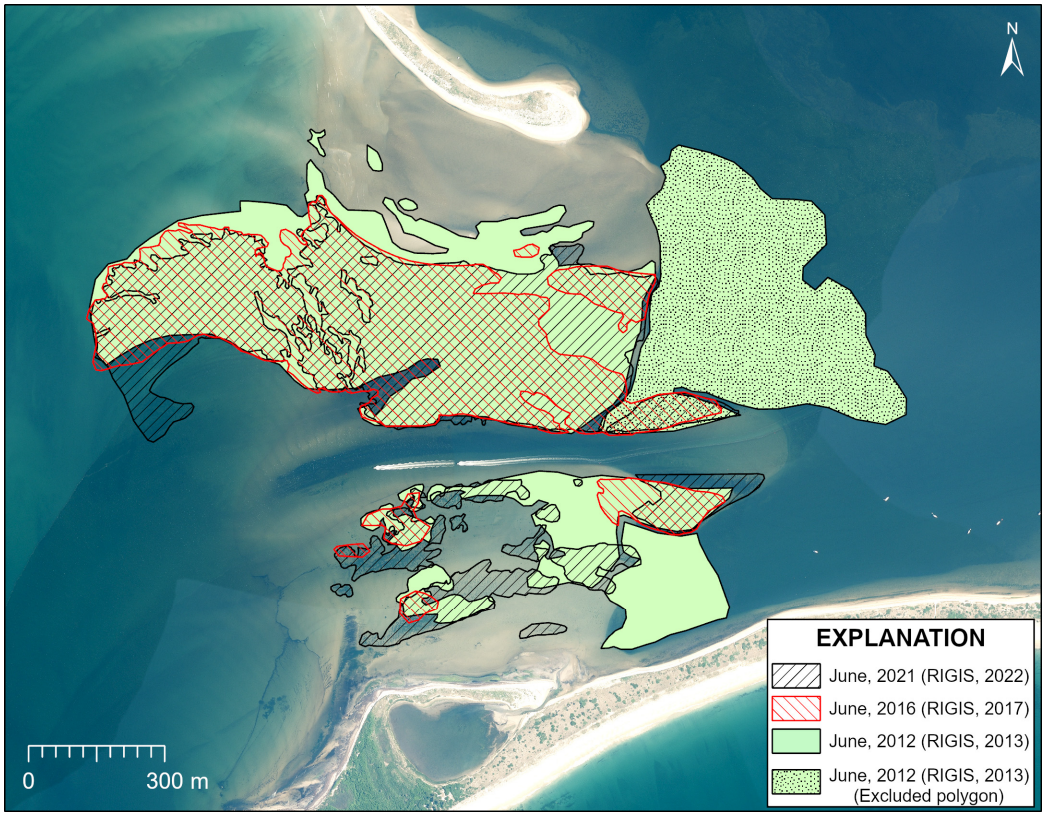

Figure 2. Mapped extent of eelgrass from previous Tier 1 projects [25–27]. The stippled polygon in the June 2012 coverage has been reinterpreted to be a mapping error (Michael Bradley, personal observation) and was likely a macroalgal mat. June 2021 digital orthophotography basemap [31].

Table 1. Total eelgrass mapped in LNB using aerial imagery from June 2012 [25], June 2016 [26], and June 2022 [27].

Year	Acres	km^2
2012	141	0.57
2016	96	0.39
2021	117	0.47

2.3. Side-Scan Sonar Collection and Interpretation

Side-scan sonar, a remote sensing tool [38] utilizing soundwaves to image the seafloor, was the primary dataset used in this project. Side-scan imagery was collected using an EdgeTech (West Wareham, MA, USA) 4125 dual-frequency sonar at frequencies of 400 and 900 kHz, on parallel track lines spaced 50 m apart, with a sonar swath range of 75 m for sufficient overlap. Only the 900 kHz data was processed, as it provides more detailed seafloor images. Spatial positioning was performed using a Trimble R10 RTK GPS with <5 cm accuracy. Survey speeds were <6.5 km h^{-1}. Data were processed using SonarWiz v.6 software, adjusting for variations in contrast and time-varied gain, and applying a slant range correction. Mosaics were created for each study region with a 0.3 m pixel size and exported as a GeoTIFF for analysis in ESRI ArcMap v. 10.6. Individual georeferenced side-scan files were exported as 0.1 m pixel size GeoTIFFs, providing detailed views useful in sparse eelgrass areas. Side-scan sonar records are interpreted based on the texture and intensity of the returning acoustic energy, identifying spatially recognizable areas with different backscatter patterns. Eelgrass beds have a distinct side-scan signature, and these areas were identified and manually digitized onto the GeoTiffs at a 1:300 scale in ESRI ArcMap v. 10.6 GIS software (ESRI, Redlands, CA, USA). The total area of eelgrass polygons was calculated for each survey. Polygons from 2019 to 2022 were converted to a raster format in ESRI ArcMap, with values of 1 indicating presence and 0 indicating absence. Raster surfaces were summed using the ESRI ArcMap Raster Calculator tool to assess bed persistence over time.

Underwater video and static imagery collected with GoPro (San Mateo, CA, USA) cameras either mounted on a small PVC sled or by diver-collected imagery within a 10 m radius of a fixed position were used to supply ground truth on the presence/absence of eelgrass and verify side-scan sonar interpretation. Video imagery provides qualitative details on the continuity of individual patches. Imagery in 2019 was collected by two divers drifting with the tidal current from east to west, recording time-lapse images of the seafloor every 10 s. The position of the divers was recorded using a Bad Elf (West Hartford, CT, USA) GNSS Surveyor GPS mounted to the dive flag in a float trailing <3 m behind the diver, and the spatial information was added to the imagery using ROBOGEO v. 6.3 software. The 2020 survey consisted of time-lapse static images, collected at 10 s intervals using a handheld GoPro Hero 5. A Sofar (San Fransico, CA, USA) Ocean Trident Underwater drone system provided additional ground truth at the 8 sites examined in 2020. This system provided comparable results to the diver-filmed GoPro imagery [39]. The video imagery was played back in the lab, and representative still-frame images were selected. These images were spatially overlain in a Geographic Information System (ESRI ArcMap) to check the initial side-scan sonar interpretations of habitat extent. Mapped boundaries were subsequently revised based on these observations in an iterative process to improve spatial accuracy.

3. Results

The full extent of the LNB eelgrass beds was surveyed using side-scan sonar in August 2019, 2020, and 2022. Partial coverage was collected in August 2021 (Figure 3). Underwater video or static imagery at set (anchored) positions was collected in 2020, 2021, 2022, and 2023 (Figure 4). The 2019 diver drift time-lapse imagery was collected along four drifts, resulting in a total of 208 images, and each drift was 8 to 10 min in length and covered ~200 to 300 m. Surveys in 2020 collected time-lapse images at eight survey stations. The 2020 static images were converted into videos for sharing and display. An additional 10 videos were collected as part of a comparison study using a Sofar Ocean Trident underwater drone system [39]. The 2021 survey collected videos at 14 stations, and 8 of those sites were

surveyed again in 2022. Figure 5 shows example images collected from August 2022. The videos are available via YouTube at the links provided in the Supplementary Materials.

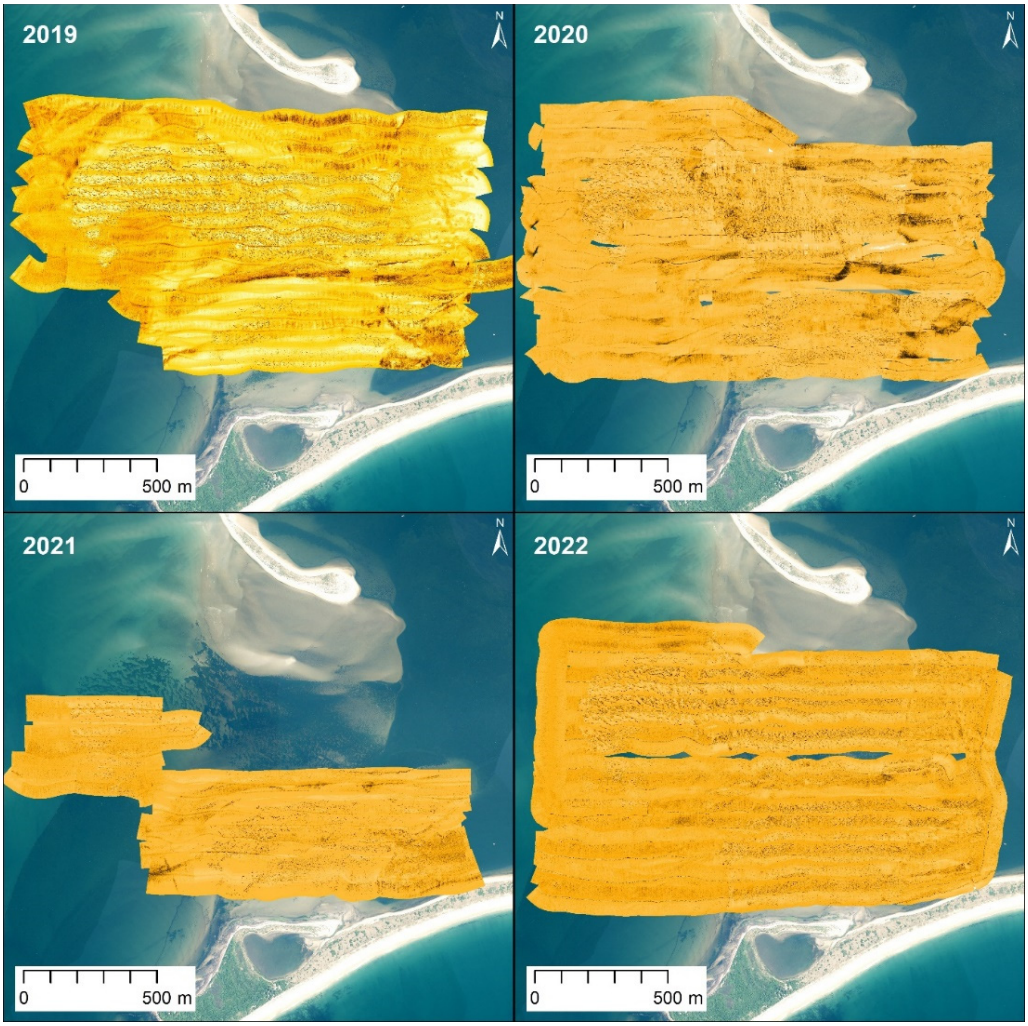

Figure 3. Side-scan sonar mosaics collected in 2019, 2020, 2021 (partial coverage), and 2022. The basemap is a June 2021 digital orthophotograph [31].

The extent of the beds measured using side-scan sonar increased by 45% between 2019 (0.52 km^2 (128 acres)) and 2022 (0.75 km^2 (185 acres)) (Table 2; Figure 6). The northern beds fluctuated slightly between 2019 and 2022, with more appreciable growth along the western edge (Figure 6). The southern beds expanded laterally, infilling the scattered polygons mapped in 2019. While not quantified, the percent cover of the beds also increased, particularly in the southern part of the study area. Figure 7 shows this variation in cover, with dense eelgrass (contiguous patches >90% cover extending up to ~1000 m^2) and visible bare sand intermixed. This region was mapped as a continuous bed, as the acoustic shadow limited the penetration of the side-scan sonar signal and prevented delineation of the ratio of bare sand/eelgrass. Figure 7C shows eelgrass of moderate (25–50%) cover and low cover (<25%) south of The Cut; individual clumps of eelgrass here range from tens of m^2 to <5 m^2. The positional accuracy of the GPS (~5 cm) used to locate the sonar data, combined with a very short layback (distance between the GPS and sonar) of <1 m, produces an overall positional uncertainty of the sonar of ~1 m. While we did not independently test the accuracy of each sampling method for this study, previous studies indicate that mapping accuracies for side-scan sonar and aerial imagery are similar and particularly accurate (>85%) for eelgrass over 11% cover [23,40].

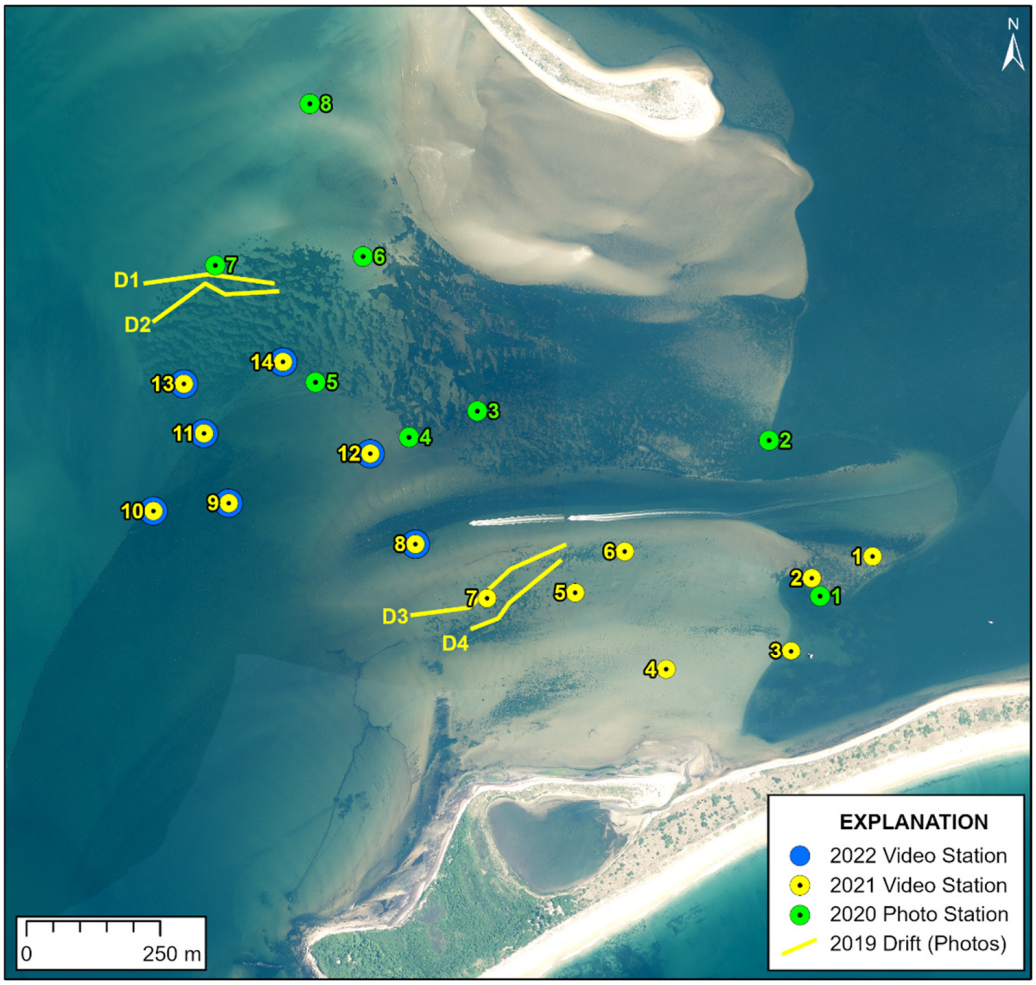

Figure 4. Locations of underwater imagery collected 2019–2022. Note that stations in 2022 occupied the same locations as some of the 2021 surveys. The basemap is a June 2021 digital orthophotograph [31]. Numbers and letters are station ID codes.

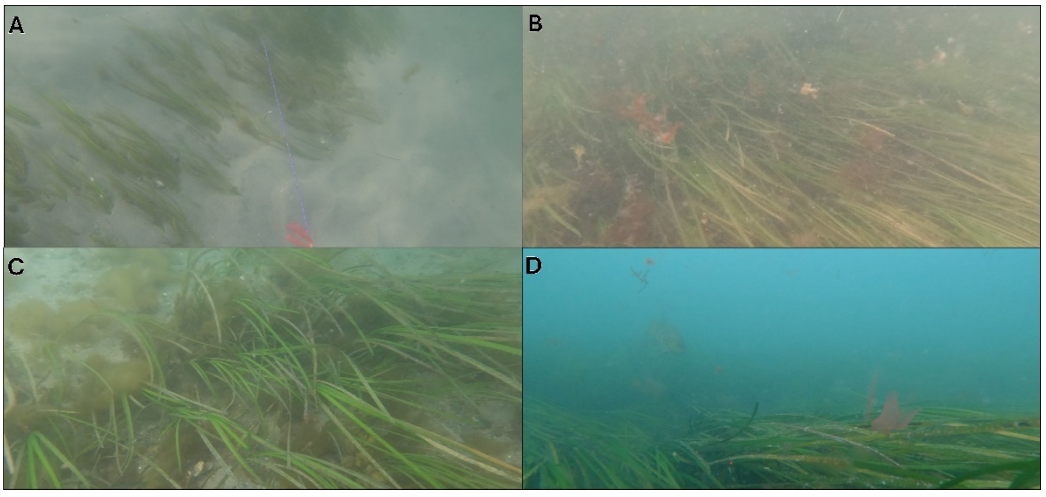

Figure 5. Examples from underwater video collected in August 2022. (**A**) Fifty meters south of Station 4, (**B**) Station 9, (**C**) Station 14, and (**D**) Station 8. See Figure 4 for the location of each station.

Table 2. Total side-scan sonar coverage, mapped extent of eelgrass, and percent of eelgrass change (relative to the 2019 side-scan sonar survey). The partial mapping in 2021 is excluded from the total coverage and percent change calculation.

Year	Side-Scan Sonar Coverage: km^2 (Acres)	Total Eelgrass Coverage: km^2 (Acres)	Percent Change (Relative to 2019)
2019	1.56 (385)	0.52 (128)	N/A
2020	1.64 (405)	0.57 (142)	+11%
2021	0.81 (200)	N/A	N/A
2022	1.74 (430)	0.75 (185)	+45%

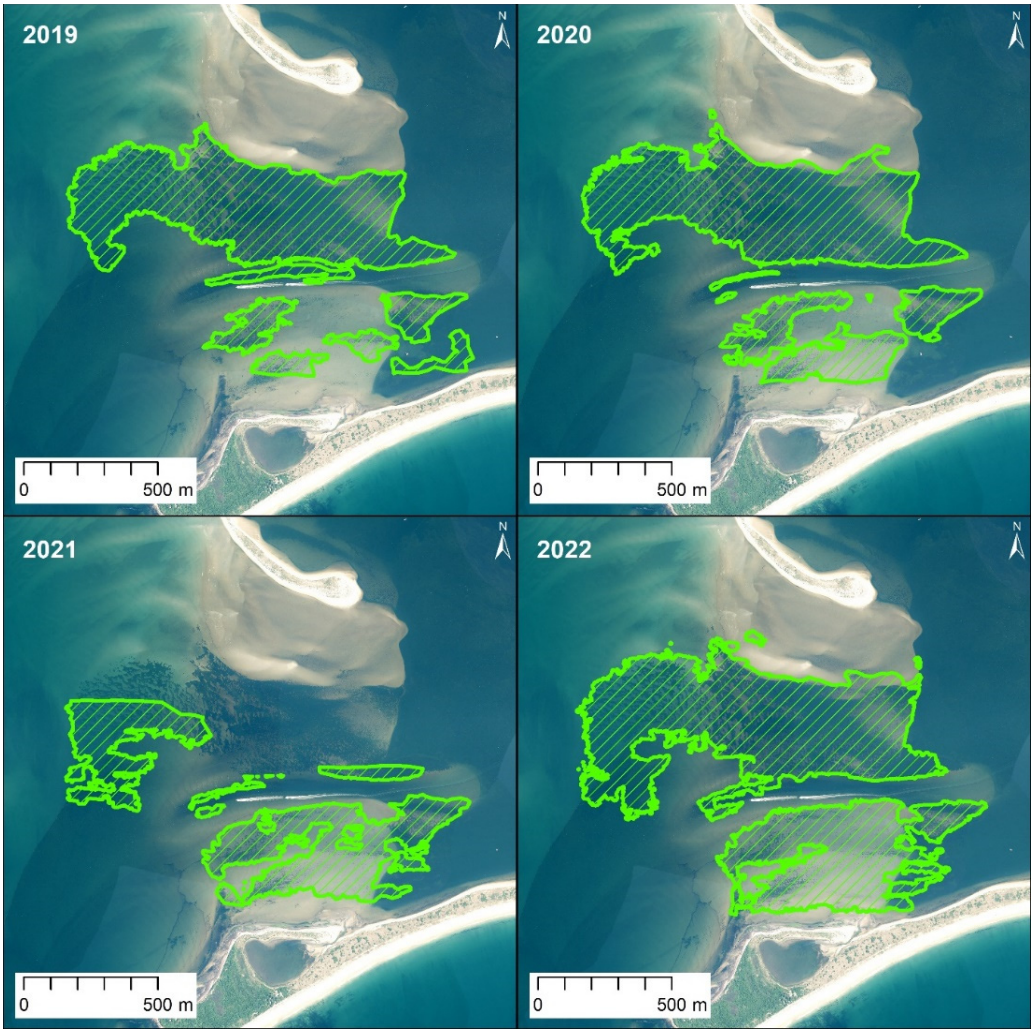

Figure 6. Mapped extent of eelgrass beds between 2019 and 2022 using side-scan sonar (note the partial coverage of mapping in 2021). The basemap is a June 2021 digital orthophotograph [31].

The persistence of eelgrass beds was examined by summing the raster surfaces created from the polygon coverages for 2019, 2020, and 2022 (Figure 8); 2021 was omitted because the side-scan survey only covered the southern half of the study area. This provides a visual assessment of where the eelgrass beds are persistent and where they have changed over time. A value of 1 represents areas where eelgrass was only visible in one survey; a value of 3 had eelgrass in all three surveys. The large swath of area mapped as '1' south of The Cut largely represents expansion of eelgrass into these areas in the 2022 survey. Areas where eelgrass was only present in one survey also show the expansion of the northern

bed (Figure 8). The underwater video imagery and aerial imagery show bare sand in these areas prior to 2022.

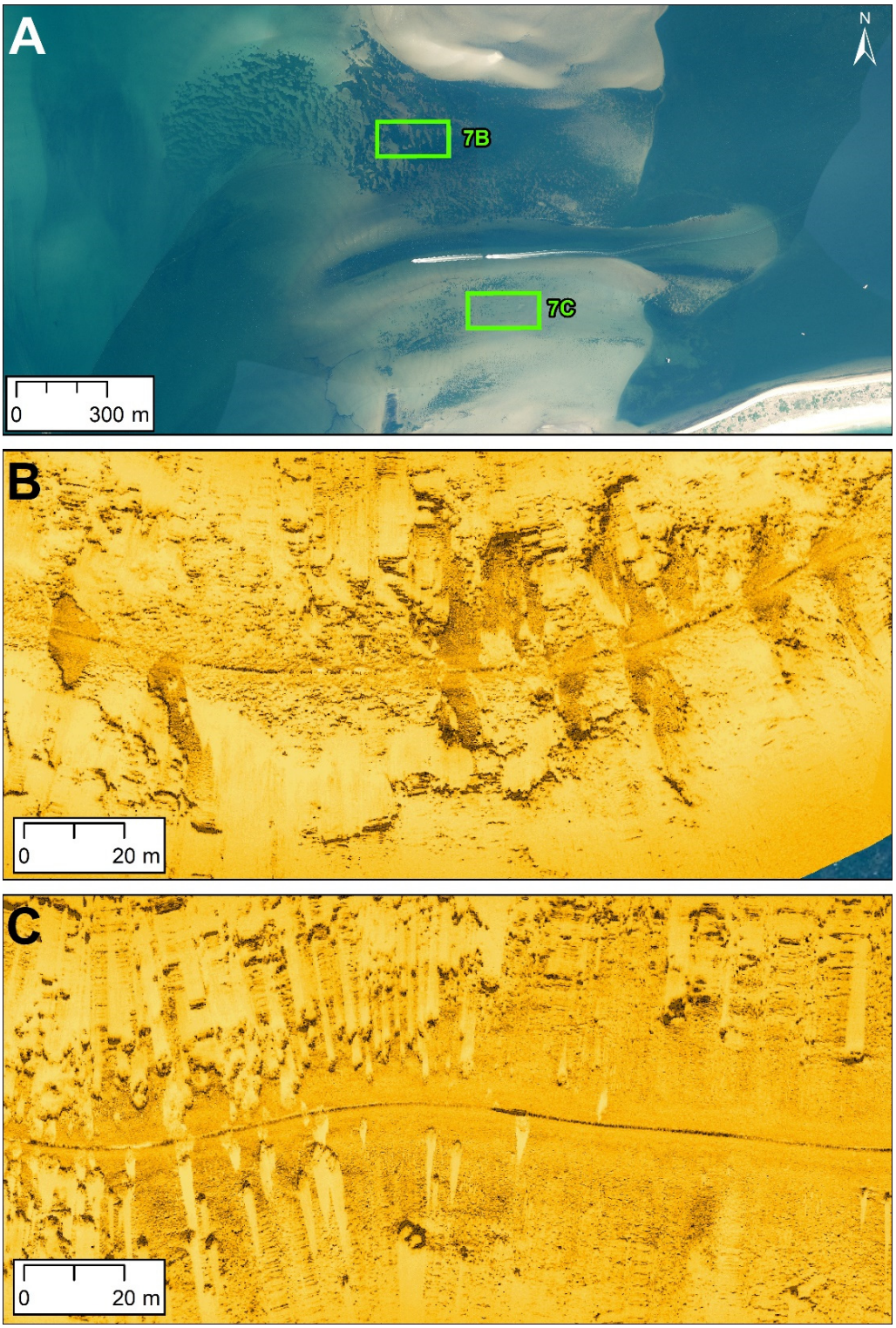

Figure 7. (**A**) June 2021 orthophoto [31] showing the location of panels 7B and 7C. (**B**) August 2022 side-scan sonar record showing dense eelgrass in the northern bed; note the large clumps and visible bare patches within the denser parts of the bed. The very light streaks in the data are acoustic shadows where the sonar signal was blocked by eelgrass blades. (**C**) August 2022 side-scan sonar record from the southern bed showing a general decrease in percent cover of eelgrass from west to east (left to right).

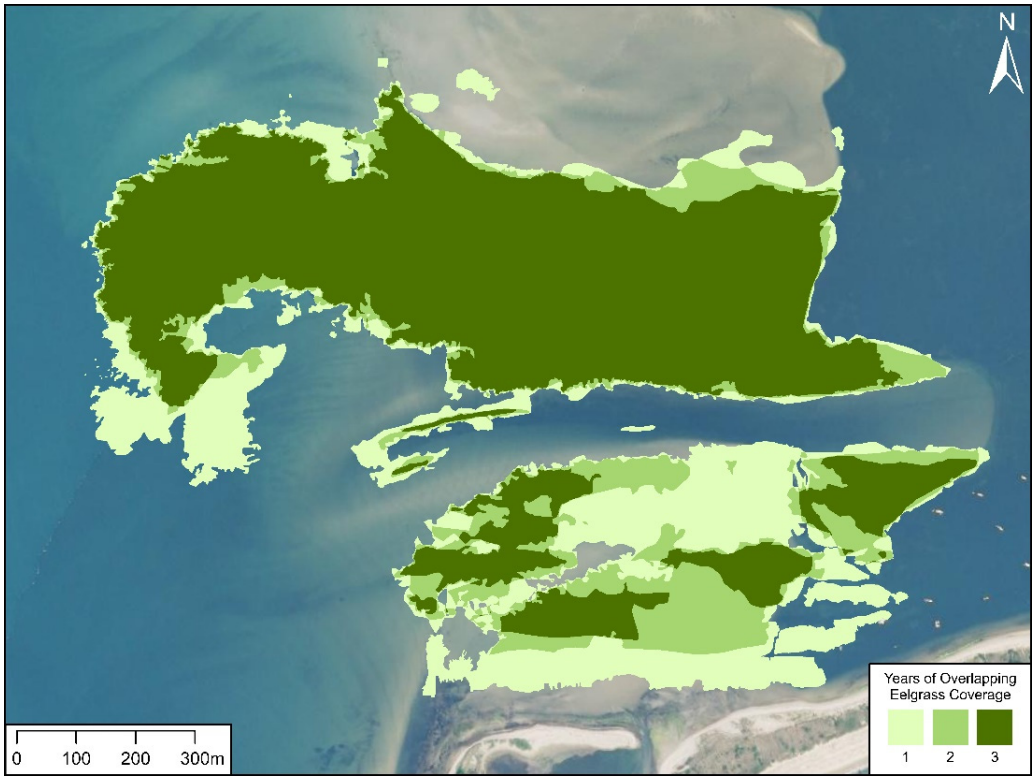

Figure 8. The result of the raster-based analysis of the eelgrass coverage in 2019, 2020, and 2022. Note that 2021 was omitted because the side-scan sonar coverage was limited to the southern half of the study area. Areas of dark green correspond to a value of 3; e.g., eelgrass was present at that site in all three years.

4. Discussion

Eelgrass beds in Little Narragansett Bay were mapped effectively using a combination of side-scan sonar and underwater video imagery. The mapping conducted between 2019 and 2022 found eelgrass coverage comparable to previous mappings that utilized aerial imagery with underwater video imagery [23]. The general (independent) agreement between the aerial imagery-based mapping [23,24,27,41] and side-scan sonar mapping (Figure 9) suggests that both techniques are producing reasonable maps of eelgrass extents, with some expected differences based on water depth and the time of year the imagery was collected. Side-scan sonar and aerial imagery share similar resolutions, and both provide accurate mapping of eelgrass; for example, accuracy exceeded 90% when eelgrass cover was greater than 11% [40]. Some differences in individual interpretations are to be expected, as both datasets require expert interpretation and require judgment calls on the continuity of individual beds. Absolute accuracy was not assessed for each survey; however, the similar mapped extent of the northern beds suggests that the interpretations are consistent from year to year. The sonar appears to have identified some eelgrass along deeper water portions of the area that may have been missed in the aerial imagery (Figure 9). The variability between these two amounts to a potential difference in total acreage of ~10%. Total eelgrass coverage increased between 2019 and 2022, suggesting that despite overall declines in eelgrass abundance globally and regionally [6,24,42–44], there has been a recent expansion of eelgrass beds within LNB. Submerged aquatic vegetation decreased by 28% in Rhode Island between 2012 and 2021, with most of the losses occurring in the coastal lagoons along the Rhode Island south shore [23]. The lack of side-scan sonar data from before 2019 limits our temporal interpretation of patch expansion; however, the aerial imagery suggests that the coverage decreased between 2012 and 2017 and then increased in 2021 (Table 1). Other local areas, including the West Passage of Narragansett Bay [23]

and portions of eastern Long Island Sound [24,45], have seen increased eelgrass coverage in recent years as well.

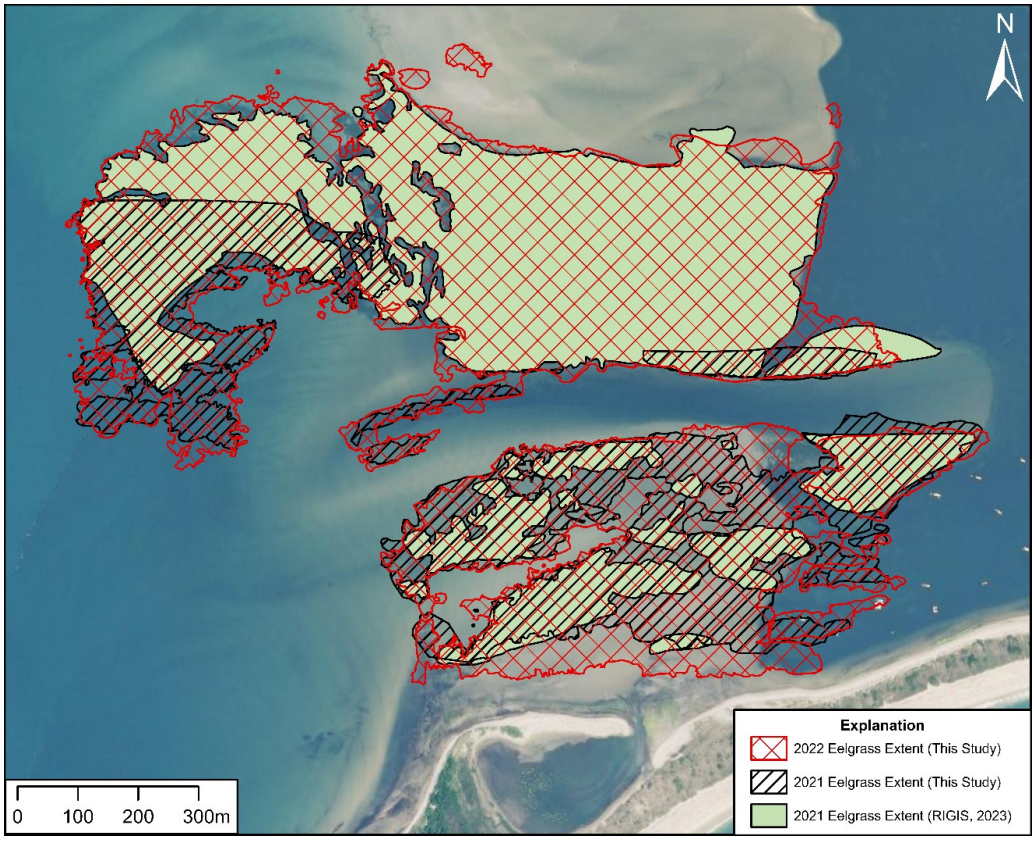

Figure 9. Comparison of side-scan sonar mapped extent of eelgrass (2021, 2022, hatched polygons) and aerial imagery (June 2021, green polygon) [25]. Note the overall similarity in the extent of the bed, with the exception being the deeper western part of the northern bed and the shallow area south of the channel. June 2021 orthoimagery basemap [31]. The area containing the large eelgrass patch to the north was not included in the side-scan sonar mapping in 2021.

The reasons for eelgrass coverage increasing here remain unclear, and given the limited temporal range, discerning if this increase is part of a broader pattern of interannual variability remains challenging. Changing characteristics of the seabed and transport of sediment influence seagrass distribution for sandy areas that are exposed to wave action [46,47]. Overall, beds situated in higher-energy systems may exhibit more interannual and even monthly fluctuations in bed size due to the variability of the system [48]. Such dynamics can drive variability in bed sizes over interannual cycles. The results of this study show an overall bed size increase from 2012 to 2022, and the steady increase over time suggests the expanded eelgrass beds are persistent over this period. Additionally, European Green Crabs (*Carcinus maenas*) have been linked to declines in eelgrass [49]; however, we do not have detailed records on changes in the crab populations in LNB over this time. Future mapping can help determine if the increases seen in this study are part of the expected variability of the system or representative of a long-term recovery within the site.

Various causes have been attributed to the loss of eelgrass. Nitrogen loading in LNB is 10 to 20 times higher than levels considered amenable to creating sustainably healthy eelgrass populations [19]. The total nitrogen load measured in 2018 was higher than in 2002, with a general increase over time [19]. Despite the reported heavy nitrogen load to LNB, we have recorded expansion of eelgrass extent in the study area. Others have suggested that meteorologic conditions, including annual average water temperatures, may explain eelgrass

variability [50], and these factors may also play a role here. We also hypothesize that the proximity of the LNB eelgrass beds to Block Island Sound (and ostensibly the open Atlantic Ocean) increases tidal flushing, which may also mitigate the impact of nutrient loading on eelgrass [51]. The size of the estuary may also reduce the impact of higher nitrogen loads [52]. The strong tidal currents (spring tide currents range from 0.3 to 0.7 m s^{-1} [36]) in the area likely limit the persistence of macroalgae mats on the eelgrass beds, which can impede growth and cause mortality [53]. Drifting algae mats are readily transported at velocities of 0.1 to 0.2 m s^{-1} [54]. These hypotheses remain untested at present.

Hurricane Sandy made landfall in New Jersey in October 2012 four months after the June 2012 aerial eelgrass survey [24,25] (Table 1). Given the geographic size of the storm, impacts in southern New England were comparable to those of a Category 1 hurricane [55]. Peak water levels reached a maximum elevation of 1.8 m NAVD88, which coincides with approximately a 25-year return period storm at both the Newport, RI, and New London, CT, tide gauges [56,57]. Offshore significant wave heights recorded at a buoy 75 km SE of the study area exceeded 9 m [58]. The potential influence of storms on eelgrass meadows is apparent, particularly in shallow, dynamic areas like the areas where eelgrass occurs in LNB. Changes in bed elevation can have negative impacts on *Z. marina* growth, so deposition following a storm could reduce the extent and density of eelgrass. Burial of *Z. marina* plants with >8 cm of sediment can reduce photosynthetic ability and disrupt respiratory processes in the buried portions of the above-ground biomass [59]. A similar experiment noted that sediment burial above 5 cm led to mortality in shoots [60]. Erosion of the eelgrass beds by natural events and human-induced changes reduces the anchoring capacity of the shoots and makes detachment of plants easier [61]. Waves from larger coastal storms can uproot seagrasses and influence burial and erosion of sediments within seagrass beds [62]. The combination of wave orbital motion and storm surge-induced currents could easily exceed the threshold velocity for sand and mobilized sediment in this area. Other studies in Rhode Island suggest that eelgrass in sandy sediment can tolerate 1.2 to 1.5 m s^{-1} of flow [63]. Flow velocities of up to 2 m s^{-1} were observed during Sandy in Jamaica Bay, New York [64], and while no direct observations were recorded in LNB, it is likely that current velocities scaled with the increased water level during the storm, increasing above the fair-weather current velocities (0.3–0.7 m s^{-1} [36]). Wave orbital velocities for a 0.75 m wave with T = 14 s and depth = 1 m (matching observations from recent storms) exceed 0.8 m s^{-1}. The combined effect here of waves and tidal currents could easily exceed the threshold velocity for eelgrass [63]. Taken together, Hurricane Sandy was likely the cause of the LNB bed decrease in 2012. The authors have observed breaking waves across this area during more recent storm events; however, the driving factor (deposition/burial or bed erosion) cannot be discerned. We attempted to address this hypothesis by analyzing changes in the elevation of the area around the eelgrass beds in LNB using topobathymetric LiDAR collected in 2010, 2014, and 2018. However, few discernible changes could be detected that exceeded the vertical uncertainty of the LiDAR data (0.12 to 0.2 m) [30,65,66].

The beds were not resurveyed using side-scan sonar following winter storms that occurred in December 2023 and January 2024; these events produced offshore wave heights of up to 9 m and water levels exceeding 1.3 m above NAVD88 [32,58]. Qualitative analysis using underwater video imagery collected in June 2025 and orthophotographs and vertical aerial imagery from 2024 and 2025 [67–69] suggest that these storms did not negatively impact the extent of eelgrass in LNB, and that coverage in the southern beds had increased since 2022. Why these storms did not have the same impact on the eelgrass beds as Hurricane Sandy remains unclear; the magnitudes of these recent storms (surge elevation, duration, offshore wave heights) were substantially lower than Sandy. Future works examining the extent and percent cover of eelgrass before and after storm events, coupled

with detailed mapping on changes in bed elevation, would help constrain the role these processes play in the variability of eelgrass at this site. Changes in future storm frequency and intensity [70] with a warming climate could also impact the variability of the eelgrass coverage at this site. The results presented here also provide baseline conditions that could be used to assess the impacts on LNB eelgrass following planned upgrades to the wastewater treatment facility that discharges into the Pawcatuck River.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/coasts5030035/s1, Table S1. Location of Underwater video image and links to the videos.

Author Contributions: Conceptualization, B.A.O. and P.V.A.; methodology, B.A.O., P.V.A., and M.B.; software, B.A.O.; formal analysis, B.A.O., E.W., and N.M.; investigation, B.A.O., P.V.A., E.W., and N.M.; data curation, B.A.O.; writing—original draft preparation, B.A.O. and E.W.; writing—review and editing, B.A.O., E.W., P.V.A., A.D., and M.B.; visualization, B.A.O. and E.W.; project administration, B.A.O., P.V.A., and D.T.C.; funding acquisition, P.V.A., B.A.O., and D.T.C. All authors have read and agreed to the published version of the manuscript.

Funding: This project was supported by the University of Rhode Island Coastal Institute, Rhode Island Sea Grant, The Watch Hill Conservancy, The Eastern Connecticut State University Foundation, The Eastern Connecticut State University Department of Environmental Earth Science, The University of Rhode Island Environmental Data Center, and The Alfred M. Roberts, Jr. Charitable Foundation.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: Fieldwork was assisted by Grant Simmons, Caitlin Chaffee, Braden Fleming, Melissa Cote, and Janice Sassi with the Napatree Point Conservation Area, The Watch Hill Conservancy; and Chuck LaBash, Beck LaBash and Christopher Damon with the Environmental Data Center, Department of Natural Resources Science, University of Rhode Island.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Thayer, G.W.; Kenworthy, W.J.; Fonseca, M.S. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile*; Fish and Wildlife Service, US Department of the Interior: Washington, DC, USA, 1984.
2. Leblanc, M.-L. *Eelgrass (Zostera marina) Ecosystems in Eastern Canada and Their Importance to Migratory Waterfowl*; McGill University (Canada): Montreal, QC, Canada, 2021.
3. Lilley, R.J.; Unsworth, R.K. Atlantic Cod (*Gadus morhua*) benefits from the availability of seagrass (*Zostera marina*) nursery habitat. *Glob. Ecol. Conserv.* **2014**, *2*, 367–377. [CrossRef]
4. Nelson, W.G.; Sullivan, G. Effects of microtopographic variation and macroalgal cover on morphometrics and survival of the annual form of eelgrass (*Zostera marina*). *Aquat. Bot.* **2018**, *145*, 37–44. [CrossRef]
5. Vincent, A.C.; Berglund, A.; Ahnesjö, I. Reproductive ecology of five pipefish species in one eelgrass meadow. *Environ. Biol. Fishes* **1995**, *44*, 347–361. [CrossRef]
6. Burdick, D.M.; Edwardson, K.J.; Gregory, T.; Matso, K.; Mattera, T.; Paly, M.; Peter, C.; Short, F.; Torio, D.D. *A Case for Restoration and Recovery of Zostera marina L. in the Great Bay Estuary*; PREP Reports & Publications: Durham, NH, USA, 2020.
7. Sandoval-Gil, J.; Alexandre, A.; Santos, R.; Camacho-Ibar, V.F. Nitrogen uptake and internal recycling in *Zostera marina* exposed to oyster farming: Eelgrass potential as a natural biofilter. *Estuaries Coasts* **2016**, *39*, 1694–1708. [CrossRef]
8. RIDEM. Coastal Pond Seine Survey. 2022. Available online: https://dem.ri.gov/programs/marine-fisheries/surveys-pubs/coastal-pond-seine.php (accessed on 10 December 2024).
9. Rodrigue, K.; McManus, C.M.; August, P.V.; Desbonnet, A.; Sassi, J. (Eds.) *The Juvenile Fish Assemblage of Little Narragansett Bay*; BRG Scientific: Washington, DC, USA, 2024; p. 352.
10. Dorf, B.A.; Powell, J.C. Distribution, abundance, and habitat characteristics of juvenile tautog (*Tautoga onitis*, Family Labridae) in Narragansett Bay, Rhode Island, 1988–1992. *Estuaries* **1997**, *20*, 589–600. [CrossRef]

11. Goldberg, R.; Phelan, B.; Pereira, J.; Hagan, S.; Clark, P.; Bejda, A.; Calabrese, A.; Studholme, A.; Able, K.W. Variability in habitat use by young-of-the-year winter flounder, *Pseudopleuronectes americanus*, in three northeastern US estuaries. *Estuaries* **2002**, *25*, 215–226. [CrossRef]
12. RICRMC. Rhode Island Coastal Resources Management Program: Rhode Island Coastal Resources Management Council. 1995. Available online: https://rules.sos.ri.gov/regulations/part/650-20-00-1 (accessed on 10 December 2024).
13. Duarte, C.M. The future of seagrass meadows. *Environ. Conserv.* **2002**, *29*, 192–206. [CrossRef]
14. Orth, R.J.; Carruthers, T.J.; Dennison, W.C.; Duarte, C.M.; Fourqurean, J.W.; Heck, K.L.; Hughes, A.R.; Kendrick, G.A.; Kenworthy, W.J.; Olyarnik, S. A global crisis for seagrass ecosystems. *Bioscience* **2006**, *56*, 987–996. [CrossRef]
15. Unsworth, R.K.; McKenzie, L.J.; Collier, C.J.; Cullen-Unsworth, L.C.; Duarte, C.M.; Eklöf, J.S.; Jarvis, J.C.; Jones, B.L.; Nordlund, L.M. Global challenges for seagrass conservation. *Ambio* **2019**, *48*, 801–815. [CrossRef] [PubMed]
16. Cotton, A. Disappearance of *Zostera marina*. *Nature* **1933**, *132*, 277.
17. Short, F.T.; Ibelings, B.; Den Hartog, C. Comparison of a current eelgrass disease to the wasting disease in the 1930s. *Aquat. Bot.* **1988**, *30*, 295–304. [CrossRef]
18. Fulweiler, R.W.; Nixon, S.W. Export of nitrogen, phosphorus, and suspended solids from a southern New England watershed to Little Narragansett Bay. *Biogeochemistry* **2005**, *76*, 567–593. [CrossRef]
19. Rollinson, V.R.; Granger, J.; Clark, S.C.; Blanusa, M.L.; Koerting, C.P.; Vaudrey, J.M.P.; Treibergs, L.A.; Westbrook, H.C.; Matassa, C.M.; Hastings, M.G.; et al. Seasonality of nitrogen sources, cycling, and loading in a New England river discerned from nitrate isotope ratios. *Biogeosciences* **2021**, *18*, 3421–3444. [CrossRef]
20. Short, F.T.; Neckles, H.A. The effects of global climate change on seagrasses. *Aquat. Bot.* **1999**, *63*, 169–196. [CrossRef]
21. Dunic, J.C.; Brown, C.J.; Connolly, R.M.; Turschwell, M.P.; Côté, I.M. Long-term declines and recovery of meadow area across the world's seagrass bioregions. *Glob. Change Biol.* **2021**, *27*, 4096–4109. [CrossRef]
22. Lefcheck, J.S.; Wilcox, D.J.; Murphy, R.R.; Marion, S.R.; Orth, R.J. Multiple stressors threaten the imperiled coastal foundation species eelgrass (*Zostera marina*) in Chesapeake Bay, USA. *Glob. Change Biol.* **2017**, *23*, 3474–3483. [CrossRef]
23. Bradley, M.; Boyd, J.; Goetsch, B.; Goulet, D.; Mitchel, J.; LaBash, B. 2021 Tier 1 Mapping of Submerged Aquatic Vegetation (SAV) in Rhode Island and Change Analysis. 2022. Available online: https://www.crmc.ri.gov/sav/Tier1_Mapping_SAV_2021.pdf (accessed on 10 December 2024).
24. Bradley, M.; Paton, S. *Tier 1 2017 Mapping of Zostera marina in Long Island Sound and Change Analysis*; Fish and Wildlife Service: Washington, DC, USA, 2018.
25. RIGIS. *Submerged Aquatic Vegetation (SAV) in Rhode Island Coastal Waters (2012)*; Univ. of Rhode Island Environmental Data Center, Ed.; Rhode Island Geographic Information System (RIGIS) Data Distribution System: Kingston, RI, USA, 2013.
26. RIGIS. *Submerged Aquatic Vegetation (SAV) in RI Coastal Waters (2016)*; Univ. of Rhode Island Environmental Data Center, Ed.; Rhode Island Geographic Information System (RIGIS) Data Distribution System: Kingston, RI, USA, 2017.
27. RIGIS. *Submerged Aquatic Vegetation (SAV) in RI Coastal Waters (2021)*; Univ. of Rhode Island Environmental Data Center, Ed.; Rhode Island Geographic Information System (RIGIS) Data Distribution System: Kingston, RI, USA, 2023.
28. Oakley, B.; Alvarez, J.; Boothroyd, J. Benthic Geologic Habitats of Shallow Estuarine Environments: Greenwich Bay and Wickford Harbor, Narragansett Bay, Rhode Island, USA. *J. Coast. Res.* **2012**, *28*, 760–773. [CrossRef]
29. Stolt, M.; Bradley, M.; Turenne, J.; Payne, M.; Scherer, E.; Cicchetti, G.; King, J.; Shumchenia, E.; Guarinello, M.; Boothroyd, J.C.; et al. Mapping Shallow Coastal Ecosystems. *J. Coast. Res.* **2011**, *27*, 1–15. [CrossRef]
30. USACE. 2018 USACE NCMP Topobathy Lidar: East Coast. 2020. Available online: https://www.fisheries.noaa.gov/inport/item/55882 (accessed on 10 December 2024).
31. RIGIS. *June 2021 Orthophotographs*; Rhode Island Coastal Resources Management Council, Univ. of Rhode Island Environmental Data Center United States Geological Survey, Eds.; Rhode Island Geographic Information System: Kingston, RI, USA, 2023.
32. USGS. USGS Current Conditions for Rhode Island: 411838071513000 Watch Hill Cove Tide Gage Westerly, RI. Available online: https://waterdata.usgs.gov/ri/nwis/uv/?site_no=411838071513000&PARAmeter_cd=00065,00060 (accessed on 10 December 2024).
33. Ehinger, R.; Folit, R.; Zeitlin-Hale, L. *The Pawcatuck River Estuary and Little Narragansett Bay*; Coastal Resources Center, University of Rhode Island Location: Narragansett, RI, USA, 1978. Available online: https://repository.library.noaa.gov/view/noaa/43253/noaa_43253_DS1.pdf (accessed on 10 December 2024).
34. Nichols, R.L.; Marston, A.F. Shoreline changes in Rhode Island produced by hurricane of September 21, 1938. *Bull. Geol. Soc. Am.* **1939**, *50*, 1357–1370. [CrossRef]
35. Cashel, F.S.; Knightes, C.D.; Lupo, C.; Iott, T.; Streich, K.; Conville, C.J.; Bridges, T.W.; Dombroski, I. Using monitoring and mechanistic modeling to improve understanding of eutrophication in a shallow New England estuary. *J. Environ. Manag.* **2024**, *355*, 120478. [CrossRef]
36. MARACOOS. Oceansmap. Available online: https://maracoos.org/oceansmap/ (accessed on 10 December 2024).
37. Neckles, H.A.; Kopp, B.S.; Peterson, B.J.; Pooler, P.S. Integrating Scales of Seagrass Monitoring to Meet Conservation Needs. *Estuaries Coasts* **2012**, *35*, 23–46. [CrossRef]

38. Fish, J.P.; Carr, H.A. *Sound Underwater Images: A Guide to the Generation and Interpretation of Side-Scan Sonar Data*; American Underwater Search and Survey, Ltd.: Cataumet, MA, USA, 1990.
39. August, P.V.; Bradley, M.; Oakley, B.A.; LaBash, C.; LaBash, B.; Damon, C.; Simmons, G.; Fleming, B.; Sassi, J. (Eds.) *Assessing Seagrass Field-Mapping Techniques in the Napatree/Sandy Point Eelgrass Meadow*; BRG Scientific: Washington, DC, USA, 2024; p. 352.
40. Carr, J.; Callaghan, T. An Inter-Method Comparison of Drones, Side-Scan Sonar, Airplanes, and Satellites Used for Eelgrass (*Zostera marina*) Mapping and Management. *Geosciences* **2024**, *14*, 345. [CrossRef]
41. Tiner, R.; McGuckin, K.; MacLachlan, A. *2012 Eelgrass Survey for Eastern Long Island Sound, Connecticut and New York*; National Wetlands Inventory Report; U.S. Fish and Wildlife Service, National Wetlands Inventory Program: Hadley, MA, USA, 2013.
42. Costello, C.T.; Kenworthy, W.J. Twelve-year mapping and change analysis of eelgrass (*Zostera marina*) areal abundance in Massachusetts (USA) identifies statewide declines. *Estuaries Coasts* **2011**, *34*, 232–242. [CrossRef]
43. Keser, M.; Swenarton, J.T.; Vozarik, J.M.; Foertch, J.F. Decline in eelgrass (*Zostera marina* L.) in Long Island Sound near Millstone Point, Connecticut (USA) unrelated to thermal input. *J. Sea Res.* **2003**, *49*, 11–26. [CrossRef]
44. Koch, E.; Beer, S. Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. *Aquat. Bot.* **1996**, *53*, 97–107. [CrossRef]
45. Bradley, M. *Tier 1 2024 Mapping of Submerged Aquatic Vegetation in Long Island Sound and the Peconic Estuary*; University of Rhode Island—Environmental Data Center: Kingston, RI, USA, 2025.
46. Masselink, G.; Brown, T.; Scott, T.; Brodie, L. Sediment sorting within a relatively wave-exposed and sandy subtidal seagrass (*Zostera marina*) meadow. *Mar. Geol.* **2024**, *476*, 107385. [CrossRef]
47. Stevens, A.W.; Lacy, J.R. The Influence of Wave Energy and Sediment Transport on Seagrass Distribution. *Estuaries Coasts* **2012**, *35*, 92–108. [CrossRef]
48. Douglass, J.G.; Douglass, J.G.; France, K.E.; France, K.E.; Richardson, J.P.; Duffy, J.E. Seasonal and interannual change in a Chesapeake Bay eelgrass community: Insights into biotic and abiotic control of community structure. *Limnol. Oceanogr.* **2010**, *55*, 1499–1520. [CrossRef]
49. Neckles, H.A. Loss of Eelgrass in Casco Bay, Maine, Linked to Green Crab Disturbance. *Northeast. Nat.* **2015**, *22*, 423, 478–500. [CrossRef]
50. Vaudrey, J.M.P.; Krumholz, J.; Calabretta, C. Eelgrass Success in Niantic River Estuary, CT, Quantifying Factors Influencing Interannual Variability of Eelgrass (Zostera marina) Using a 30-Year Dataset. 2019. Available online: https://vaudrey.lab.uconn.edu/wp-content/uploads/sites/1663/2019/10/Vaudrey_NRE_DataSynthesis_Final_v02Oct2019.pdf (accessed on 10 December 2024).
51. RIDEM. *Total Maximum Daily Load Analysis for the Pawcatuck River and Little Narragansett Bay Waters Bacteria Impairments*; Rhode Island Department of Environmental Managent Office of Water Resources: Providence, RI, USA, 2010.
52. Vaudrey, J.M. *Establishing Restoration Objectives for Eelgrass in Long Island Sound Part II: Case Studies*; University of Connecticut, Department of Marine Sciences: Groton, CT, USA, 2008.
53. Rasmussen, J.R.; Pedersen, M.F.; Olesen, B.; Nielsen, S.L.; Pedersen, T.M. Temporal and spatial dynamics of ephemeral drift-algae in eelgrass, *Zostera marina*, beds. *Estuar. Coast. Shelf Sci.* **2013**, *119*, 167–175. [CrossRef]
54. Biber, P.D. Transport and persistence of drifting macroalgae (Rhodophyta) are strongly influenced by flow velocity and substratum complexity in tropical seagrass habitats. *Mar. Ecol. Prog. Ser.* **2007**, *343*, 115–122. [CrossRef]
55. Blake, E.S.; Kimberlain, T.B.; Berg, R.J.; Cangialosi, J.P.; Beven II, J.L. *Tropical Cyclone Report Hurricane Sandy (AL182012) 22–29 October 2012*; National Hurricane Center: Miami, FL, USA, 2013.
56. NOS. Extreme Water Levels 8461490 New London, Thames River, CT. Available online: https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=8461490 (accessed on 10 December 2024).
57. NOS. Extreme Water Levels 8452660 Newport, RI. Available online: https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=8452660 (accessed on 10 December 2024).
58. NDBC. Station 44097—Block Island, RI: Historical Data & Climatic Summaries. Available online: https://www.ndbc.noaa.gov/station_page.php?station=44097 (accessed on 10 December 2024).
59. Mills, K.E.; Fonseca, M.S. Mortality and productivity of eelgrass *Zostera marina* under conditions of experimental burial with two sediment types. *Mar. Ecol. Prog. Ser.* **2003**, *255*, 127–134. [CrossRef]
60. Munkes, B.; Schubert, P.R.; Karez, R.; Reusch, T.B. Experimental assessment of critical anthropogenic sediment burial in eelgrass Zostera marina. *Mar. Pollut. Bull.* **2015**, *100*, 144–153. [CrossRef]
61. Cabaço, S.; Santos, R.; Duarte, C.M. The impact of sediment burial and erosion on seagrasses: A review. *Estuar. Coast. Shelf Sci.* **2008**, *79*, 354–366. [CrossRef]
62. Oprandi, A.; Mucerino, L.; De Leo, F.; Bianchi, C.; Morri, C.; Azzola, A.; Benelli, F.; Besio, G.; Ferrari, M.; Montefalcone, M. Effects of a severe storm on seagrass meadows. *Sci. Total Environ.* **2020**, *748*, 141373. [CrossRef]
63. Fonseca, M.S.; Zieman, J.C.; Thayer, G.W.; Fisher, J.S. The role of current velocity in structuring eelgrass (*Zostera marina* L.) meadows. *Estuar. Coast. Shelf Sci.* **1983**, *17*, 367–380. [CrossRef]

64. Wang, H.; Chen, Q.; Hu, K.; Snedden, G.; Hartig, E.K.; Couvillion, B.; Johnson, C.; Orton, P. *Numerical Modeling of the Effects of Hurricane Sandy and Potential Future Hurricanes on Spatial Patterns of Salt Marsh Morphology in Jamaica Bay, New York City*; US Geological Survey: Reston, VA, USA, 2017; p. 56.
65. NOAA. 2014 NOAA NGS Topobathy Lidar: Connecticut. 2014. Available online: https://www.fisheries.noaa.gov/inport/item/48169 (accessed on 10 December 2024).
66. USACE. 2010 USACE NCMP Topobathy Lidar: Northeast Atlantic Coast (CT, MA, ME, NH, RI). 2010. Available online: https://coast.noaa.gov/htdata/raster5/elevation/USACE_NE_Atl_DEM_2010_9447/stac/index.html (accessed on 10 December 2024).
67. RIGIS. *2024 March Rhode Island Digital Aerial Photographs*; Technologies, Rhode Island Department of Transportation and Rhode Island Geographic Information System; RIGIS: Kingston, RI, USA, 2025. Available online: https://www.rigis.org/apps/940f8aaf9f9d464c98aba4e7b926ddb5/explore (accessed on 10 December 2024).
68. RIGIS. *2024 2025 Winter Rhode Island Digital Aerial Photographs*; Technologies, Rhode Island Department of Transportation and Rhode Island Geographic Information System; RIGIS: Kingston, RI, USA, 2025. Available online: https://edc.maps.arcgis.com/home/item.html?id=7c707cf68e3b40628d9bbccc47801c96 (accessed on 10 December 2024).
69. NV5Geospatial. *New York Eelgrass Orthoimagery Project Report*; NV5 Geospatial, Inc.: Lexington, KY, USA, 2024.
70. Emanuel, K. Atlantic tropical cyclones downscaled from climate reanalyses show increasing activity over past 150 years. *Nat. Commun.* **2021**, *12*, 7027. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.