Appendix 9.8: Duck Creek Estuary North

Written by Erin Giese and Dr. James Horn

<table>
<tr><td>Location (centroid)</td><td>Lat. 44.570742°, Lon. -88.043562°[1] (NAD 1983, UTM Zone 16N)</td></tr>
<tr><td>Total Area (ha)</td><td>82.49 ha</td></tr>
<tr><td>Area Public Land (ha)</td><td>77.43 ha, land owned by the Wisconsin Department of Natural Resources</td></tr>
<tr><td>Area of Habitat Types Present (ha) and Percent of Each Habitat Type</td><td>Dominant Habitat Types: These habitat types were documented during a July 2015 habitat mapping effort led by the University of Wisconsin-Green Bay Cofrin Center for Biodiversity (CCB) across the Lower Green Bay and Fox River Area of Concern (LGB&FR AOC)[2]. Habitat types within Duck Creek Estuary North are displayed as a static map at the bottom of this document. Note that the extent of submergent marsh was refined by the CCB's 2017 submerged aquatic vegetation field surveys. There is a total of 82.21 ha of natural habitat in Duck Creek Estuary North.

<table>
<tr><th>Habitat Type</th><th>Area (ha)</th><th>Percent</th></tr>
<tr><td>Emergent Marsh (High Energy Coastal)</td><td>35.18</td><td>42.80</td></tr>
<tr><td>Hardwood Swamp</td><td>17.00</td><td>20.68</td></tr>
<tr><td>Shrub Carr</td><td>19.75</td><td>24.03</td></tr>
<tr><td>Submergent Marsh</td><td>10.25</td><td>12.47</td></tr>
<tr><td>Tributary Open Water</td><td>0.02</td><td>0.03</td></tr>
</table>

Disclaimer! Because this priority area is located within the Great Lakes coastal zone, the amount of habitat types can vary drastically across years and even within years (or months) due to changing Great Lakes water levels, precipitation, and seiche. Within this priority area specifically, the amounts of emergent and submergent marsh are known to fluctuate significantly from year to year and within years. The habitat types listed above and mapped below are based on a field effort conducted in July 2015. Plants recorded in the "Natural Habitat Communities and Significant Plants" section were primarily documented in July 2015 and late summer/fall 2016 and 2017. Great Lakes water levels were much higher in 2016 and 2017 than in July 2015.</td></tr>
<tr><td>General Description</td><td>Duck Creek Estuary North is located north of the mouth of Duck Creek alongside Interstate 41 and is a part of the Duck Creek Delta wetland complex. While the priority area has been significantly modified over the years from development, road construction, and agricultural/storm water runoff, it still features a natural hydrologic gradient that grades from submergent/emergent marsh into southern sedge meadow, shrub carr, and hardwood swamp. While Duck Creek flows northeast from roughly 22 km (13.8 mi) inland and empties into the bay of Green Bay, it has been known to reverse course and flow upstream (i.e., southwest) as far as 6.4 km (4 mi) during high water levels and seiche in the bay[1][2]. It primarily consists of Tedrow loamy fine sand soils and Keowns silt loam[3].

Historically, however, this priority area was a part of a huge wetland complex of submergent and emergent marsh of >200 ha that was protected by a group of barrier islands called the Cat Island Chain, as seen on 1938 aerial imagery from the Brown County Online GIS Portal. This wetland complex provided critical wildlife habitat for fish, birds, invertebrates, and furbearers and offered a protected refugium for native plants, including wild rice (Zizania palustris) and wild celery (Vallisneria americana).</td></tr>
</table>

[1] File "AOC_PriorityAreas.v09_20171212.shp"
[2] LGB&FR AOC 2015 habitat field mapping effort
[3] Soil Survey Geographic (SSURGO) by the United States Department of Agriculture's Natural Resources Conservation Service. Published Dec 2010. Available: http://uwgb.maps.arcgis.com/home/item.html?id=204d94c9b1374de9a21574c9efa31164; accessed 15 Dec 2017.

	Unfortunately, due to extremely high water levels in the bay, massive storms, and hardened shorelines, these islands largely washed away during the spring of 1973[4,5]. The huge Duck Creek Delta wetland complex vanished because the islands no longer provided the much needed wave/storm protection[4,5]. In May of 2013, these barrier islands were reconstructed along a causeway with artificial islands called "cells" (project called the Cat Island Wave Barrier), where shipping canal dredge material will be placed over the next 20-30 years. This project was originally initiated by a local group of dedicated conservationists in the 1980s, and the hope is that this once extensive submergent and emergent marsh will reform in the coming years given the right conditions and lake levels. Including the Duck Creek Estuary North priority area, the Duck Creek Delta is a heavily studied area in the lower bay. Researchers and managers from the Wisconsin Department of Natural Resources (WDNR), U.S. Fish and Wildlife Service (FWS), UW-Green Bay, and Oneida Tribe have conducted studies on plants, fish, birds, anurans (frogs + toads), spiders, and water quality as well as multiple restoration efforts, including the attempt to re-establish wild rice. Because of the added protection of the Cat Island Wave Barrier and pockets of relatively good quality habitat, the Duck Creek Estuary North priority area has great potential to be improved and restored and should be considered a high priority restoration site.
Special Features	• Offers a landscape of submergent and emergent marsh that grades into southern sedge meadow, shrub carr, and hardwood swamp; this landscape describes the historical mosaic originally found in lower Green Bay[2,6,7]. • Features a small patch of southern sedge meadow, which is a rare habitat in the LGB&FR AOC and across the state, that is largely dominated by broad-leaved woolly sedge (*Carex pellita*) and common tussock sedge (*Carex stricta*). • Forster's Terns nest on artificial nesting structures in the Duck Creek Delta[8]. • Important habitat for muskrats in the emergent marsh. • Northern border of the mouth of Duck Creek, which forms a bird's-foot delta.
Natural Habitat Communities and Significant Plants (ordered in terms of ecological importance and size/amount)	Despite many anthropogenic modifications, the Duck Creek Estuary North priority still maintains a natural coastal gradient from submergent marsh to emergent marsh, southern sedge meadow, shrub carr, and finally to hardwood swamp. Nearly half of this priority area consists of **emergent marsh**, which is largely dominated by common reed (*Phragmites australis*; hereafter referred to as "*Phragmites*") and hybrid cattail (*Typha* × *glauca*)[2,7,9]. Native plant species are present in this emergent marsh, but mostly confined to its periphery, and constitute c. 2% of the total extent of vegetation coverage. Broad-leaved arrowhead (*Sagittaria latifolia*), arum-leaved arrowhead (*Sagittaria cuneata*), and northern water-plantain (*Alisma triviale*) were aspect dominants in this marginal band of mostly native species during the 2016 surveys of LGB&FR AOC biodiversity hotspots. The **shrub carr** is dominated by meadow willow (*Salix petiolaris*), sandbar willow (*Salix interior*), red-osier dogwood (*Cornus sericea*), and eastern meadowsweet (*Spiraea alba*) with an herbaceous layer of sedges (*Carex* spp.), marsh bluegrass (*Poa palustris*), and goldenrod (*Solidago* spp.)[2,7,9]. Along the northern edge of this priority area, the **hardwood swamp** has a canopy of green ash (*Fraxinus pennsylvanica*), cottonwood (*Populus deltoides*), trembling aspen

[4] Brown County Port and Resource Recovery Cat Island document: https://static1.squarespace.com/static/56ec0372859fd0e272858772/t/574db48fab48de7bc23597a0/1464710289702/2014+Cat+Island+Abstract+Spring.pdf
[5] Frieswyk and Zedler 2007
[6] Bertrand et al. 1976: The Green Bay Watershed Past/Present/Future
[7] LGB&FR AOC plant biodiversity hotspots field effort
[8] LGB&FR AOC Stakeholder Meeting on 23 June 2015 per Gary Van Vreede
[9] LGB&FR AOC submerged aquatic vegetation mapping led by Dr. Amy Wolf and Dr. James Horn

	(*Populus tremuloides*), paper birch (*Betula papyrifera*), and box elder (*Acer negundo*) and an understory of gray dogwood (*Cornus foemina*), cherry (*Prunus* sp.), nannyberry (*Viburnum lentago*), sensitive fern (*Onoclea sensibilis*), goldenrod, and sedges (*Carex* spp.). Parts of the forest's understory are heavily dominated by glossy buckthorn (*Frangula alnus*) [2,7,9]. Along the eastern edge is a narrow band of **submergent marsh** that consists of a few natives[2,7,9]: • Coontail (*Ceratophyllum demersum*), common • Forked duckweed (*Lemna trisulca*), moderately common • Slender riccia (*Riccia fluitans*, a thallose liverwort), moderately common • Sago pondweed (*Stuckenia pectinata*), moderately common • Common bladderwort (*Utricularia vulgaris*), moderately common • Wild celery (*Vallisneria americana*), moderately common Patches of submergent marsh dominated by fragrant water-lily (*Nymphaea odorata*) are conspicuous along the north bank of the north Duck Creek inlet, at the southern edge of this priority area. Eurasian water-milfoil (*Myriophyllum spicatum*) is also mixed in with natives and is moderately common in the submergent marsh along the shore of Peats Lake[2,7,9]. There is also a small patch of disturbed **southern sedge meadow** that is largely dominated by native plants including broad-leaved woolly sedge (*Carex pellita*) and common tussock sedge (*Carex stricta*). This parcel is one of the most species-rich areas in the LGB&FR AOC for vascular plants with almost 60 native species documented in the 2016 plant surveys. Reed canary grass (*Phalaris arundinacea*) also occurs here, though it is not a dominant. Dominant and significant natives include[2,7,9]: • Bebb's sedge (*Carex bebbii*), moderately common • Giant goldenrod (*Solidago gigantea*), moderately common • Marsh bluegrass (*Poa palustris*), moderately common • Common goldenrod (*Solidago canadensis*), moderately common • Water-parsnip (*Sium suave*), rare • Eastern meadowsweet (*Spiraea alba*), rare • Common lake sedge (*Carex lacustris*), rare • Fox sedge (*Carex vulpinoidea*), rare • Loesel's twayblade orchid (*Liparis loeselii*), rare • Common false foxglove (*Agalinis tenuifolia*), rare • Tufted loosestrife (*Lysimachia thyrsiflora*), rare • Marsh fern (*Thelypteris palustris*), rare However, this sedge meadow was not digitized or mapped during the 2015 LGB&FR AOC field effort because it is small and forms a mosaic with adjacent shrub carr, which is why it is not delineated in the habitat map below. Its general location is identified with a star symbol.

Significant Animals	**Birds**:
	• Over 200 bird species have been recorded along parts of the west shore, including[10]
	  ○ Four state endangered species (Caspian Tern [*Hydroprogne caspia*], Common Tern [*Sterna hirundo*], Forster's Tern [*Sterna forsteri*], and Peregrine Falcon [*Falco peregrinus*])
	  ○ Four state threatened species (Great Egret [*Ardea alba*], Acadian Flycatcher [*Empidonax virescens*], Yellow-crowned Night-Heron (*Nyctanassa violacea*), and Cerulean Warbler [*Setophaga cerulea*])

[10] LGB&FR AOC Biota Database: file "AOCBiota_DB_ShareableVersion_20171213.accdb"

	○ Forty-one Wisconsin Wildlife Action Plan Species of Greatest Concern (e.g., Brown Thrasher [*Toxostoma rufum*], Canada Warbler [*Cardellina canadensis*]) ○ Forty-two state special concern species (e.g., Yellow-billed Cuckoo [*Coccyzus americanus*], Bald Eagle [*Haliaeetus leucocephalus*], Black-throated Blue Warbler [*Setophaga caerulescens*], Purple Martin [*Progne subis*]) ○ Seven International Union for Conservation of Nature-listed species as vulnerable (e.g., Rusty Blackbird [*Euphagus carolinus*]) or near threatened (e.g., Golden-winged Warbler [*Vermivora chrysoptera*], Red-headed Woodpecker [*Melanerpes erythrocephalus*]) ○ Migratory waterfowl and gulls, including scaup, use the waters off the shores of Duck Creek Estuary North • Despite the emergent marsh's lack of native plant diversity, it provides critical nesting habitat for many marsh- (and sometimes secretive) breeding birds, although the presence of some of these species depends on lake levels[11]: ○ Forster's Tern ○ American Coot (*Fulica americana*) ○ Pied-billed Grebe (*Podilymbus podiceps*) ○ Sora (*Porzana carolina*) ○ Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*) ○ Red-winged Blackbird (*Agelaius phoeniceus*) • Cliff Swallows (*Petrochelidon pyrrhonota*) and Barn Swallows (*Hirundo rustica*) nest under the Interstate 41 bridge on the western edge of this priority area's border[11]. **Fish**: • Although >80 fish species have been recorded in the pelagic zone of the lower bay, only some of which may use areas near the Duck Creek Delta including[10]: ○ One federally endangered species: chinook salmon (*Oncorhynchus tshawytscha*) ○ Three state special concern species, including: American eel (*Anguilla rostrata*), banded killifish (*Fundulus diaphanus*), and lake sturgeon (*Acipenser fulvescens*) ○ One International Union for Conservation of Nature-listed species as vulnerable (bloater [*Coregonus hoyi*]) and one as endangered (American eel) ○ Two globally list species (G3 = vulnerable): redside dace (*Clinostomus elongatus*) and lake sturgeon (*Acipenser fulvescens*) ○ Northern pike (*Esox lucius*) **Mammals**: • Although ~50 mammal species are known to or are expected to occur along the west shore (as noted in Roznik 1979)[12], only a few likely use the emergent and submergent marshes of the Duck Creek Delta, including muskrat (*Ondatra zibethicus*), North American river otter (*Lontra canadensis*), and American mink (*Neovison vison*)[13,14]. ○ In fact, when looking at Google Earth's 2017 aerial imagery, dozens of muskrat lodges are visible along the eastern edge of this priority area in the emergent marsh.

[11] WI Breeding Bird Atlas II Project – data available here: http://ebird.org/ebird/atlaswi/explore
[12] Green Bay West Shores Master Plan Concept Element 1979 by Roznik et al.
[13] Wisconsin Department of Natural Resources Technical Report PUB-LF-073.
[14] Wisconsin Department of Natural Resources 2015 muskrat house survey

	Anurans:
	• Spring peeper (*Pseudacris crucifer*) and American toad (*Bufo americanus*) have been recorded calling within the emergent marsh based on 2012 and 2017 surveys[15]. Other anurans may use this marsh, too, such as eastern gray treefrog (*Hyla versicolor*).
	
	Mollusks:
	• Within the pelagic zone of the lower bay, the following has been recorded:
	  ○ Freshwater clams: fingernail claim (*Sphaerium* sp.), pea clam (*Pisidium* sp.)
	  ○ Three snails: mud bithynia (*Bithynia tentaculata*), river snail species (*Campeloma* sp.), and valve species (*Valvata* sp.)
	
	Arthropods:
	• Several species have been recorded in the pelagic zone of the lower bay in the 1990s, including:
	  ○ Long-horn caddisfly (*Oecetis* sp.)[10]
	  ○ Buzzer midge (*Chironomus plumosus*)[10]
	  ○ Green midge (*Tanytarsus* sp.)[10]
	  ○ Riffle beetle species (*Ordobrevia* sp.) from 2007[10]
	  ○ Non-biting midges (*Polypedilum* sp., *Paratanytarsus* sp., *Parachironomus* sp., and *Parakiefferiella* sp.) from 1995[16]
	• Several different spider species, including[17]:
	  ○ *Clubiona pallidula*
	  ○ *Larinioides cornutus*
	  ○ *Leiobunum flavum*
	  ○ *Pachygnatha dorothea*
	
	Annelids:
	• Aquatic oligochaete worms have been recorded in the pelagic zone of the lower bay in the early 1990s, including[10]:
	  ○ *Aulodrilus americanus*
	  ○ *Dero digitata*
	  ○ *Nais pardalis*
	  ○ *Nais communis*

Habitat Quality	Overall, the ecological quality of Duck Creek Estuary North's habitats is mediocre though parts of this priority area are in fairly good condition. For example, there is a nice mix of native plants in the submergent marsh and southern sedge meadow, in which invasive plants are not the dominants. There is great potential for this priority area to be improved and restored, particularly the sedge meadow which could be expanded.

Significant Invasive Species Issues	**Invasive Plant Species**: Each of these species outcompetes and crowds out native plants[2,7,9]:
	• Eurasian water-milfoil (*Myriophyllum spicatum*)
	  ○ Found within the submergent marsh mixed in with native submergents
	• Common reed (*Phragmites australis*)
	  ○ *Phragmites* is found closest to the road mixed in with hybrid cattail. Some management has occurred in recent years in open areas (2011-2012)
	• Hybrid cattail (*Typha* × *glauca*)
	  ○ It is mixed in with *Phragmites* along the road but dominates >90% of the emergent marsh
	• Glossy buckthorn (*Frangula alnus*)

[15] Great Lakes Coastal Wetland Monitoring Program anuran surveys, 2012 and 2017; per Erin Giese
[16] Schneider & Sager 2007: "Structure & ordination of epiphytic invertebrate communities of four coastal wetlands in Green Bay, Lake Michigan"
[17] Draney and Jaskula 2004: Araneae and Opiliones from *Typha* spp. and *Phragmites australis* stands of Green Bay

	○ Commonly found throughout most of the hardwood swamp • Reed canary grass (*Phalaris arundinacea*) ○ Found in the small patch of southern sedge meadow, though it is not a dominant • Honeysuckle (*Lonicera* × *bella*) ○ Rare in hardwood swamp understory • Bittersweet nightshade (*Solanum dulcamara*) ○ Rare in hardwood swamp understory • European fireweed (*Epilobium hirsutum*) ○ Rare in sedge meadow **Invasive Animal Species**: • *Birds*[10] ○ European Starling (*Sturnus vulgaris*) ▪ Poses some threat to native species, particularly cavity nesters (e.g., Tree Swallow), by outcompeting them and occupying potential nest sites; not currently being managed. ○ It is possible that House Sparrows (*Passer domesticus*) occur along the road/interstate, potentially outcompeting Cliff and Barn Swallows for nests since House Sparrows are known to use old swallow nests; not currently being managed. • *Fish*[10] ○ Alewife (*Alosa pseudoharengus*)[18] ▪ Poses a threat to native fish species by consuming zooplankton and disturbing the natural food web; not currently being managed ○ Common carp (*Cyprinus carpio*)[19] ▪ Destroy vegetation by uprooting plants and increasing cloudiness of water; not currently being managed ○ Rainbow smelt (*Osmerus mordax*)[20] ▪ Negatively affect uncommon to rare native fish species; not currently being managed ○ Round goby (*Neogobius melanostomus*)[21] ▪ Prey on small native fish and eggs (e.g., darters) and outcompete similarly sized native fish; not currently being managed ○ White perch (*Morone americana*)[22] ▪ Prey on native fish eggs, such as walleye; not currently being managed • *Freshwater mussels*[10] ○ Zebra mussel (*Dreissena polymorpha*)[23]

[18] Fuller, P., E. Maynard, D. Raikow, J. Larson, A. Fusaro, and M. Neilson. 2016. *Alosa pseudoharengus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=490 Revision Date: 9/25/2015. Accessed 17 Oct 2016.
[19] Nico, L., E. Maynard, P.J. Schofield, M. Cannister, J. Larson, A. Fusaro, and M. Neilson. 2016. *Cyprinus carpio*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=4 Revision Date: 7/15/2015. Accessed 17 Oct 2016.
[20] Fuller, P., E. Maynard, J. Larson, A. Fusaro, T.H. Makled, and M. Neilson. 2016. *Osmerus mordax*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=796 Revision Date: 9/29/2015. Accessed on 17 Oct 2016.
[21] Fuller, P., A. Benson, E. Maynard, M. Neilson, J. Larson, and A. Fusaro. 2016. *Neogobius melanostomus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=713 Revision Date: 1/7/2016. Accessed on 17 Oct 2016.
[22] Fuller, P., E. Maynard, D. Raikow, J. Larson, A. Fusaro, and M. Neilson. 2016. *Morone americana*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=777 Revision Date: 1/15/2016. Accessed on 17 Oct 2016.
[23] Wisconsin Department of Natural Resources Technical Report PUBL ER-818 2010: file "WDNR2010_RapidEcologicalAssmtForGBWestShores WildlifeArea.pdf"

	▪ Poses threat to native freshwater mussels; not currently being managed • *Annelids*[10] ○ A tubificid worm (*Potamothrix moldaviensis*)
Management and Restoration Recommendations	• Control the spread of the *Phragmites* and invasive cattail and maintain extensive, high quality native plants in the emergent marsh (high energy coastal). • Expand existing southern sedge meadow remnants, control invasive plants, restore hydrology if needed, and promote the spread of native plants. • Control introduced plant species (e.g., Eurasian watermilfoil) and maintain extensive and high quality submerged aquatic vegetation (SAV) with native plants at Duck Creek. • Control woody invasive plants (e.g., glossy buckthorn) in the hardwood swamp. • Continue investigating the re-establishment of wild rice and wild celery near the mouth of Duck Creek. • Place woody debris for fish habitat. • Continue providing artificial nest structures for Forster's Terns. • Construct nest structures for nesting Black Terns. • Promote best management practices and innovative nutrient management measures in the Fox River watershed.
Reference Links and Documents	**Web Links**: • Dam removal on Duck Creek with Oneida Tribe, Wisconsin Department of Natural Resources, Brown County, U.S. Fish and Wildlife Service, and Oneida Golf and Country Club: https://greatlakesinform.org/projects-and-progress/498 • Wild rice seeding in the lower bay of Green Bay, led by Dr. Amy Carrozzino-Lyon: http://www.ducks.org/conservation/glar/wisconsin/green-bay-partnership-to-improve-wildlife-habit-water-quality • History of the Village of Howard as it pertains to the Duck Creek area: http://www.villageofhoward.com/245/History • Nonpoint Source Control Plan for the Duck, Apple, and Ashwaubenon Creeks Priority Watershed Project: http://dnr.wi.gov/topic/nonpoint/documents/9kep/Duck_Apple_Ashwaubenon_Creeks-Plan.pdf **Reference Documents**: • Bosley, T.R. 1978. Loss of wetlands on the west shore of Green Bay. Wisconsin Academy of Sciences, Arts, and Letters 66:235-245. • Chow-Fraser P. 2006. Development of the wetland Water Quality Index for assessing the quality of Great Lakes coastal wetlands. In: Simon TP, Stewart PM (eds) Coastal wetlands of the Laurentian Great Lakes: health, habitat and indicators. Indiana Biological Survey, Bloomington, IN, pp 137-166. • Dorney, J.R. 1975 The vegetation pattern around Green Bay in the 1840s as related to geology, soils, and land use by Indians with a detailed look at the Townships of Scott, Green Bay, and Suamico. Book available through the UW-Green Bay Cofrin Library Archives and Area Research Center. • Frieswyk, C.B., C.A. Johnston, and J.B. Zedler. 2007. Identifying and characterizing dominant plants as an indicator of community condition. Journal of Great Lakes Research. 33(3):125-135. ○ Available: http://glei.nrri.umn.edu/default/documents/frieswyk_jglr_2007.pdf • Harris, V.A. 1998. Waterfowl use of lower Green Bay before (1977-78) and after (1994-97) zebra mussel invasion. Master's thesis from the University of Wisconsin-Green Bay. • Mossman, M.J. 1989. Wisconsin Forster's Tern Recovery Plan. Passenger Pigeon 51(2):171-186.

	http://images.library.wisc.edu/EcoNatRes/EFacs/PassPigeon/ppv51no02/reference/econatres.pp51n02.mmossman.pdf • Wisconsin Department of Natural Resources. 2013. Regional and property analysis: Green Bay Planning Group. Technical Report PUB-LF-073. • Wisconsin Department of Natural Resources. 2014. Green Bay Planning Group Master Plan. Technical Report PUB-LF-075.
Site History (e.g., original vegetation, past conservation projects)	In the early 1630s, Frenchman Jean Nicolet first arrived in lower Green Bay when it was primarily inhabited by Native American tribes[24]. Lower Green Bay consisted of large beds of wild rice (*Zizania* sp.) and wild celery (*Vallisneria americana*), extensive emergent marsh (*Schoenoplectus* spp., cattail [*Typha* sp.]), sedge meadows (*Calamagrostis canadensis*), shrub carr (e.g., *Cornus* spp., *Salix* spp.), swamps, and wet conifer forest (black spruce [*Picea mariana*], balsam fir [*Abies balsamea*])[25,26,27,28,29]. Between the late 1600s and 1800s, European fur trade, duck hunting, fishing, logging, shipping, and agriculture were important early industries in lower Green Bay[30,31,32]. In the early 1800s, there were a few small settlements and farms of Europeans and Native Americans in the lower Bay[31]. In fact, there were a few Native American campsites near the mouth of Duck Creek with villages further upstream[33]. Historical vegetation of the Duck Creek Delta was described as consisting of a grassy marsh and meadow with swamp forest of tamarack and black ash[33,34]. This site was an important migratory stopover site for waterfowl, especially for Tundra Swans[35]. Early European settlers founded the Town of Howard in 1835 and settled along Duck Creek. Residents worked in the timber, farming, quarry, and mail carrier businesses[36]. According to Roznik (1979), even in the 1930s, huge numbers of migratory waterfowl using this area rivaled historic levels. In the late 1960s and early 1970s, vegetation associated with Atkinson's Marsh, which is a part of the Duck Creek Delta complex, consisted of bulrush (*Scirpus* spp.), spike-rush (*Eleocharis* spp.), cattail, sedges (*Carex* spp.), grasses (*Calamagrostis* spp.), and organic mats of vegetation[37]. Panfish, carp, bullhead, yellow perch, and northern pike were found in large numbers in Duck Creek in the 1970s, especially yellow perch[12,35]. In fact, there used to be a carp fishing crew based out of the Duck Creek area[37].

[24] Jean Nicolet: French Explorer. By The Editors of Encyclopaedia Britannica. Available: https://www.britannica.com/biography/Jean-Nicolet (accessed on 24 Oct 2016).
[25] Arthur C. Neville's Map of Historic Sites on Green Bay, Wisconsin 1669-1689. Available: http://s3.amazonaws.com/labaye/data/Bay%20Settle ment%20Map%20WI%20Historical%20Bulletin%201926.pdf (accessed on 24 Oct 2016).
[26] Survey of the N.W. Lakes: East Shore of Green Bay 1843. Available: http://s3.amazonaws.com/labaye/data/1843%20East%20Shore%20of %20Green%20Bay.jpg (accessed on 24 Oct 2016).
[27] 1845 Chart of Green Bay. Available http://s3.amazonaws.com/labaye/data/1845%20Chart%20of%20Green%20Bay.pdf (accessed on 24 Oct 2016).
[28] 1820s Fox River Military Road Map to Ft. Crawford. Available: http://s3.amazonaws.com/labaye/data/1820s%20Fox%20River%20Military%20 Road%20Map%20to%20Ft.%20Crawford.pdf (accessed on 24 Oct 2016).
[29] UW-Green Bay personal communication with Thomas Erdman.
[30] City of Green Bay's History Webpage: http://www.ci.green-bay.wi.us/history/1800s.html (accessed on 20 Oct 2016).
[31] Excerpt from "Recollections of Green Bay in 1816-17" by James W. Biddle. Available: http://s3.amazonaws.com/labaye/data/Recollections %20of%20Green%20Bay%20in%201816-1817.pdf (accessed on 24 Oct 2016).
[32] The Early Outposts of Wisconsin: Green Bay for Two-Hundred Years, 1639-1839. Available: http://labaye.org/item/70/2810 (accessed on 25 Oct 2016).
[33] The vegetation pattern around Green Bay in the 1840s as related to geology, soils, and land use by Indians with a detailed look at the Townships of Scott, Green Bay, and Suamico by John Dorney, 1975
[34] Wisconsin Public Land Survey System (1834) from file "PLSS_SurveyData.shp"
[35] Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Volume 5: Lake Michigan, Part 3, October 1981
[36] History of the Village of Howard: http://www.villageofhoward.com/245/History (accessed on 16 Dec 2017)
[37] Howlett, Jr. 1974: The rooted vegetation of west Green Bay with reference to environmental change

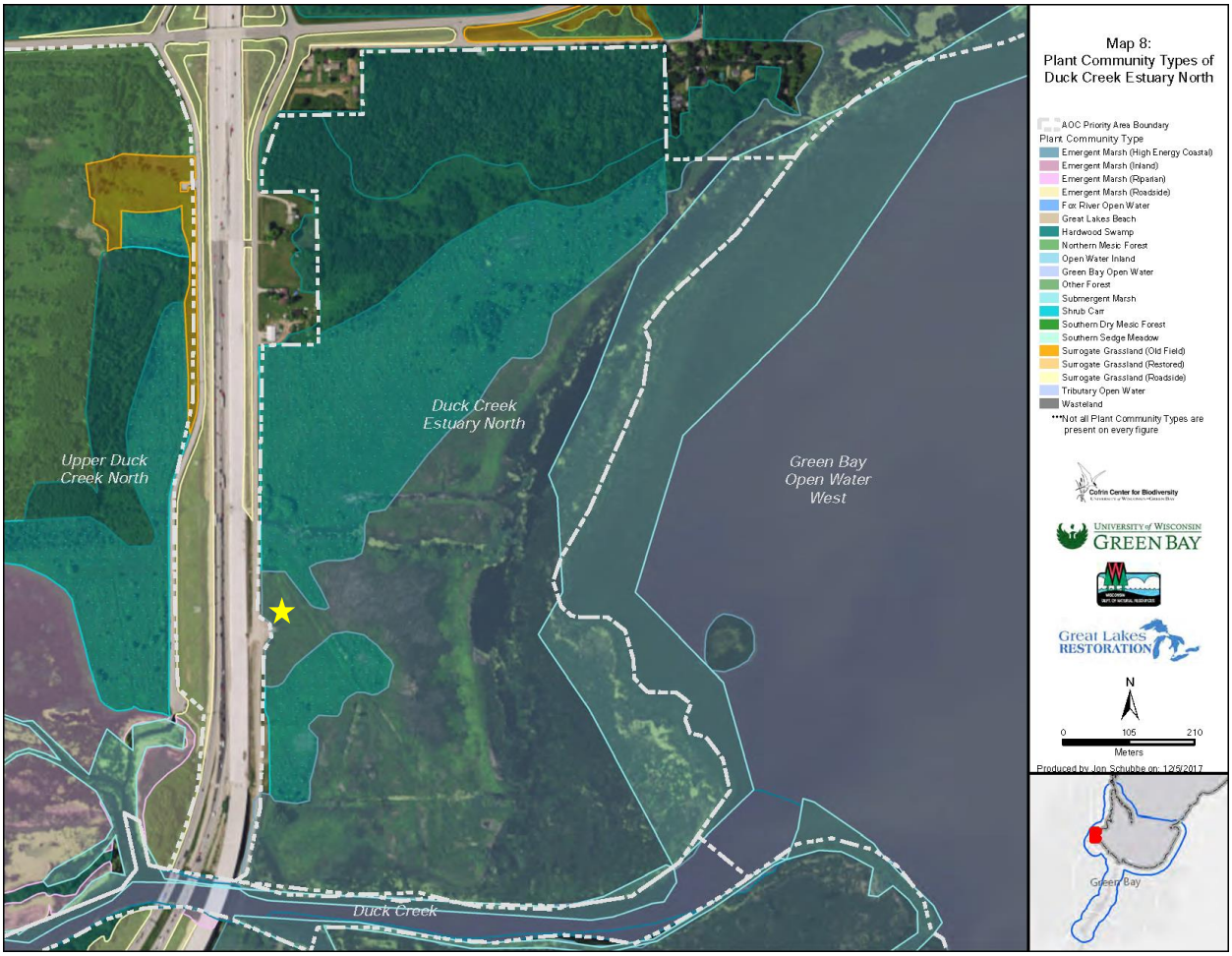
	This priority area was also a part of a huge wetland complex of submergent and emergent marsh of >200 ha that was protected by a group of barrier islands called the Cat Island Chain, as seen on 1938 aerial imagery from the Brown County Online GIS Portal. Unfortunately, between 1834 and 1975, 3.64 km^2 (2.26 mi^2) out of 4.07 km^2 (2.53 mi^2) of marsh were lost between the Fox River and Duck Creek due to the construction of Highways 41 and 141, a landfill, and dredge spoil deposition[38]. Between Duck Creek and the Little Suamico River, 1.92 km^2 (1.19 mi^2) out of 2.56 km^2 (1.59 mi^2) of wetland were also lost[38]. The destruction of these wetlands by the 1970s roughly coincided with extremely high water levels in the bay and massive storms in the spring of 1973[39,40]. The Cat Island Chain of islands washed away, which ultimately caused the once extensive Duck Creek Delta wetland complex to vanish because the islands no longer provided the much needed wave/storm protection[4,5], though a small part of the original Duck Creek Delta wetland complex still exists today. In the 1980s, a group of local conservationists proposed the idea of reconstructing these three barrier islands and formalized the idea in the LGB&FR AOC's 1988 Remedial Action Plan[41]. It took decades for that idea to materialize and became a reality, but it finally happened[41]. By May of 2013, these barrier islands were reconstructed along a causeway with artificial islands called "cells" (project site called the Cat Island Wave Barrier), where shipping canal dredge material will be placed over the next 20-30 years. The hope is that the once extensive Duck Creek Delta submergent and emergent marsh will reform in the coming years given the right conditions and lake levels. Because of the added protection of the Cat Island Wave Barrier and pockets of relatively good quality habitat, the Duck Creek Estuary North priority area has great potential to be improved and restored and should be considered a high priority restoration site. Including the Duck Creek Estuary North priority area, the Duck Creek Delta has recently been a heavily studied area in the lower bay: • In 2002, Dr. Michael Draney and UW-Green Bay student, Jeanette Jaskula, conducted a spider/harvestman study in Duck Creek and other neighboring marshes in 2002 with sample sites in cattail and *Phragmites* marshes[17]. • The U.S. Fish and Wildlife Service (FWS) coordinate an early detection and monitoring program of aquatic invasive species in Lake Michigan, and many of their sampling locations are in the LGB&FR AOC, including along the southern border of the Duck Creek Estuary North priority area[42]. They survey for ichthyoplankton, carp, macroinvertebrates, and nearshore fishes[42]. • In 2011-2012, the WDNR applied herbicide primarily targeting *Phragmites* throughout the emergent high energy marsh[43]. • The Oneida Tribe recently led a dam removal project in collaboration with the WDNR, Brown County, FWS, and the Oneida Golf and Country Club[44]. By the fall of 2012, they had removed two dams and modified another one in order to improve fish passage for northern pike and other fish[44]. • A group of high school students and teachers have conducted water quality monitoring (e.g., stream flow, pH, dissolved oxygen) for many years upstream in Duck Creek for the Lower Fox River Watershed Monitoring Program[45].

[38] Bosley 1978: Loss of wetlands on the west shore of Green Bay
[39] Brown County Port and Resource Recovery Cat Island document: https://static1.squarespace.com/static/56ec0372859fd0e272858772/t/574db48fab48de7bc23597a0/1464710289702/2014+Cat+Island+Abstract+Spring.pdf
[40] Frieswyk and Zedler 2007: "Identifying and characterizing dominant plants as an indicator of community condition"
[41] Brown County Port and Resource Recovery Cat Island document: https://static1.squarespace.com/static/56ec0372859fd0e272858772/t/574db48fab48de7bc23597a0/1464710289702/2014+Cat+Island+Abstract+Spring.pdf
[42] Green Bay Fish Working Group Annual Meetings on 4 January 2017
[43] WDNR Phragmites treatment shapefile: "Aerial.shp"
[44] Dam removal project led by the Oneida Tribe: https://greatlakesinform.org/projects-and-progress/498
[45] Lower Fox River Watershed Monitoring Program: https://www.uwgb.edu/watershed/monitoring/overview.asp

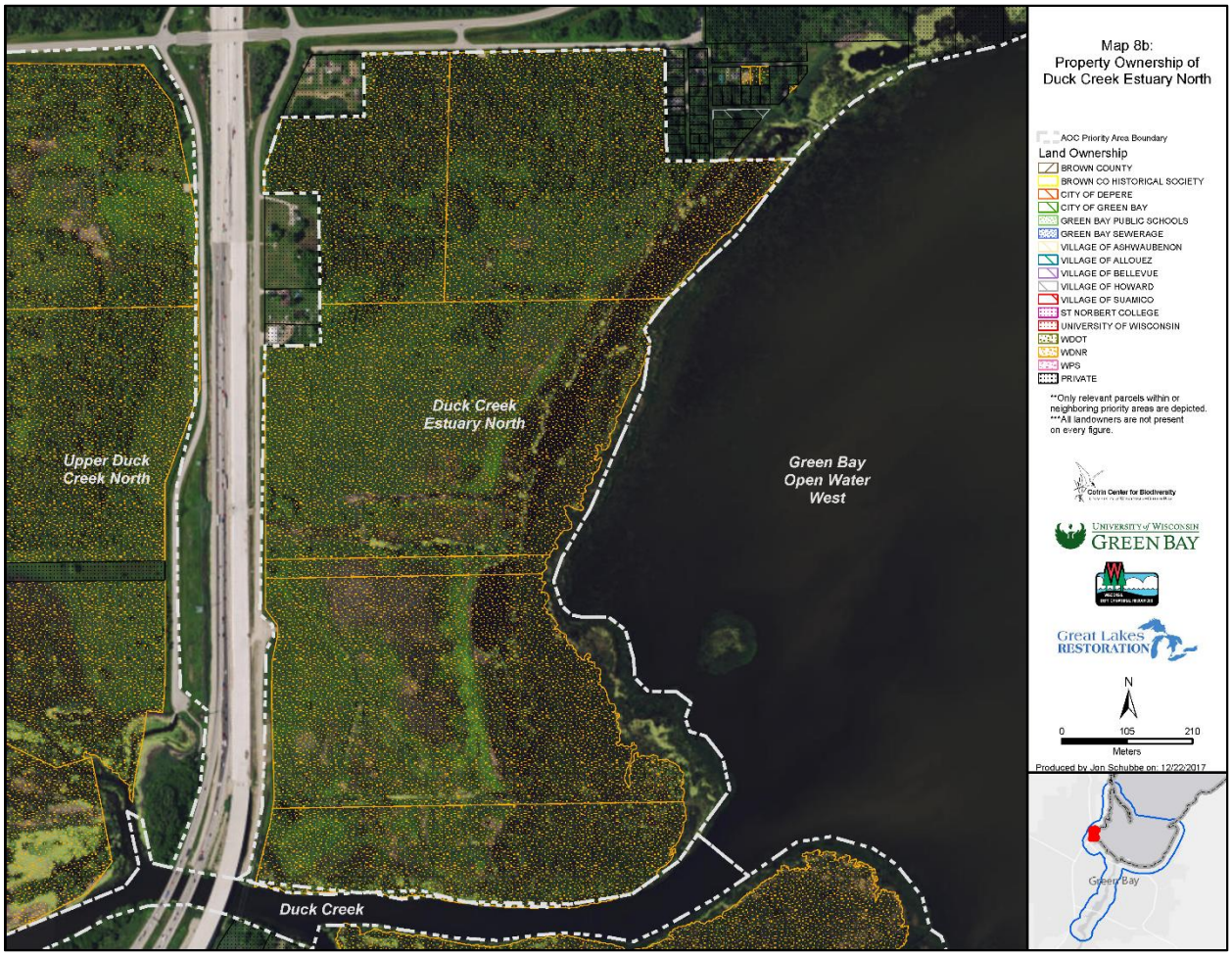
	• Over the past several years, UW-Green Bay's Dr. Patrick Robinson, Dr. Christopher Houghton, and others have been leading a project attempting to restore aquatic submergent vegetation on the Duck Creek Delta behind the Cat Island Wave Barrier. They have conducted extensive plant surveys and measured water depth for multiple years. In 2016, they also seeded wild rice along the southeastern edge of this priority area as well as on the south side of the mouth of Duck Creek[46]. • In 2012 and 2017, UW-Green Bay field crews conducted surveys on anurans and birds for the Great Lakes Coastal Wetland Monitoring Program under the leadership of Dr. Robert Howe and Erin Giese[47]. • In 2016-2017, under the guidance of Dr. Howe, Dr. Amy Wolf, and Erin Giese, Tom Prestby surveyed migratory waterfowl within the LGB&FR AOC, including a sampling location on the Cat Island Wave Barrier where he could see the mouth of Duck Creek[48]. • In 2016-2017, the WDNR constructed artificial nesting platforms near this priority area for Forster's Terns, who have successfully nested there both years[8,49]. • In the fall of 2017, UW-Green Bay's Dr. Wolf, Dr. James Horn, and Dr. Howe mapped submerged aquatic vegetation beds throughout the LGB&FR AOC, including this priority area[50]. • UW-Green Bay's Dr. Amy Carrozzino-Lyon, Dr. Patrick Robinson, and Dr. Mathew Dornbush and Duck's Unlimited Brian Glenzinski are trying to re-establish wild rice in the bay of Green Bay (2017-2018), including seeding near the mouth of Duck Creek[51].

[46] Green Bay Fish Working Group Annual Meeting on 4 January 2017.
[47] Great Lakes Coastal Wetland Monitoring Program: http://www.greatlakeswetlands.org/Home.vbhtml, per Erin Giese
[48] LGB&FR AOC Migratory Waterfowl Surveys 2016-2017 – led by Dr. Amy Wolf, Dr. Bob Howe, Tom Prestby, and Erin Giese
[49] Personal communication with WDNR's Joshua Martinez.
[50] LGB&FR AOC Submerged Aquatic Vegetation Surveys 2017 – led by Dr. Amy Wolf and Dr. James Horn
[51] Wild rice seeding in the lower bay of Green Bay, led by Dr. Amy Carrozzino-Lyon:
http://www.ducks.org/conservation/glar/wisconsin/green-bay-partnership-to-improve-wildlife-habit-water-quality

Map of Duck Creek Estuary North's plant communities, which are delineated based on the UW-Green Bay 2015 habitat mapping effort and 2017 submerged aquatic vegetation surveys. Map made by UW-Green Bay's Jon Schubbe. A small patch of southern sedge meadow was found by Dr. James Horn during the LGB&FR AOC 2016 plant biodiversity hotspot mapping and its general location is indicated by the yellow star below.



Land ownership boundaries at Point Sable. Map made by UW-Green Bay's Jon Schubbe.



Photograph of Duck Creek Estuary North facing northwest. Photograph taken by Erin Giese on 2 December 2016.