Assessment of Potential Dike-Breach Restoration of Estuarine Wetlands in Tillamook Bay, Oregon

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Table of Contents

List of Figures

List of Tables

Appendices

EXECUTIVE SUMMARY

In 1995-1996, the University of Washington, School of Fisheries' Wetland Ecosystem Team (WET), Oregon Division of State Lands (ODSL) and Philip Williams & Associates (PWA) proposed and were awarded a Tillamook Bay National Estuary Project (TBNEP) Action Plan Demonstration Project to assess the potential of restoring historically diked areas to tidal inundation as a means to recover estuarine rearing habitat for juvenile salmonids (*Oncorhynchus* spp.) in Tillamook Bay. This assessment was predicated on assumptions that certain wetland habitat types, structures and landscape positions that would benefit Tillamook watershed salmonid populations over short- and long-term restoration scenarios. The project was not designed to provide recommendations for acquisition of specific land parcels for restoration, but rather to establish scientific and technical criteria for setting priorities to focus on developed regions of the Bay that had the highest probability for contributing to juvenile salmonid recovery if restored. However, as it was based on or generated GIS data, our results provide both the opportunity and technical mechanism for GIS-based analyses of economic and other factors that would likely be a subsequent step in developing a plan for restoration of the Bay's estuarine wetlands.

The analysis almost exclusively utilized spatial data, which in all cases was converted into GIS; no field investigations were conducted. We assessed estuarine wetland restoration potential in Tillamook Bay by generating and comparing GIS-derived parameters on historic habitat type, location and landscape structure with comparable data for the modern distribution of diked tidelands. We also evaluated among the array of existing diked tidelands the likelihood of successful restoration of juvenile salmonid rearing habitat by ranking parameters according to their distribution and landscape structure. The rate and pattern of restoration of breached-dike wetlands was assessed by tracing the developmental trends in naturally breached dike sites in Tillamook Bay using a historic sequence of aerial photographs.

From the combination of these GIS data layers, we used the GIS-based parameters to generate metrics of the potential (diked) restoration sites, their potential to provide juvenile salmonid rearing habitat, and contingent factors that might affect the likelihood that restoration would occur. We organized these metrics into seven categories defining and describing the historically diked wetland within Tillamook Bay: (1) identification; (2) description; (3) structure; (4) restoration feasibility; (5) probability of salmonid utilization; (6) salmonid rearing landscape; and (7) water quality indicators. We normalized all metric values by the maximum value of each metric, resulting in a range of zero to one. Of these available metrics, we used twelve to rank the restoration potential according to three categories — *historic wetland structure* (3 metrics), *probability of salmonid utilization* (6 metrics), and *salmonid rearing landscape* (3 metrics). Our assessment of the technical feasibility of restoration considered thirteen more metrics among two categories — *restoration feasibility* (6 metrics), and *water quality* (7 metrics).

To test if we could detect patterns and trends in the rates of estuarine wetland restoration of breached dike sites, we also examined chronological changes in three marshes (Goose Point/Kilchis River and Wilson River deltas) in Tillamook Bay that we interpreted to have been previously diked and appeared to be progressing or have become fully restored after dikes were breached. For each site, we examined U.S. Army Corps of Engineers aerial photographs from the taken between 1939 and 1989 for changes in the following wetland attributes or human

alterations: upland, shrub/scrub, high marsh, and emergent marsh boundaries; tidal channel geomorphology; waterline; and dikes, roads, houses and railroad tracks.

We identified 17 relatively discrete sites of diked estuarine wetland that represented potential restoration sites for juvenile salmonid rearing habitat in Tillamook Bay; two sites of these sites do not overlap significantly with historic wetland, or we interpreted them to be already restored, and we dropped them from further consideration. The remaining 15 potential restoration sites are distributed predominantly in the lower half of the Bay, within four of the five major Tillamook Bay tributary basins, and range in size from approximately 11 ha to more than 180 ha. Many sites are integrated into the human infrastructure around the Bay, and a single site may include more than 50 buildings, be associated (e.g., fall within a census block) with almost 1,500 people, and include several kilometers of major and minor roads. However, at least nine sites have essentially no major roads and encompass five or fewer buildings. Nine sites are also associated in four contiguous blocks, usually separated by cross dikes, minor roads and/or channels. Because without extensive field investigations we cannot identify the integrity of the separation between these sites, we cannot preclude that returning tidal inundation to one will not result in flooding of a contiguous site and they may represent the following, potentially larger and more complex, sites.

Our assessment of the restoration potential of historic estuarine wetland habitat for juvenile salmonids indicated that the five highest ranking sites were located in the proximity of Memaloose Point, Hall Slough, Wilson River, Tomilinson Slough, and Nolan Slough. When considering potential combinations of contiguous sites, the Hall Slough-Wilson River, Memaloose Point North and South-Nolan Slough complexes all included relatively highly-ranked sites. Alternatively, this analysis indicated that, except for the Tillamook North site, most of the Tillamook River sites and Vaughn Creek ranked in the lower range of juvenile salmonid rearing potential if they were restored. Our assessment of the technical feasibility indicated that sites ranking low for feasibility and constraints typically ranked high for contributing to juvenile salmonid rearing habitat. Only the diked site at Hall Slough ranked high for both salmonid habitat potential and feasibility of restoration.

Our analysis of patterns and rates in the restoration of breached dike sites indicated that, contrary to our fundamental assumption, substantial human modifications had occurred at the selected breached-dike sites even after the breaching of the dike(s). Thus, without groundtruthing the current status of remnant and restoring tidal channels and drainage ditches, it was impossible to interpret what changes in wetland and channel structure could be attributed to natural restoration processes or to human manipulation. Given the relatively small, inconsistent changes, we could not interpret restoration pattern or rate from these data because either the dike had breached significantly earlier than 1939 and had already progressed through the early stages of wetland restoration or it had only been diked a short time and typical degradation of the site (e.g., subsidence) had not become advanced before the dike was breached.

In interpreting these results, we point out some of the problems we encountered in developing key GIS datasets, potential alternative and additional assessment criteria that we could not quantify, problems with interpreting dike and upland boundaries of potential restoration sites, subsidence within diked areas, and dike and tidegate integrity. Final recommendations of optimum potential and feasibility of restoring juvenile salmonid rearing habitat assigned highest priority to three sites, located adjacent to Nolan Slough, Hall Slough and the Kilchis River delta, and contiguous sites that might be incorporated concurrently or in the future. Prior to implementation, we also recommend intensive studies of site geomorphology and juvenile salmon occurrence, establishment of estuarine wetland reference sites, measurement of natural sediment accretion rates, precise surveying of dikes and other estuarine habitat features (e.g., tidal channels), and improvement of the positional, attribute and topological accuracy of existing GIS data layers.

INTRODUCTION

Objective

In August 1995, the University of Washington, School of Fisheries' Wetland Ecosystem Team (WET), Oregon Division of State Lands (ODSL) and Philip Williams & Associates (PWA) were awarded a Tillamook Bay National Estuary Project (TBNEP) Action Plan Demonstration Project. The objective of this project was to assess the potential and limitations, probability of success, and rate of restoring estuarine wetlands for juvenile salmonids (*Oncorhynchus* spp.) rearing in Tillamook Bay by restoring selected diked areas to tidal inundation. The following describes the background and rationale behind this initiative, the approach and responsibilities of the participants in addressing this objective.

Background and Rationale

During the process of nomination, the Tillamook Bay National Estuary Program (TBNEP) had identified the degradation of critical estuarine habitat, particularly affecting juvenile salmonids, as one of the Program's three priority problems. Tillamook Bay has lost over 72% of its historic 3,832 ac of estuarine wetlands, primarily due to agricultural development (Boulé and Bierly 1987; Oregon Division of State Lands 1972); urban development has likely accounted for only ~2%. As a result, estuarine rearing habitat has been reduced to some unknown degree for several populations of salmon and anadromous trout that likely utilized the Bay's historic wetlands. This reduction in habitat has probably had its greatest impact on chum (*Oncorhynchus keta*) and chinook salmon (*O. tshawytscha*), which are extensively depended upon estuarine wetland habitats for extended rearing in estuaries (Simenstad et al. 1982). It is particularly important to note that Tillamook Bay supports one of the last remnant chum salmon populations in Oregon.

One of the five primary goals of the TBNEP is to identify methods and opportunities to protect and enhance anadromous fish spawning and rearing habitat. This project on diked estuarine wetlands addressed both the feasibility and mechanisms of developing a restoration strategy for restoring estuarine wetland rearing habitat in Tillamook Bay. It is predicated on the concept that the carrying capacity, and potential enhancement of salmonid estuarine and marine survival, of Tillamook Bay could be increased by restoring estuarine wetland habitat, especially if located and designed to take advantage of particular landscape (ecology) features such as corridors to historic distributary and dendritic tidal channel systems. Diked tidelands are some of the best candidates for restoration since they were historically tidally influenced wetlands and show promise for rapid recovery when the dikes are breached (Simenstad and Feist 1996).

Although the focus of restoration as a goal toward recovery of depressed salmon populations is almost exclusively concentrated on freshwater spawning and rearing habitats, salmon ecologists are gradually recognizing the importance of estuarine habitats and their restoration for many salmon species and life history stages. In particular, species such as chum salmon and life history types such as 'ocean-type' chinook salmon are broadly recognized as being more dependent on estuarine habitats for their early life history (Healey 1982, 1991; Levy and Northcote 1982; Simenstad *et al.* 1982; Salo 1991; Johnson *et al.* 1992). Even sub-yearling, "ocean type" coho salmon (*O. kisutch*) may utilize tidal freshwater and oligohaline reaches of estuaries for overwintering and early estuarine residence more extensively than previously appreciated (Tschaplinski 1982, 1987; Ryall and Levings 1987; Miller and Simenstad 1998;

unpub. information from Salmon River estuary, D. Bottom and T. Cornwell, ODFW). Manipulation experiments using chinook salmon in the Campbell River estuary, Vancouver Island, (Macdonald *et al.* 1988) and coho in coastal Oregon (Solazzi *et al.* 1991) have provided evidence that estuarine residency is generally, but not necessarily uniformly, correlated with higher marine survival, confirming earlier descriptive information from the Sixes River estuary (Reimers 1973).

Where restoration, enhancement or creation of estuarine wetlands in the Pacific Northwest has involved assessment of responses by juvenile salmon, there are often indications of rapid occupation of the natant habitat, although the initial functioning (e.g., growth, prey consumption, survival) for juvenile salmon rearing can vary (Shreffler *et al.* 1990, 1992; Levings and Nishimura 1997; Miller and Simenstad 1998). As a result, several approaches to assessing wetland function for juvenile salmon rearing have evolved to address the mechanisms of support, such as production and availability of preferred prey in different estuarine habitats (Simenstad et al., 1991; Simenstad and Cordell, in revision). However, assessment of estuarine habitat restoration to support juvenile salmon has yet to address issues, approaches and criteria at the landscape scale that juvenile salmon interact with estuaries (Simenstad *et al*., submitted).

Approach

Although our explicit goal was to develop an estuarine wetland strategy for Tillamook Bay, we intentionally designed our approach and methods to be applicable to restoration of juvenile salmonid rearing habitat in other estuaries in the region. In particular, the development and use of Geographic Information System (GIS) data into a landscape-based assessment of juvenile salmonid habitat quality should be applicable to similar assessments to other Pacific Northwest estuaries that have available similar GIS layers. This specifically addresses another of the five primary goals of the Tillamook Bay National Estuary Project: to actively apply lessons learned in Tillamook to other estuaries in Oregon and the region.

Our assessment was predicated on assumptions of the wetland habitat type, structure and landscape position that would benefit Tillamook watershed salmonid populations over short- and long-term restoration scenarios. The analysis almost exclusively utilized spatial data, which in all cases was converted into GIS. We assessed estuarine wetland restoration potential in Tillamook Bay by generating and comparing GIS data on historic habitat type, location and landscape structure with comparable data for the modern distribution of diked tidelands. Inherent in this approach is the contingency that the resolution of the spatial data on the historical habitat structure of the Bay to a great degree dictated our ability to interpret the degree of change in fine-scale habitat features.

We also evaluated among the array of existing diked tidelands the likelihood of successful restoration of juvenile salmonid rearing habitat by applying criteria to GIS-based data to evaluate their distribution and landscape structure. We evaluated the rate and pattern of restoration of breached-dike wetlands by tracing the developmental trends in naturally breached dike sites in Tillamook Bay using a historic sequence of aerial photographs.

In order to maintain objectivity, we analyzed the spatial data without consideration of ownership and other jurisdictional boundaries or of the relative availability (e.g., land use, cost) of specific tracts. As such, this project was not intended to provide recommendations for acquisition of specific land parcels for restoration, but rather to establish scientific and technical criteria for setting priorities to focus on developed regions of the Bay that had the highest probability for contributing to juvenile salmonid recovery if restored. However, as it was based on or generated GIS data, our results should provide both the opportunity and technical mechanism for GIS-based analyses of economic and other factors that would likely be a subsequent step in developing a plan for restoration of the Bay's estuarine wetlands.

Our primary tasks and components included:

(1) Assess estuarine wetland restoration potential:
   a. compare GIS overlays of historic estuarine habitat structure with modern land use;
   b. identify feasible diked-wetland restoration sites;
   c. develop criteria for categorizing diked wetland restoration potential;
   d. identify land ownership and availability; and,
   e. rank feasibility of potential diked wetland restoration sites.

(2) Assess probability of successful restoration:
   a. develop criteria for ranking landscape structure attributes that likely relate to juvenile salmonid rearing habitat quality;
   b. analyze historic GIS landscape layers to generate indices of landscape structure relative to juvenile salmonid habitat; and,
   c. rank site-specific probability of restoring juvenile salmonid rearing habitat.

(3) Evaluate restoration rate:
   a. analyze GIS overlays of two naturally breached-dike sites over at least four time intervals (since breaching) to quantify incremental change in wetland habitat and landscape structure;
   b. generate habitat and landscape structure trajectories for several breached-dike sites; and,
   c. interpret rate and stage of development and estimate time required to achieve historic juvenile salmonid rearing status.

(4) Identify restoration limitations:
   a. identify sites with significant economic use; and,
   b. identify sites with extensive floodplains (e.g., high dike cost).

(5) Interpret optimum restoration plan:
   a. interpret combined results of restoration potential, probability of success and estimated rate to identify highest priority sites for restoration; and,
   b. make recommendations.

Estuarine wetland types included all those affected by tidal action, including the lower portions of tidal freshwater (tidal-fluvial) regions the lower reaches of the Miami, Kilchis, Wilson, Trask, and Tillamook rivers tributary to the Bay. The rate of restoration of specific wetland types and landscape features (e.g., dendritic channels) would be estimated by evaluating the rates and patterns of change in three existing, naturally breached-dike wetlands in the Bay (Simenstad and Feist 1996).

Team Responsibilities

Wetland Ecosystem Team, WET (C. Simenstad and B. Feist) managed the study, conducted the GIS assessment of historic and modern estuarine habitat composition and distribution, analyzed landscape structure elements and attributes of historic, modern and existing breached-dike sites, identified and evaluated potential diked-wetland restoration sites, and evaluated dike-breach restoration potential of high priority sites. ODSL (K. Bierly and J. Morlan) provided GIS technical support and technical input to analyses and evaluations of breached-dike restoration potential. PWA (P. Williams and associates) provided historic GIS data, advised on interpretation of historic estuarine habitat structure, contributed to breached-dike restoration evaluation and predictions, and contributed to documents and other products describing results.

METHODS

Identifying and Assessing Potential Restoration Sites and Probability

We used overlap between two GIS data layers that we assembled and other, currently available data layers to delineate potential sites for estuarine wetland restoration and to assess their potential and probability to contribute to increased estuarine rearing habitat for juvenile salmonids. From the combination of these GIS data layers, we generated descriptors, metrics or ranks of the potential (diked) restoration sites, their potential to provide juvenile salmonid rearing habitat and contingent factors that might affect the likelihood that restoration would occur. We organized the descriptors, metrics and ranks in the following categories:

- Diked Wetland Identification: location and other information identifying the site
- Diked Wetland Description: demographic and characteristics, including area, boundary lengths, perimeters, population, buildings, etc.
- Wetland Structure: restorable wetlands within dikes and likely channel characteristics that would be restored
- Restoration Feasibility: aspects of the diked area that may affect the probability that diking breaching is feasible, such as human infrastructure, and pose other potential constraints, such as non-point source pollution; while we have applied them primarily as cost constraints, they can also be viewed as economic and social constraints on the decision about whether or not to restore invested properties
- Salmonid Utilization Probability: factors that would likely determine that juvenile salmonids would be available to utilize restored estuarine wetlands at the site
- Salmonid Rearing Landscape: relationship to other estuarine habitats important for rearing juvenile salmonids
- Water Quality Indicators: existing or potential long-term factors that might affect water quality even after restoration.

Because there was redundancy in the composition of some of the metrics in these categories, not all were ranked relative to their contribution to the successful restoration of juvenile salmonid estuarine rearing habitat (See Results section and Appendix D).

UW Generated GIS Layers

We generated two spatial datasets for this project: **dikes** and **hisestuw**. See Appendices A and B, respectively, for FGDC-compliant metadata information contained in *dikes.met* and *histestuw.met*. The **dikes** dataset was derived from a 1964 Soil Conservation Service Soil Survey Publication that showed aerial photographs of levees in Tillamook Bay as of 1964. The "Index to Map Sheets" map was registered in MapInfo and control points for obvious landmarks were extracted from this index map for the aerial photos of each area. Four control points were generated for each aerial photo. The positional accuracy is not known and should be used only for general locations of levees. The data represents a 1964 condition, and was not field checked for currentness. We derived theoretical MHHW lines by overlaying the **dikes** layer with the **hisestuw** layer in MapInfo using "Grassy Tidal Marsh" and "Tidally-Influenced Forest" polygons as guides (**hisestuw** methods follow).

The **hisestuw** GIS data layer (Figure 1) was generated from the historical reconstruction map of Coulton *et al*. (1996) that delineated the historical landscape of the Tillamook Valley in 1856-1857. The map from this report was hand drawn from historical General Land Office Original Survey Notes (1856 -1857), coordinated with U.S.G.S. 1:24,000 scale topographic maps, the photo series from the 1964 Soil Conservation Service Soil Survey Publication, 1978 Flood Insurance Rate Maps, and 1939 U.S. Army Corps aerial photographs. The hard copy of this map was hand digitized on a digitizing tablet, connected to a Unix workstation running ESRI ArcInfo®. Four control points were used for this map that would tie-in the map's township and section grid from 1856 with the Oregon Lambert Coordinate system. The positional accuracy of this registration was not and cannot be verified. However, the general size and locations of various polygons are sufficient for this analysis. Field surveys and verification of any prospective restoration diked area would be prudent in order to determine accurate elevation profiles, subsidence, and levee conditions.

In the following lists of diked wetland identification and assessment parameters, the names of GIS spatial datasets are in **bold**-face type, and the database columns used within any given dataset are provided as necessary. All spatial datasets with the exception of **dikes**, **hisestuw**, and the 1965 U.S. Army Corps floodplain survey were from the TBNEP GIS CD-ROM (October 1997, v. 2).

GIS Data Categories

1. **Diked Wetland Identification**

(I.D.): Each diked area was assigned a numerical identification from original count. Some numbers are missing because there were deletions of apparent diked areas.

Name: Arbitrary name assigned to each diked area based on names of associated streams, sloughs, or rivers visible on USGS 7.5' quads, 1965 U.S. Army Corps flood plane survey sheets, and 1964 Soil Conservation Service soils characterization maps.

Watershed I.D.: Sub-basin(s) of the five major Tillamook Bay tributaries that any diked area fell within was determined by performing an intersect SQL selection in MapInfo between the **tillsub** vector GIS layer (TBNEP) and the **dikes** vector GIS layer (UW). The selection had to be verified manually as a result of alignment problems between the two layers.

Centroid Latitude: North latitude of dike centroid was determined using MapInfo (theoretical center of gravity for polygon) expressed in decimal degrees (DD).

Centroid Longitude: West longitude of dike centroid was determined using MapInfo (theoretical center of gravity for polygon), expressed in decimal degrees (DD).

Oregon Ownership: Ownership was determined by performing an intersect SQL selection in MapInfo between the **owner** vector GIS layer (TBNEP) and the **dikes** vector GIS layer

(UW). The selection had to be verified manually as a result of alignment problems between the two layers.

Tidegate I.D.'s: Tide or flap gates, and their identification numbers, associated with dike perimeter, as determined from Tidegate Database Survey conducted by Jay Charland, TBNEP. Association was determined visually using MapInfo. Original tidegate coordinates were obtained in the field using a standard, non-differentially corrected GPS unit with 100-m accuracy.

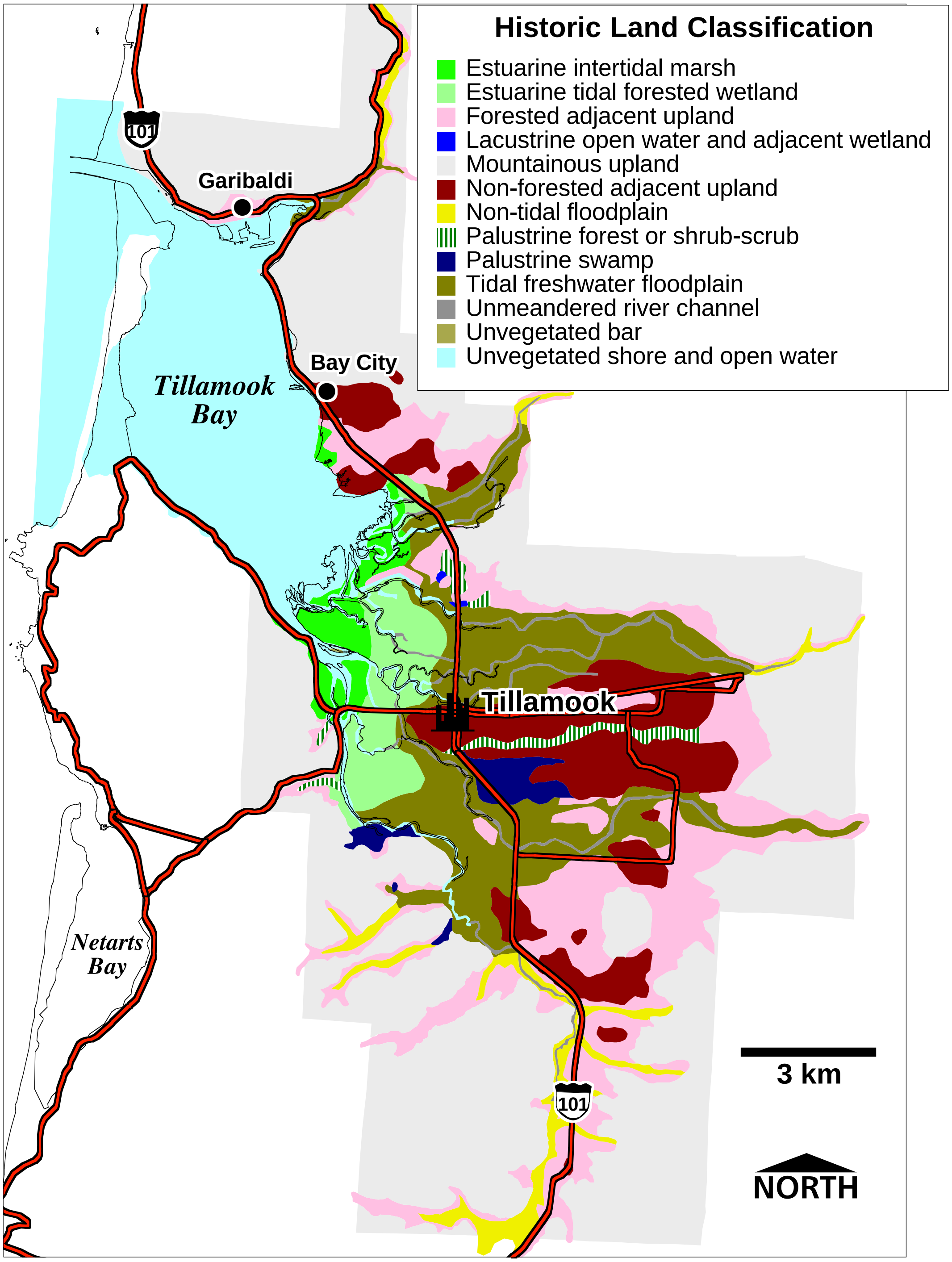

Figure 1 GIS map of historical landscape structure of Tillamook Valley in 1856-1857 digitized from Coulton *et al.* (1996) map prepared by Patricia A. Benner, Oregon State University.

Adjacent Dikes: The identification number(s) of dikes adjacent to any given diked area was determined visually using MapInfo.

2. **Diked Wetland Description**

Area (ha): Total area of each diked area was determined using MapInfo, expressed in hectares (ha).

Total Perimeter (m): Major Road + Minor Road + Channel + Minor Road & Channel + Land, in meters (m), calculated in Excel.

Major Road: Percentage of Total Perimeter consisting of Major Roads, derived from **rdsmaj** vector GIS layer (TBNEP), using MapInfo (see Data Category 4).

Minor Road: Percentage of Total Perimeter consisting of Minor Roads, derived from **rdsmin** vector GIS layer (TBNEP), using MapInfo (see Data Category 4).

Channel%: Percentage of Total Perimeter consisting of Channels

Minor Road & Channel: Percentage of Total Perimeter consisting of Minor Roads & Channels

Land: Percentage of Total Perimeter consisting of Land

3. **Wetland Structure**

Area (ha): (same as above)

Historic Channels: 1965 U.S. Army Corps floodplain survey sheets were visually inspected for the presence of existing or historic tidal channels within the diked areas. From this analysis, channel complexity was categorized as none, low, medium or high. Normalized scores were 0, 0.33, 0.66, and 1.00 respectively.

Channel: Total length of existing channels bounding diked area, in meters (m), as determined from **lstream** or **lriver** vector GIS layers (TBNEP), , using MapInfo.

4. **Restoration Feasibility**

Buildings (from 1965): Number of buildings and/or ground structures visible on 1965 U.S. Army Corps flood plane survey sheets (1:2,400 scale). Count was made manually by overlaying **dikes** vector GIS layer (UW) with registered raster images of Corps spatial data.

Census Population: Estimated population of humans associated with diked area as determined from **bgpop** vector GIS layer (TBNEP). Although we included this metric in our database as a general index of human infrastructure, because census block groups typically extend beyond the diked areas, population estimates are known to be inaccurate and we did not use it in our overall assessment.

Major Road: Total length of major roads bounding diked area, in meters (m), as determined from **rdsmaj** vector GIS layer (TBNEP), using MapInfo.

Minor Road: Total length of minor roads bounding diked area, in meters (m), as determined from **rdsmin** vector GIS layer (TBNEP), using MapInfo.

Minor Road & Channel: Total length of existing channels and minor roads (minor roads running on top of dike with channel immediately adjacent) bounding diked area, in meters (m), as determined from **lstream** and **rdsmin** vector GIS layers (TBNEP), using MapInfo.

Land: Total length of land that would bound a breached dike area, in meters (m), as determined from both **hisestuw** (Patricia A. Benner and WET) and 1965 U.S. Army Corps flood plane survey sheets, using MapInfo.

# of Adjacent Dikes: The number of diked areas sharing a common levee was recorded visually using MapInfo.

5. Salmonid Utilization Probability

Chum Spawn: The total length of chum salmon (*Oncorhynchus keta*) spawning reaches upstream of a given diked area was determined from the **chum** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 1 (spawning) Attribute for **chum**. Total length of the selection was then calculated using MapInfo.

Chum Mig + Rear: Total length of chum salmon (*O. keta*) migration and rearing reaches upstream of diked area, was determined from the **chum** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 3 (migration and rearing) Attribute for **chum**. Total length of the selection was then calculated using MapInfo.

Coho Spawn: The total length of coho salmon (*Oncorhynchus kisutch*) spawning reaches upstream of a given diked area was determined from the **coho** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 1 (spawning) Attribute for **coho**. Total length of the selection was then calculated using MapInfo.

Coho Mig + Rear: Total length of coho salmon (*O. kisutch*) migration and rearing reaches upstream of diked area, was determined from the **coho** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 3 (migration and rearing) Attribute for **coho**. Total length of the selection was then calculated using MapInfo.

Fall Chin Spawn: The total length of fall chinook salmon (*Oncorhynchus tshawytscha*) spawning reaches upstream of a given diked area was determined from the **chinfall** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 1 (spawning) Attribute for **chinfall** . Total length of the selection was then calculated using MapInfo.

Fall Chin Mig + Rear: Total length of fall chinook salmon (*O. tshawytscha*) migration and rearing reaches upstream of diked area, was determined from the **chinfall** vector GIS layer (TBNEP), expressed in kilometers (km). An intersect SQL selection was made in

MapInfo between the appropriate watershed(s) (see Watershed I.D. method) in the **tillsub** vector GIS layer (TBNEP) and Habitat = 3 (migration and rearing) Attribute for **chinfall** . Total length of the selection was then calculated using MapInfo.

6. Salmonid Rearing Landscape

Low Salt Marsh: Shortest distance to nearest low salt marsh patch (**estuhabs** vector GIS layer [TBNEP], Attribute = Habcode: 2.5.11), by following centerline of channel (derived from **estuhabs** vector GIS layer [TBNEP], Attribute = Habcode: 1.1, 1.1.6, 1.1.2, 1.1.1, 1.1.4, or 1.1D), in meters (m), using MapInfo. Centerline was heads-up digitized in MapInfo.

High Salt Marsh: Shortest distance to nearest high salt marsh patch (**estuhabs** vector GIS layer [TBNEP], Attribute = Habcode: 2.5.12), by following centerline of channel (derived from **estuhabs** vector GIS layer [TBNEP], Attribute = Habcode: 1.1, 1.1.6, 1.1.2, 1.1.1, 1.1.4, or 1.1D), in meters (m), using MapInfo. Centerline was heads-up digitized in MapInfo.

Dense Eelgrass: Shortest distance to nearest dense eelgrass patch (**eelgrass** raster GIS layer [TBNEP], Attribute = 4: Dense Eelgrass; Strittholt and Frost 1996), by following centerline of channel (derived from **estuhabs** GIS layer [TBNEP], Attribute = Habcode: 1.1, 1.1.6, 1.1.2, 1.1.1, 1.1.4, or 1.1D), in meters (m), using MapInfo. Centerline was heads-up digitized in MapInfo.

7. Water Quality Indicators

Cow Contact Within (m): Total length of streams and/or channels contained within any diked area that have potential of dairy cow contact, in meters (m), as determined from **cowstr** vector GIS layer (TBNEP) and **dikes** vector GIS layer (UW) using MapInfo. Total lengths were calculated by intersecting **dikes** polygons on **cowstr** polylines using the split command in MapInfo. Split polylines within diked polygons were then selected and their length summed using SQL in MapInfo. Selections had to be verified manually as a result of alignment problems between the two layers.

Cow Contact Outside (m): Total length of streams and/or channels upstream or adjacent to diked area that have potential of dairy cow contact, in meters (m), as determined from **cowstr** vector GIS layer (TBNEP) and **tillsub** vector GIS layer (UW) using MapInfo. Total lengths were calculated by intersecting **tillsub** polygons on **cowstr** polylines using the split command in MapInfo. Split polylines within diked polygons were then selected and their length summed using SQL in MapInfo. Selections had to be verified manually as a result of alignment problems between the two layers.

Total Cow Contact (m): Sum of Cow Contact Within with Cow Contact Outside, calculated in Excel. Because this incorporated both the Cow Contact Within and Cow Contact Outside metrics, the total was not used in our overall assessment.

DEQ Temp Failure: Total length of streams upstream or adjacent to diked area that failed ODEQ temperature standards, in meters (m), as determined from **strdeq** vector GIS layer (TBNEP). Similar methodology to Cow Contact Outside (m) analysis.

DEQ Fecal Coli Failure: Total length of streams upstream or adjacent to diked area that failed ODEQ fecal coliform standards, in meters (m), as determined from **strdeq** vector GIS layer (TBNEP). Similar methodology to Cow Contact Outside (m) analysis.

DEQ Temp & FC: Total length of streams upstream or adjacent to diked area that failed ODEQ fecal coliform and temperature standards, in meters (m), as determined from strdeq vector GIS layer (TBNEP). Similar methodology to Cow Contact Outside (m) analysis.

DEQ Total: DEQ Temp Failure + DEQ Fecal Coli Failure + DEQ Temp & FC. Because this is the sum of all the DEQ water quality metrics, the total was not used in our overall assessment.

ODEQ Status - Moderate: Total length of streams upstream or adjacent to diked area that are categorized as moderate regarding non-point source pollution, in meters (m), as determined from **northc** vector GIS layer (TBNEP). NOTE, only values of 11 were considered for any given attribute. This reduced the data to Turb, Low_do, Nutr, Toxic, B_v, Solids, Sed, Erosion, and Other, since type 11 assessments were based on data and not observations or perception criteria. Similar methodology to Cow Contact Outside (m) analysis.

ODEQ Status - Severe: Total length of streams upstream or adjacent to diked area that are categorized as severe regarding non-point source pollution, in meters (m), as determined from northc vector GIS layer (TBNEP). NOTE, only values of 21 were considered for any given attribute. This reduced the data to Turb, Low_do, Nutr, Toxic, B_v, Solids, Sed, Erosion, and Other, since type 21 assessments were based on data and not observations or perception criteria. Similar methodology to Cow Contact Outside (m) analysis.

ODEQ Total: Sum of ODEQ Status - Moderate and ODEQ. Because this is the sum of all the ODEQ water quality status metrics, the total was not used in our overall assessment.

Scoring and Ranking

We normalized all values used for assessment by dividing each diked polygon metric number (area, length, distance, etc.) by the largest metric number for that category. This gave a range of zero to one for each diked area, for each assessment category. Although we gave each category an equal weighting of one in order to provide an unbiased assessment, the weightings can be adjusted in the Excel spreadsheet for dynamic assessment purposes where different metrics were considered to be more or less valuable than others.

Total Score: Sum of all normalized scores for any given dike (greater numbers are “better”)

Final Rank: Rank each diked site received from 1 to 15 (1 is “best”)

It is important to note that this weighting strategy is based on two dubious assumptions: (1) the relationship between the metric and the ecological function contribution to juvenile salmonid production is linear; and, (2) all assessment criteria are equally important. In the absence of empirical data, it is probably safest to make the first assumption, although research should be conducted to test some of the more critical assumptions (e.g., when is the next habitat patch too far away to guarantee no impact on survival rate?). We acknowledge that the second assumption is unrealistic, but have initially adopted that weighting in order to avoid subjectivity. As we will note in the Discussion section, there are some ecological rationale that can be applied to weight some of the criteria as being more or less important to the success of restoring juvenile salmonid rearing habitat in the Bay.

Assessing Patterns and Rates of Restoration

To test if we could detect patterns and trends in the rates of estuarine wetland restoration of breached dike sites, we examined chronological changes in three marshes in Tillamook Bay that we interpreted to have been previously diked and appeared to be progressing or have become fully restored after the dikes were breached (Simenstad and Feist 1996). This assumes that, once dikes were breached human modifications and manipulations were minimal if any occurred at all, and that changes in estuarine wetland might predict what would happen in other breached-dike restoration in the Bay.

We examined U.S. Army Corps of Engineers aerial photographs from the Goose Point/Kilchis River and Wilson River deltas taken between 1939 and 1989 for changes at three breached dike sites (Table 1). A total of 10 photographs were optically enlarged to a final scale of 1:2,400. Photographs from 1939, 1955, 1965, 1980, and 1989 were overlaid with mylar and the following estuarine wetland habitats and other features were traced (wherever possible):

- Upland, shrub/scrub, high marsh and emergent marsh boundaries
- Tidal channels
- Waterline
- Dikes
- Roads
- Houses
- Railroad tracks

Table 1. Year, original scale, film type, and identification of aerial photographs for each of two sites examined for chronological changes in three marshes, Tillamook Bay, OR.

Site	Year	Scale	Film Type	Photo I.D. Number
Goose Point/Kilchis River	1939	1:10,200	Black and White	Roll 027, #39/0636
	1955	1:9,600	Black and White	Roll 452, #55/1873
	1965	1:24,000	Black and White	Roll 585, #65/4419
	1980	1:12,000	False Color IR	Roll 734, #80/1760
	1989	1:24,000	False Color IR	Roll 793, #89/0944
Wilson River	1939	1:24,000	Black and White	Roll 027, #39/0640
	1955	1:24,000	Black and White	Roll 452, #55/1878
	1965	1:24,000	Black and White	Roll 579, #65/2585
	1980	1:12,000	False Color IR	Roll 735, #80/2841
	1989	1:24,000	False Color IR	Roll 793, #89/0960

The mylar tracings were then registered (using 4 common points on each photograph) and digitized using ESRI ArcInfo®, but were not georeferenced or orthocorrected. Only the Goose Point breached dike site was analyzed and only for years 1939 and 1989 since the breach at that site apparently occurred prior to 1939. The other two breached dike sites were not analyzed because we detected periodic and often substantial anthropogenic influences over time that severely confounded time series interpretation and subsequent predicted recovery trajectories. At the Goose Point site, we measured changes in (1) uplands, (2) shrub/scrub, and (3) tidal channel networks over time.

RESULTS

Potential Breached-Dike Restoration Sites

We identified 17 relatively discrete sites of diked estuarine wetland that represented potential restoration sites for juvenile salmonid rearing habitat in Tillamook Bay (Table 3; Figure 2). Of the 17, two (#1-Garibaldi, #6-Hall Slough East) did not overlap significantly with historic wetland, or we interpreted them to be already restored, and were dropped from further consideration. GIS and all other data for this restoration assessment population of 15 sites are tabulated in Appendix D.

The potential restoration sites are distributed in the lower, southeastern half of the Bay, within four of the five major Tillamook Bay tributary basins. They range in size from approximately 11 ha to more than 180 ha. Many sites are integrated into the human infrastructure around the Bay, and a single site may include more than 50 buildings (i.e., #5-Wilson River), be associated (e.g., fall within a census block) with almost 1,500 people (i.e., #5-Wilson River; #8-Memaloose Point South), and include several kilometers of major and minor roads (e.g., #10-Tomilinson Slough; #14-Trask South). Alternatively, at least nine sites have essentially no major roads and encompass five or fewer buildings.

Table 3 Seventeen diked estuarine wetlands identified as potential breached-dike restoration sites in Tillamook Bay. The two sites identified by italics were not included in full assessment of potential contribution to restoration of juvenile salmonid rearing habitat.

Site Number	Site Name	Tillamook Bay Tributary Regions	Contiguous Site(s)
1	Garibaldi-Miami River	Miami River	
2	Vaughn Creek	Pacific Ocean	
3	Kilchis River	Wilson & Pacific Ocean	
4	Hall Slough	Wilson & Pacific Ocean	#5
5	Wilson River	Wilson & Pacific Ocean	#4
6	Hall Slough East	Wilson	
7	Memaloose Point North	Pacific Ocean	#8
8	Memaloose Point South	Pacific Ocean & Trask	#7,#9
9	Nolan Slough	Pacific Ocean & Trask	#8
10	Tomilinson Slough	Pacific Ocean & Tillamook	
11	Tillamook North	Tillamook & Trask	#12
12	Trask North	Trask	#11
13	Tillamook Central 1	Tillamook & Trask	#16
14	Trask South	Tillamook & Trask	
15	Tillamook Central 2	Tillamook	
16	Tillamook Iowa	Tillamook & Trask	#13
17	Tillamook South	Tillamook	

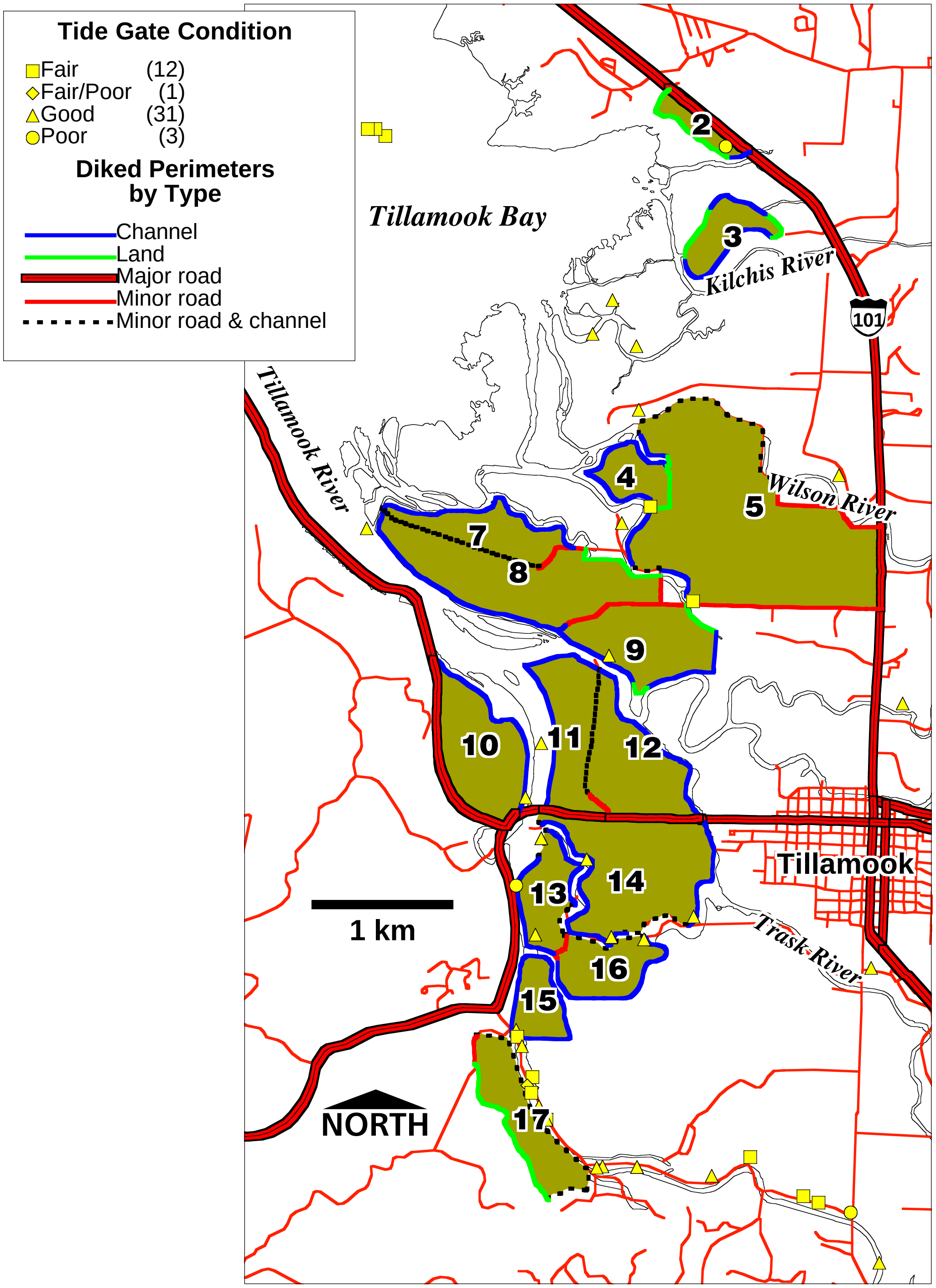

Figure 2 GIS map of fifteen diked estuarine wetlands in Tillamook Bay, OR that represent potential restoration sites for juvenile salmonid rearing habitat.

Nine sites are also associated in four contiguous blocks, usually separated by cross dikes, minor roads and/or channels. Because we cannot identify the integrity of the separation between these sites, we cannot preclude that returning tidal inundation to one will not result in flooding of a contiguous site. Combined, they may represent the following, potentially larger and more complex, sites:

- #4-Hall Slough and #5-Wilson River = 198.2 ha combined
- #7-Memaloose Point North, #8-Memaloose Point South, and #9-Nolan Slough = 158.9 ha combined
- #11-Tillamook North and #12-Trask North = 90.8 ha combined
- #13-Tillamook Central 1 and #16-Tillamook Iowa = 52.8 ha

Potential of Restoring Juvenile Salmonid Estuarine Rearing Habitat

The restoration potential of each site was ranked and scored for the three categories: (1) historic wetland structure; (2) salmonid utilization probability; and (3) salmonid rearing landscape (Table 4). GIS layers and other data included in each of these categories were described in the Methods section. Many if not all of these assessment metrics involved manual visual inspection of alignment between the various data layers since scale, accuracy, and precision varied considerably and often could not be measured. However, the overall comparisons of areas and cumulative lengths of polylines associated with diked wetland areas are reasonably accurate.

Distribution of the scores and ranks indicates that influences on the restoration of potential salmonid rearing habitat and the opportunity for salmon to utilize it can be independent (e.g., a relatively high ranking for wetland structure doesn't not necessarily correspond to similarly high rankings for the other two categories; for example, see #5-Wilson River). This highlights the concept that the importance of estuarine wetlands, and their contribution to potential salmonid recovery, must consider both the opportunity as well as the capacity of a system to provide habitat for juvenile salmonids as distinctly different contributions. Because there is no scientific evidence to the contrary, we considered all factors equally important and did not apply weighting factors to the scores.

From the standpoint of restoring estuarine wetland rearing habitat for juvenile salmonids, the five highest ranking sites included #8-Memaloose Point South, #4-Hall Slough, #5-Wilson River, #10-Tomilinson Slough, and #9-Nolan Slough. Because we used six metrics in our assessment of salmonid utilization probability, this category was somewhat more influential than either the internal wetland structure or the landscape position relative to known sources of salmonid spawning, migrating and rearing. When considering potential combinations of contiguous sites, Hall Slough-Wilson River, Memaloose Point North and South-Nolan Slough all included relatively highly-ranked sites. Alternatively, this analysis indicated that, except for Tillamook North (#11), most of the Tillamook River sites (#13, #15, #16, #17) and Vaughn Creek (#1) ranked in the lower range of juvenile salmonid rearing potential if they were restored.

Restoration Feasibility and Constraints

While our assessment of restoration potential was concerned primarily with criteria directly relating to the capacity and opportunity of juvenile salmonids to rear in restored estuarine wetlands, we also assessed the technical feasibility of restoration by ranking and scoring sites in two other categories: (1) restoration feasibility, and (2) water quality. These categories are not intended to be a comprehensive assessment of restoration feasibility, but rather provide some

Table 4 Summary (normalized) scores and rankings (in parentheses) of fifteen potential diked estuarine wetland sites for their potential contribution to restoring juvenile salmonid rearing habitat in Tillamook Bay, OR. See the text and appendices A and B for details on assessment metrics; the number of metrics included in each category scores are in brackets.

Site	Site Name	Wetland Structure [3]	Salmonid Utilization Probability [6]	Salmonid Rearing Landscape [3]	SUM TOTAL AND RANK [12]
2	Vaughn Creek	0.46 (15)	0.02 (14)	2.42 (4)	2.90 (13)
3	Kilchis River	0.97 (10)	1.14 (12)	2.46 (3)	4.57 (9)
4	Hall Slough	0.99 (9)	2.97 (2)	2.55 (2)	6.51 (2)
5	Wilson River	2.13 (1)	2.07 (6)	1.59 (9)	5.79 (3)
7	Memaloose Point North	1.84 (3)	0 (15)	2.66 (1)	4.50 (10)
8	Memaloose Point South	1.43 (7)	4.57 (1)	2.4 (5)	8.40 (1)
9	Nolan Slough	1.55 (5)	2.00 (7)	1.89 (8)	5.44 (5)
10	Tomilinson Slough	1.56 (4)	2.11 (5)	2.08 (6.5)	5.75 (4)
11	Tillamook North	0.91 (11)	2.16 (4)	2.08 (6.5)	5.15 (7)
12	Trask North	1.52 (6)	1.95 (8)	1.49 (10)	4.96 (8)
13	Tillamook Central 1	1.11 (8)	1.48 (9)	1.27 (11)	3.86 (11)
14	Trask South	2.11 (2)	2.46 (3)	0.58 (13)	5.15 (6)
15	Tillamook Central 2	0.82 (13)	1.46 (10)	0.8 (12)	3.08 (12)
16	Tillamook Iowa	0.70 (14)	0.56 (13)	0 (15)	1.26 (15)
17	Tillamook South	0.88 (12)	1.43 (11)	0.16 (14)	2.47 (14)

indication of both the opportunities and potential constraints (e.g., water quality) on successful restoration. As mentioned earlier, they may also indicate *some* of the social and cultural constraints that might be imposed upon restoration.

As might be expected, human infrastructure and other site factors that affect feasibility are often juxtaposed with factors that indicate current and future water quality (Table 5). This may particularly be the case when most of the GIS data for water quality criteria available for Tillamook Bay characterized the potential influences of dairy farming, which often occurs away from extensive human infrastructure. Comparatively opposing scores and ranks were evident for sites such as #2-Vaughn Creek and #12-Trask North, wherein either Restoration Feasibility or Water Quality were ranked 2-4 or 12-13 in opposite relationships for these two sites. Other sites, such as #4-Hall Point ranked similarly (i.e., 4-5) in both categories.

Feasibility and constraints on restoration often ranked low for sites that had been ranked high for contributing to juvenile salmonid rearing habitat. While #8-Memaloose Point South ranked first for restoration potential for salmonid habitat, it ranked 14th for feasibility and constraints. Alternatively, #16-Tillamook Iowa and 17-Tillamook South were the first and fifth most feasible sites, respectively, they ranked only 15th and 14th in terms of salmonid habitat potential. A notable exception was site #4-Hall Slough, which ranked second and sixth for salmonid habitat potential and feasibility of restoration, respectively.

Table 5 Summary (normalized) scores and rankings (in parentheses) of the feasibility and constraints to restoring fifteen potential diked estuarine wetland sites in Tillamook Bay, OR. See the text and appendices A and B for details on assessment metrics; the number of metrics included in each category scores are in brackets.

Site	Site Name	Restoration Feasibility [6]	Water Quality [7]	SUM TOTAL AND RANK [13]
2	Vaughn Creek	3.29 (13)	6.74 (2)	10.03 (4)
3	Kilchis River	4.03 (10)	6.40 (3)	10.43 (2)
4	Hall Slough	4.30 (5)	5.60 (4)	9.90 (6)
5	Wilson River	2.96 (15)	4.85 (9)	7.81 (11)
7	Memaloose Point North	4.69 (3)	5.43 (5)	10.12 (3)
8	Memaloose Point South	5.05 (1)	1.57 (15)	6.62 (14)
9	Nolan Slough	4.06 (9)	4.07 (11)	8.13 (9)
10	Tomilinson Slough	3.02 (14)	4.57 (10)	7.59 (12)
11	Tillamook North	3.52 (12)	1.95 (14)	5.47 (15)
12	Trask North	4.59 (4)	3.30 (12)	7.89 (10)
13	Tillamook Central 1	4.27 (6)	5.30 (7)	9.57 (7)
14	Trask South	4.26 (7)	2.84 (13)	7.10 (13)
15	Tillamook Central 2	3.64 (11)	5.34 (6)	8.98 (8)
16	Tillamook Iowa	4.24 (8)	6.99 (1)	11.23 (1)
17	Tillamook South	4.80 (2)	5.25 (8)	10.05 (5)

Patterns and Rates of Diked Estuarine Wetland Restoration

Our analysis of patterns and rates in the restoration of breached dike sites indicated that, contrary to our fundamental assumption, substantial human modifications had occurred at the selected breached-dike sites even after the breaching of the dike(s). At the Goose Point/Kilchis River sites (Figure 3), both ditching and repeated ponding of tidal waters was apparent after the earliest photographic record (1939; Figure 3a). It was also apparent from examination of the 1939 aerial photograph that either the tidal channel had been breached some unknown time before then or the dike had never been completed, the tidal channel blocked and tidal flooding of the diked area eliminated or significantly reduced.

Similarly, although the Wilson River site (Figure 4) appeared to progressively develop vegetated wetland and upland assemblages, ditching continued through the intervals of 1939-1955 (Figures 4a & b) and 1955-1965 (Figures 4b & c). Without groundtruthing the current status of remnant and restoring tidal channels and drainage ditches, it was impossible to interpret what changes in wetland and channel structure could be attributed to natural restoration processes or to human manipulation.

Our examination of changes at Goose Point between 1939 and 1989 (Figure 5, Table 2) indicated that changes in estuarine wetland and tidal channel structure were not extensive over that interval. Channel and upland area decreased by 9.3 and 16.3%, respectively, while shrub/scrub area increased by only 3.0%. Upland and channel edge to area ratios increased (from 0.19 to 0.28, and 0.67 to 0.79, respectively), while shrub/scrub ratios decreased (from 0.26 to 0.13). Decreases in edge to area ratios with little change in area suggests a general decrease in patchiness. This

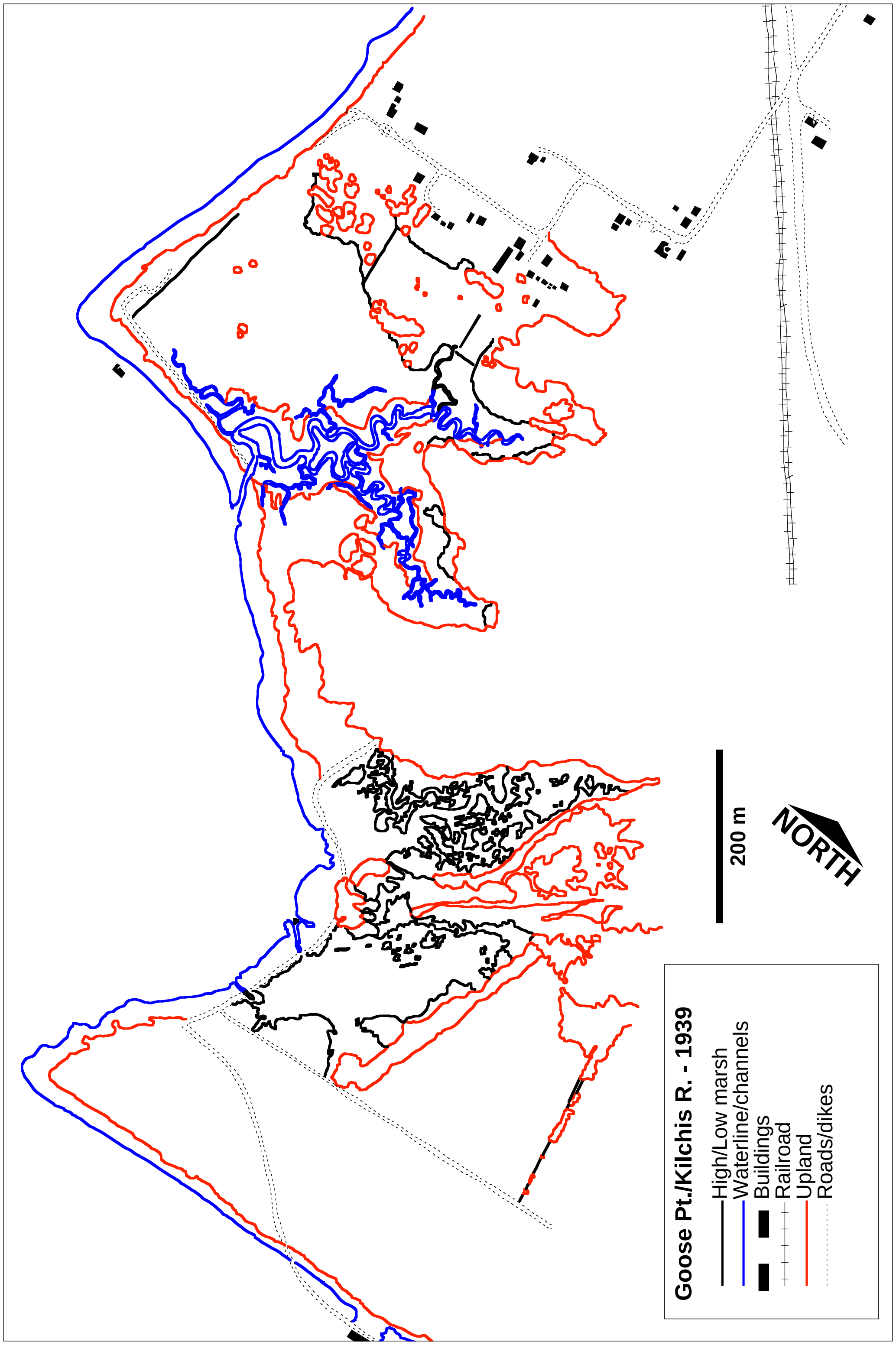

Figure 3 Chronological changes in estuarine wetland structure at Goose Point/Kilchis River breached-dike site from **1939 (a)** through 1955 (b), 1965 (c), 1980 (d) and 1989 (e).

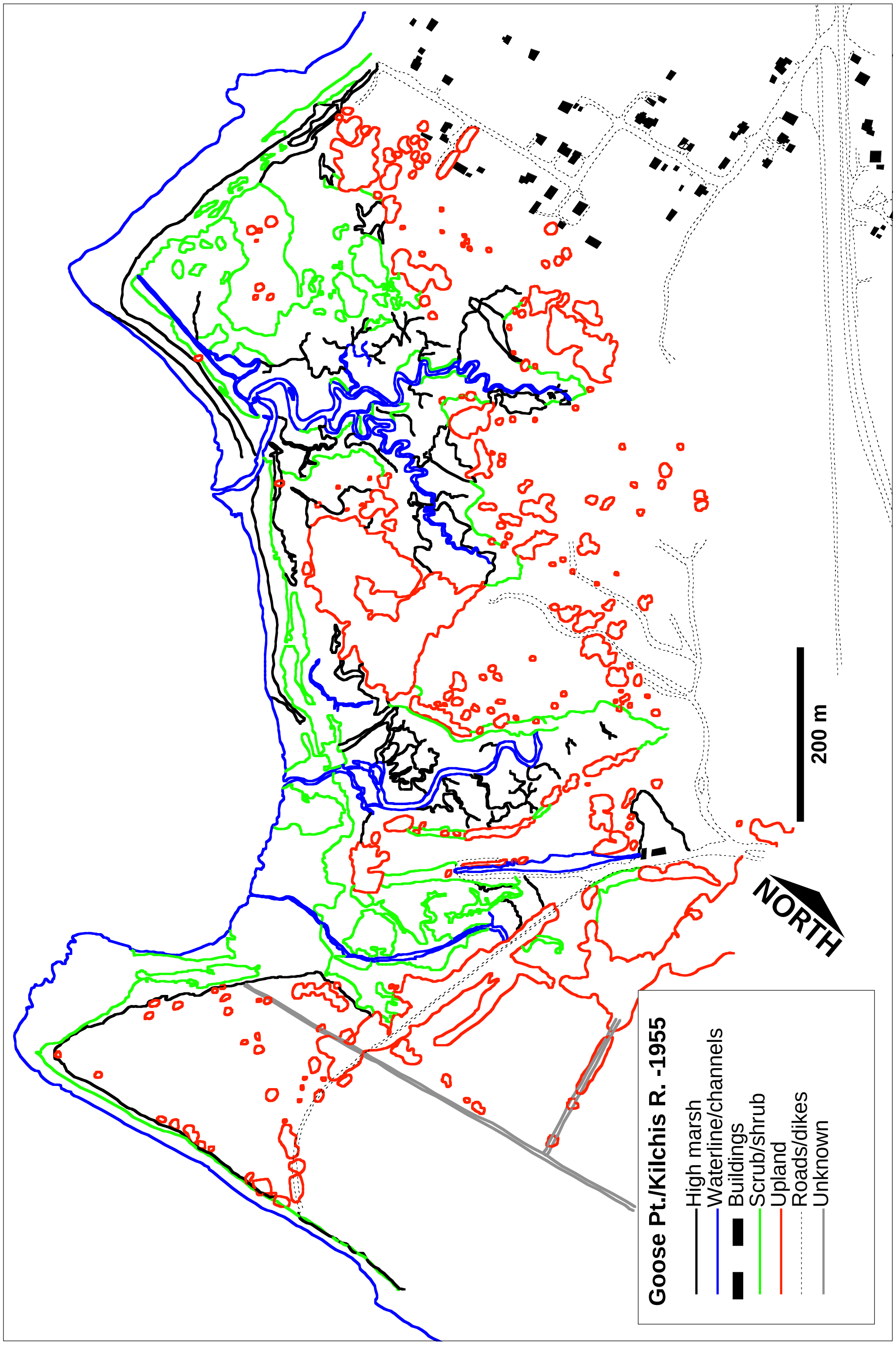

Figure 3 Chronological changes in estuarine wetland structure at Goose Point/Kilchis River breached-dike site from 1939 (a) through **1955 (b)**, 1965 (c), 1980 (d) and 1989 (e).

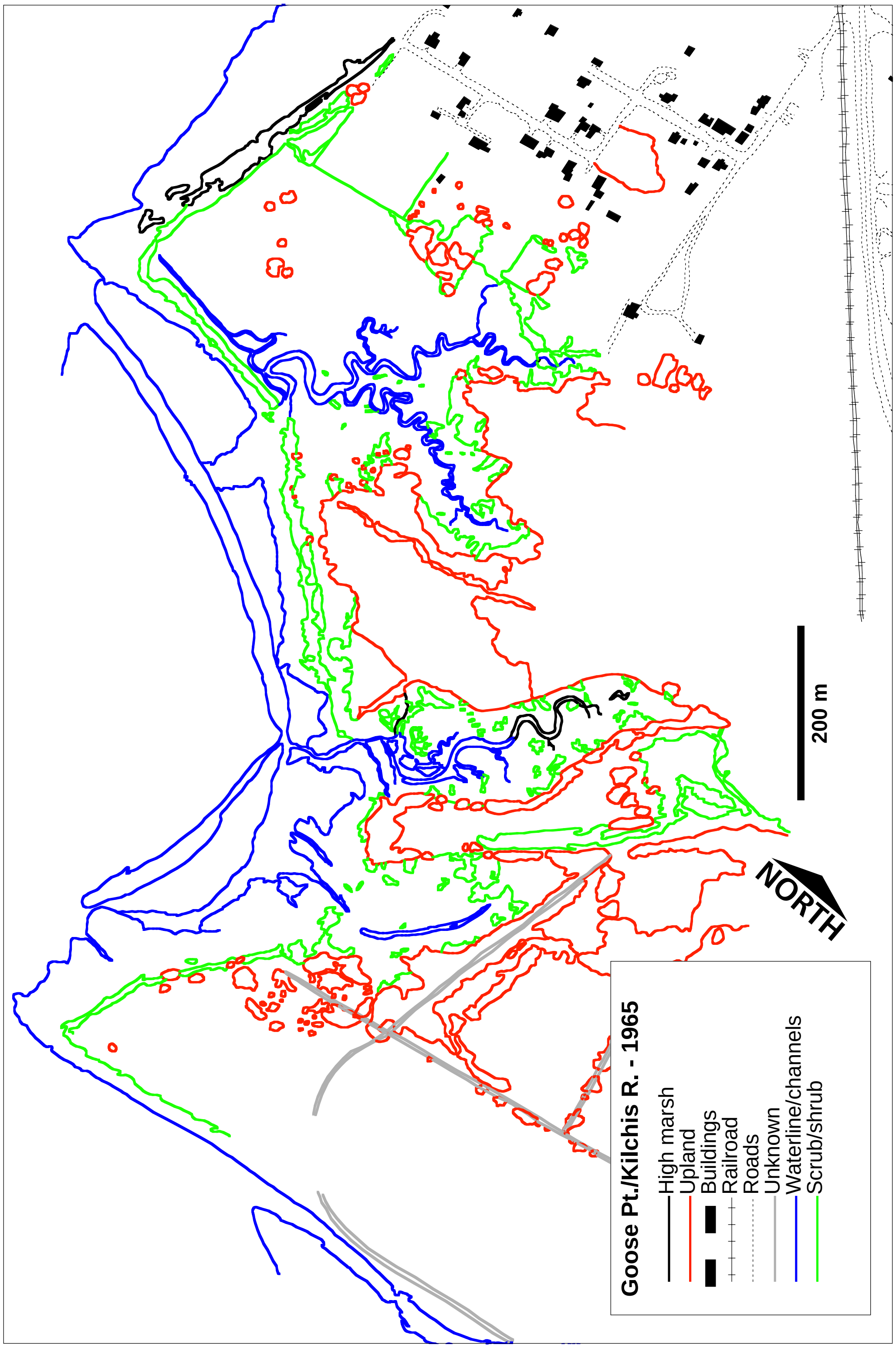

Figure 3 Chronological changes in estuarine wetland structure at Goose Point/Kilchis River breached-dike site from 1939 (a) through 1955 (b), **1965 (c)**, 1980 (d) and 1989 (e).

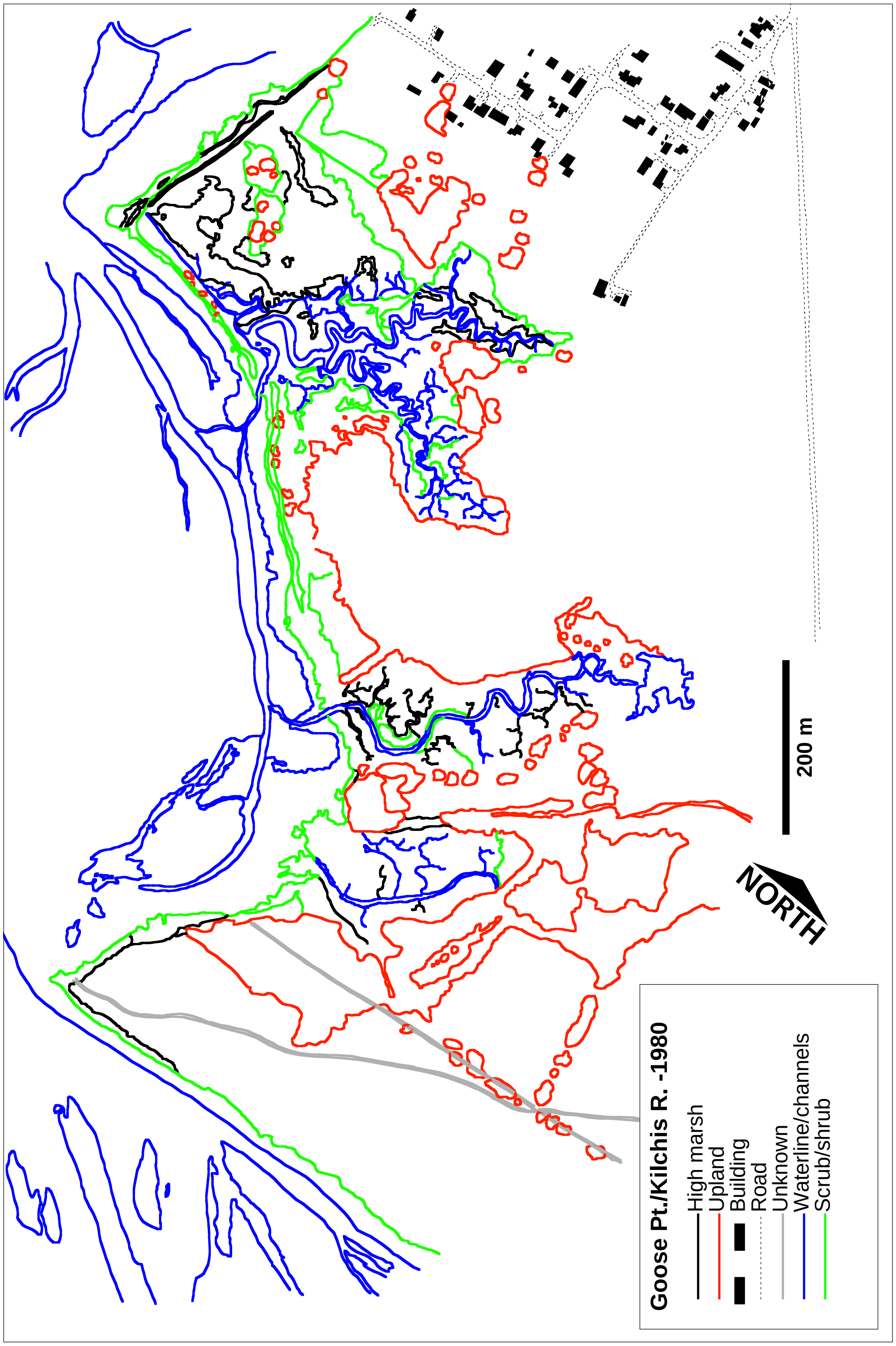

Figure 3 Chronological changes in estuarine wetland structure at Goose Point/Kilchis River breached-dike site from 1939 (a) through 1955 (b), 1965 (c), **1980 (d)** and 1989 (e).

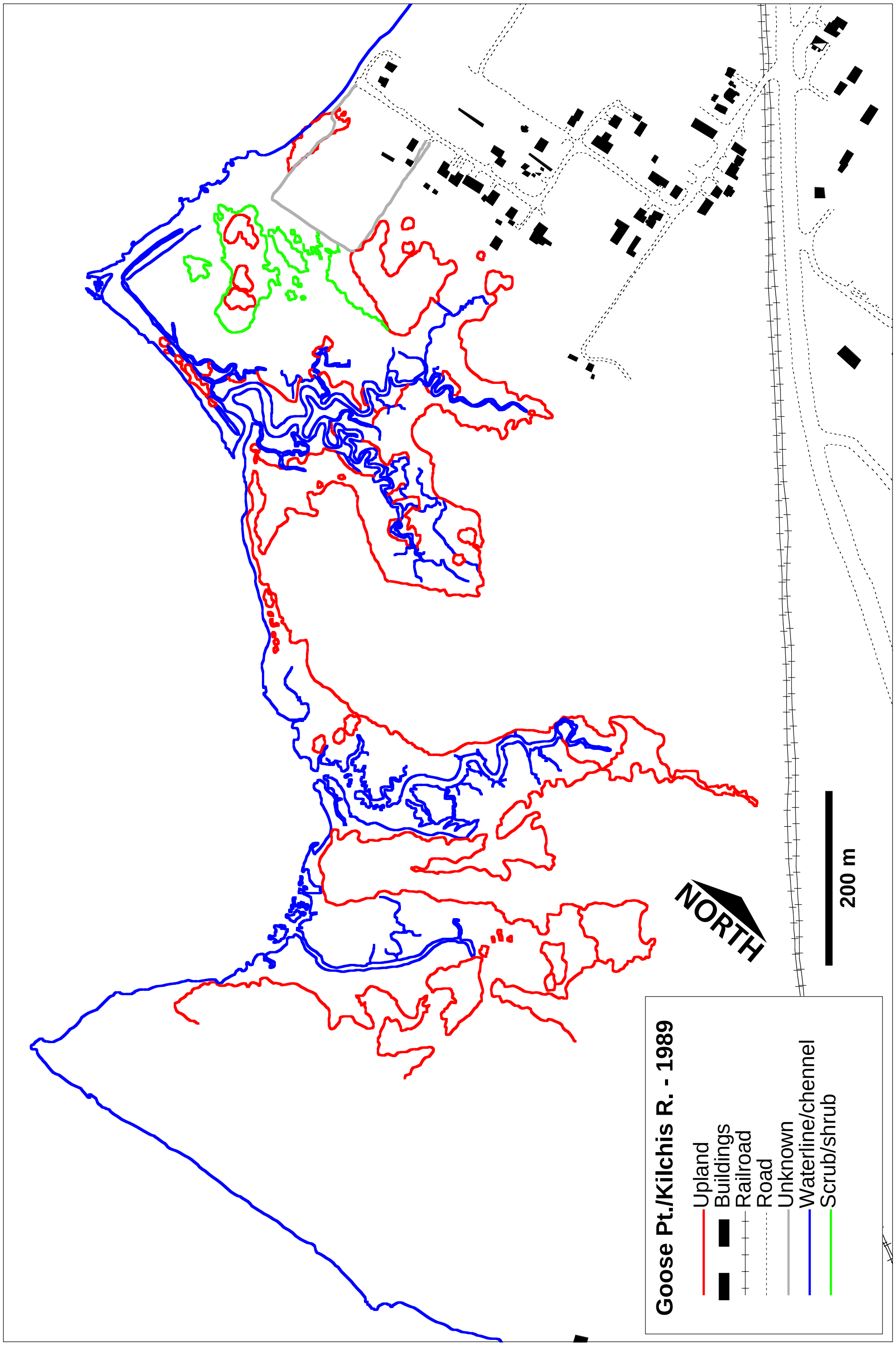

Figure 3 Chronological changes in estuarine wetland structure at Goose Point/Kilchis River breached-dike site from 1939 (a) through 1955 (b), 1965 (c), 1980 (d) and **1989 (e)**.

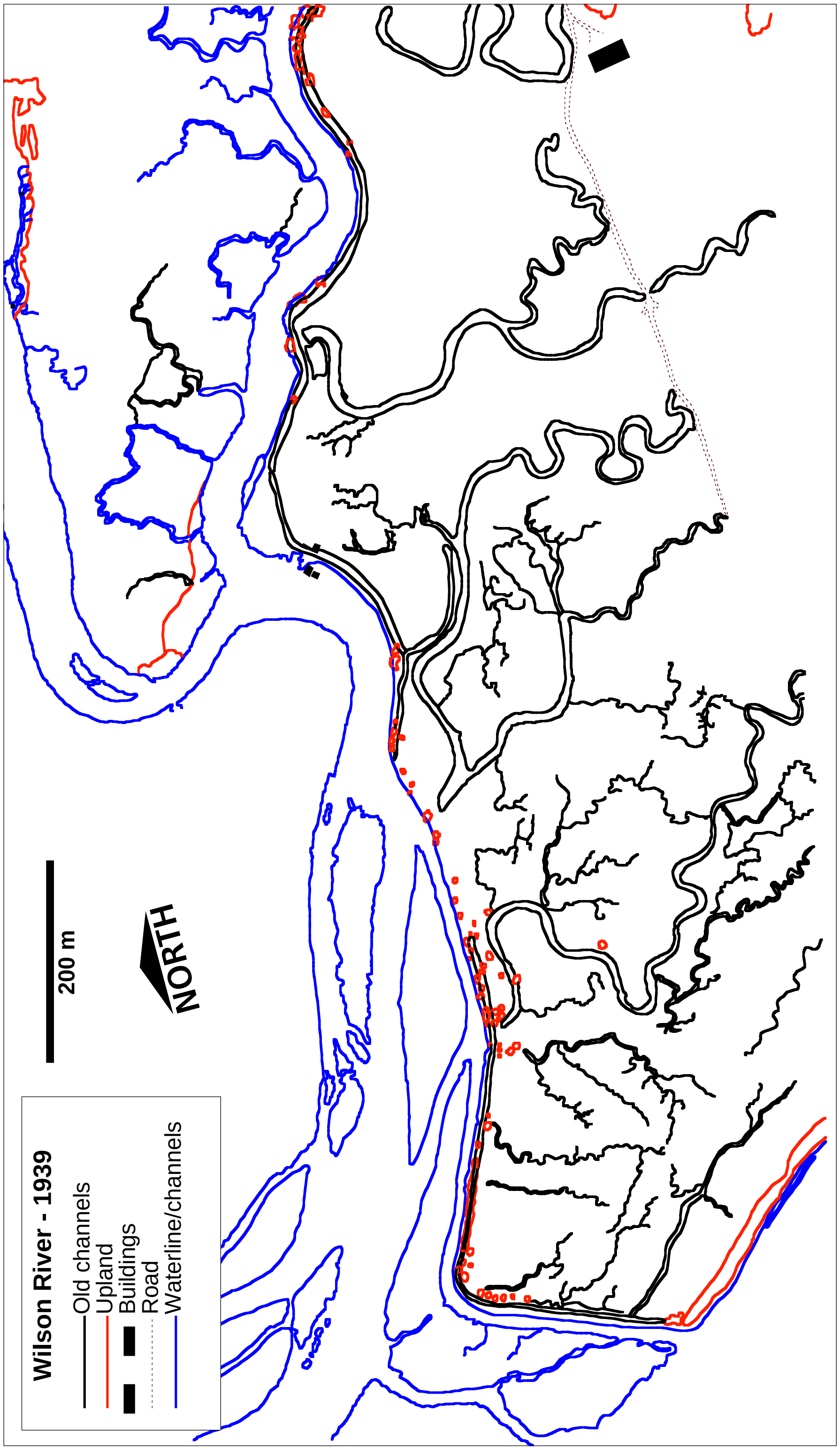

Figure 4 Chronological changes in estuarine wetland structure at Wilson River breached-dike site from **1939 (a)** through 1955 (b), 1965 (c), 1980 (d) and 1989 (e).

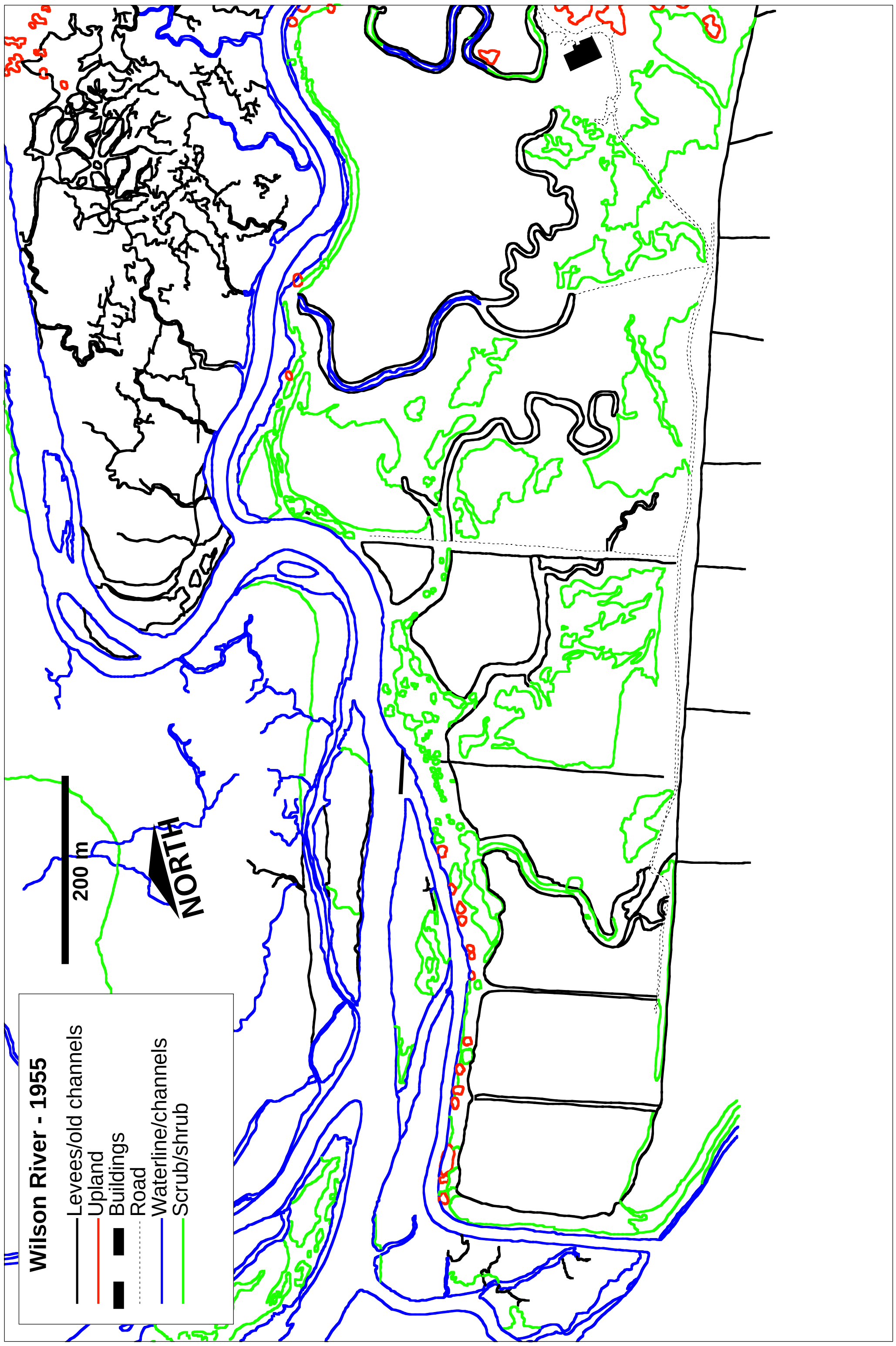

Figure 4 Chronological changes in estuarine wetland structure at Wilson River breached-dike site from 1939 (a) through **1955 (b)**, 1965 (c), 1980 (d) and 1989 (e).

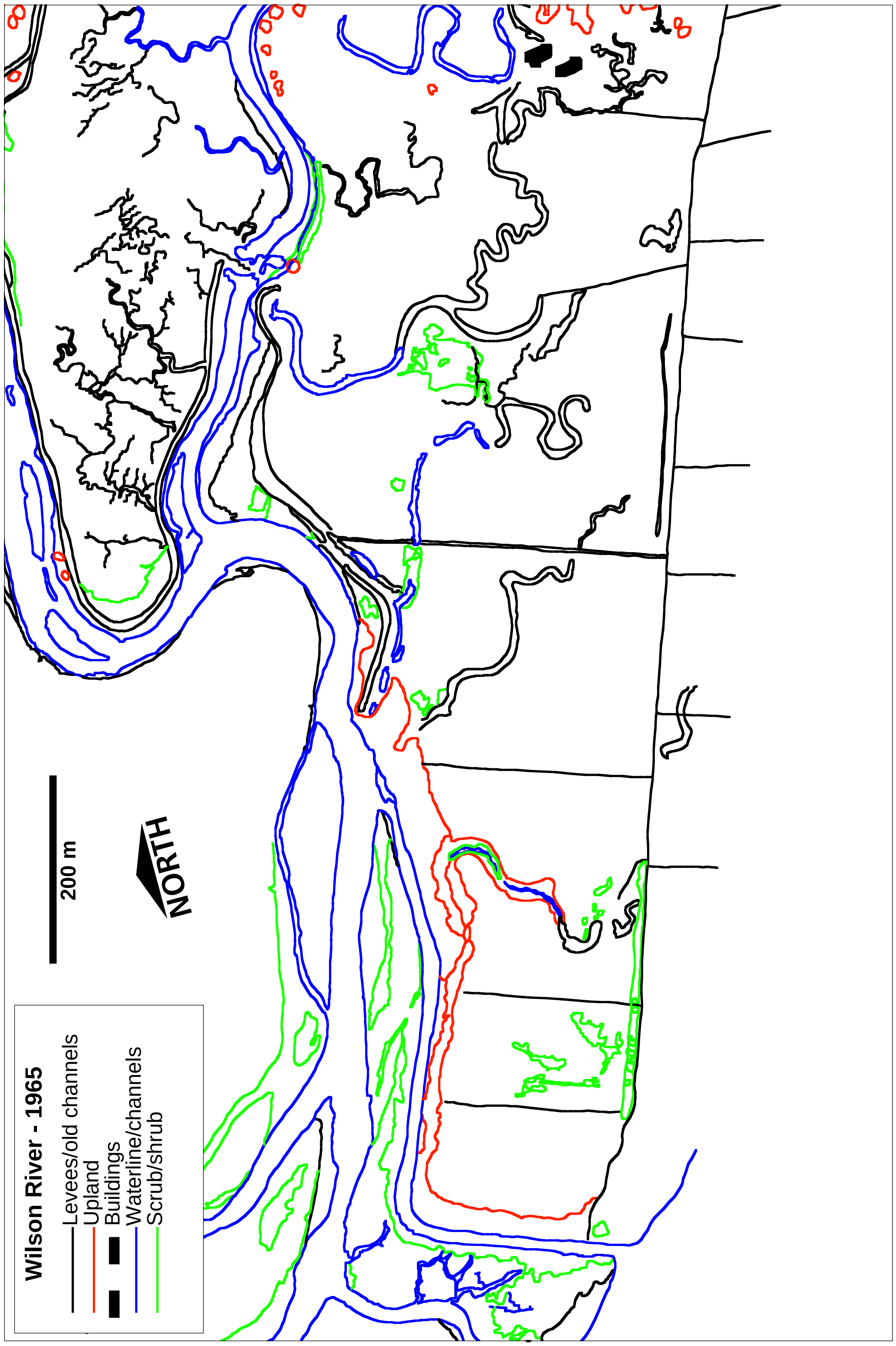

Figure 4 Chronological changes in estuarine wetland structure at Wilson River breached-dike site from 1939 (a) through 1955 (b), **1965 (c)**, 1980 (d) and 1989 (e).

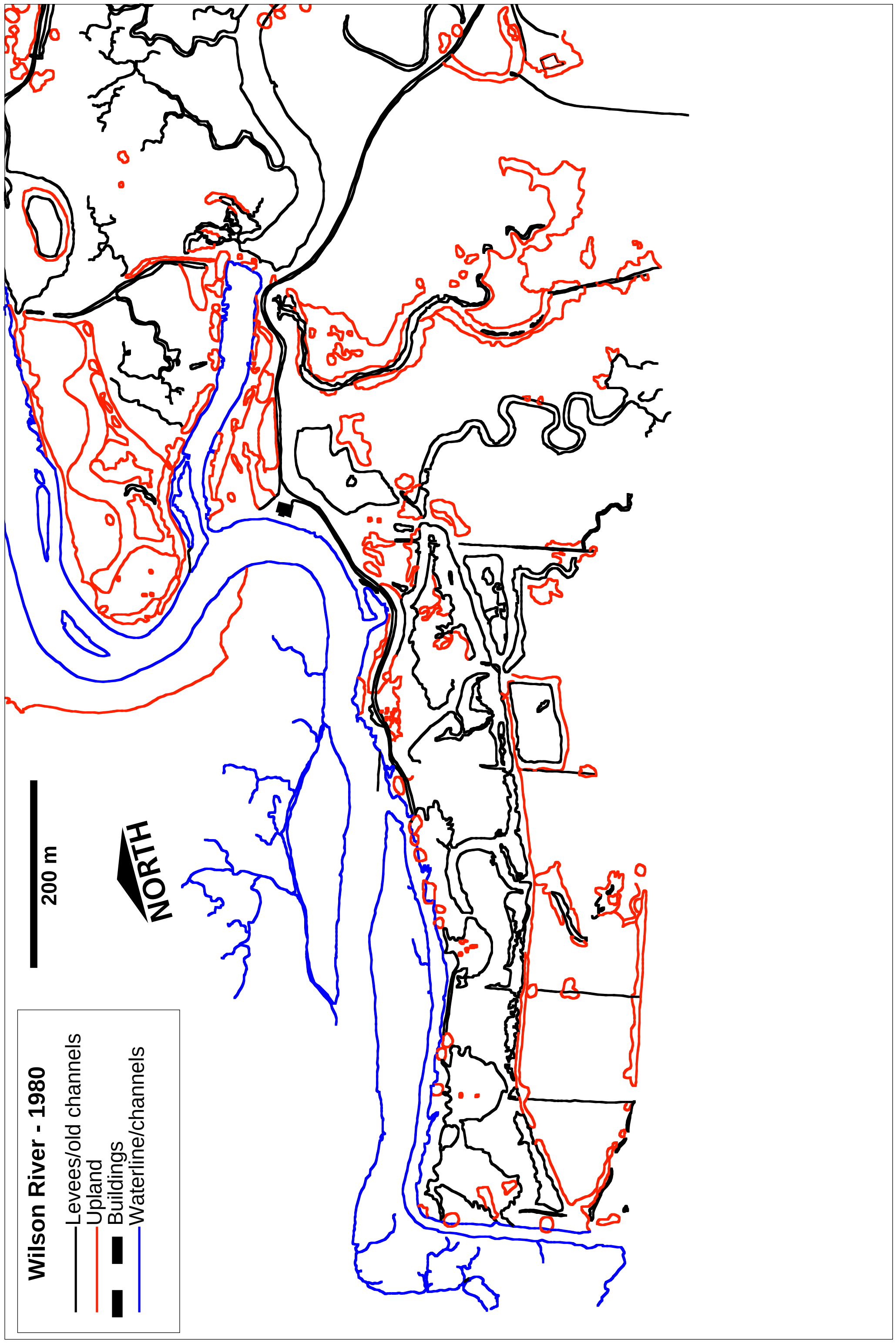

Figure 4 Chronological changes in estuarine wetland structure at Wilson River breached-dike site from 1939 (a) through 1955 (b), 1965 (c), **1980 (d)** and 1989 (e).

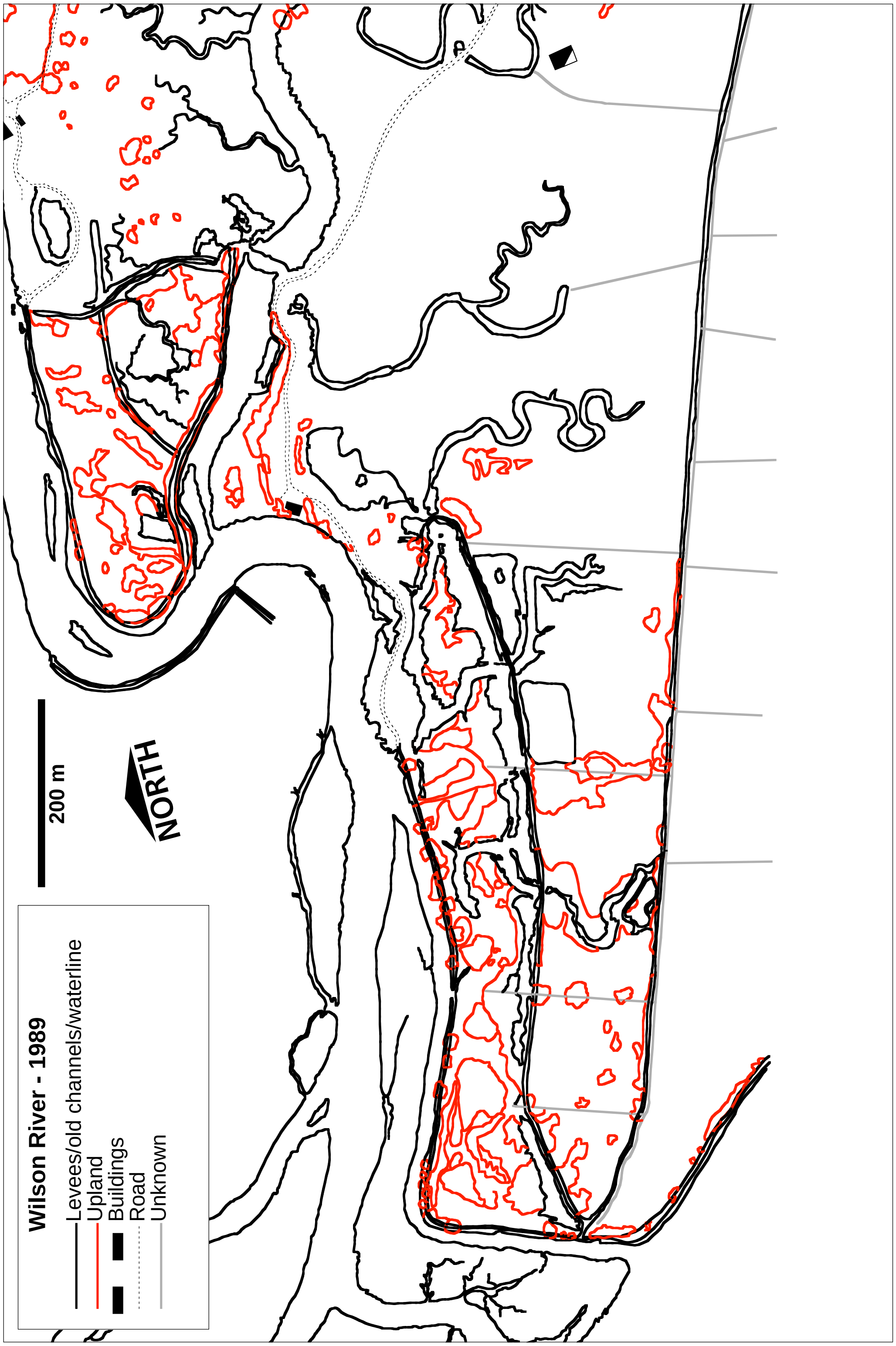

Figure 4 Chronological changes in estuarine wetland structure at Wilson River breached-dike site from 1939 (a) through 1955 (b), 1965 (c), 1980 (d) and **1989 (e)**.

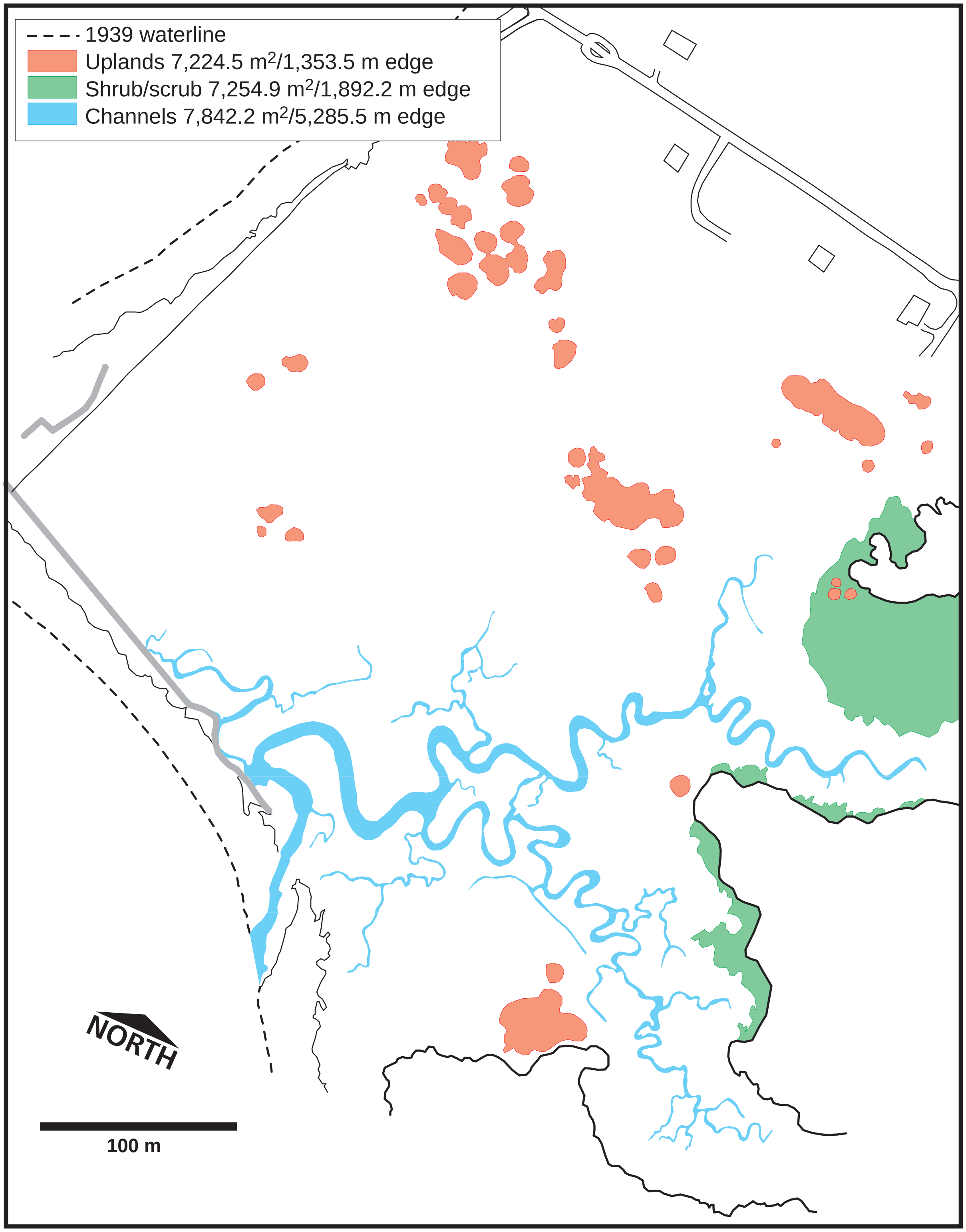

Figure 5A Chronological changes in estuarine wetland structure at Goose Point in **1939 (a)** versus 1989 (b).

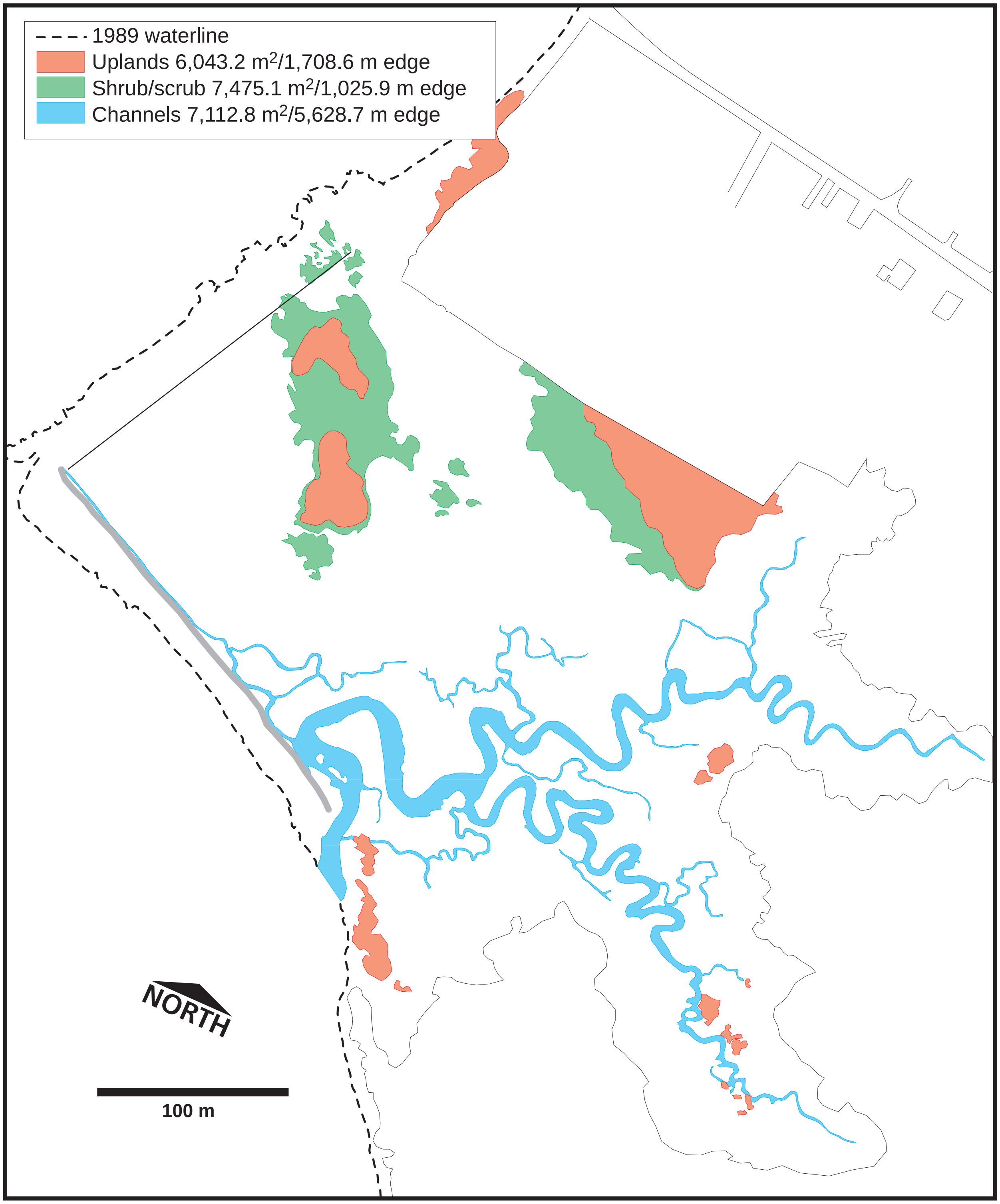

Figure 5B Chronological changes in estuarine wetland structure at Goose Point in 1939 (a) versus **1989 (b)**.

Table 2. Year, channel area and perimeter, upland area and perimeter, and shrub/scrub area and perimeter summary data for Goose Point breached dike site, Tillamook Bay, OR.

Year	Channel Area (m^2)	Channel Perimeter (m)	Upland Area (m^2)	Upland Perimeter (m)	Shrub/Scrub Area (m^2)	Shrub/Scrub Perimeter (m)
1939	7,842	5,286	7,225	1,353	7,255	1,892
1989	7,113	5,629	6,043	1,709	7,475	1,026
CHANGE	-729	343	-1,181	355	220	-866

usually is caused by decreases in the number of smaller patches as a result of coalescing, for example. Increases in edge to area ratios with concurrent decreases in area are often associated with increased habitat patchiness and fragmentation. Encroachment of the wetland also increased from human development on the north margin of the wetland. Although changes in the tidal channel network were also evident, potentially associated with changes in the tidal prism due to human encroachment and other modifications, these changes were neither consistent nor major.

Some reduction in channel density and order was evident in come cases, but extension (head-cutting) of channels was also suggested in others. Given the relatively small, inconsistent changes, we could not interpret restoration pattern or rate from these data because either (1) the dike had breached significantly earlier than 1939 and had already progressed through the early stages of wetland restoration or (2) it had only been diked a short time and typical degradation of the site (e.g., subsidence) had not become advanced before the dike was breached. The effect of periodic encroachment and development of wetland from the upland margin was also assumed to drive some of the changes (e.g., increased fragmentation) that we observed, but the effects could not be effectively separated from natural changes in the wetland.

DISCUSSION

These results are contingent upon both the quality of the data and the assumptions which guided the inclusion of assessment metrics. These are not mutually exclusive; while we were sometimes forced to use GIS data that had less than desirable accuracy in order to include an important metric. And, while we developed an assessment matrix that incorporates weighting factors, we did not weight the metrics because of the element of scientific subjectivity that would be introduced into the final ranking.

Problems in Developing Key GIS Data

Comparison of geospatial data layers to interpret landscape changes is only as inclusive and precise as the accuracy of the attribute data and the position to which it is attributed. In preparing this analysis, we encountered extreme variance in the level of precision that we could depend upon in conducting GIS overlays. Alignment of GIS layers that presumably should have been properly QA/QC'd by TBNEP and others was often difficult and problematic. However, the methodology that we developed for this project is sound and its analytical power increases with increasing spatial accuracy.

The historical habitat data layer (hisestuw) had four major problems with respect to positional and attribute accuracy. First, the data layer was hand drawn by interpreting SCS field notes, not from original maps. Second, historical habitat boundaries were interpolated while simultaneously viewing current USGS 1:24,000 scale 7.5-minute series, quad maps. Third, the only georeferencing on the final map was township and range. Township and range georeferencing is highly inaccurate, and the grid systems are frequently updated over time without documentation. Finally, the map was hand digitized into the GIS, introducing further positional error. Therefore, the positional accuracy of this data layer is nearly impossible to characterize. We anticipated during the planning stages of this project that this data layer would be a cornerstone of our analysis, and its “coarseness” precluded further analyses.

The dikes data layer was less problematic than the hisestuw data layer with regards to positional and attribute accuracy. The main problem with the dikes data layer was its age: 1953 to 1955. Some of the areas diked back then may be breached at present. However, unlike the hisestuw data layer, diked areas can be field verified. Since this data layer was used primarily to identify the locations and sizes of potential restoration sites, we do not characterize its attribute accuracy as critical for the purposes of our analyses.

With regards to existing geospatial data layers provided by TBNEP, we identified two major limitations. First, the positional accuracy between various data layers was off by as much as 100 - 300 meters with respect to edge matching. For example, the estuhabs data layer (created by NWI) and rivers data layer, when overlaid, illustrate this problem well. Here the offset is around 100 m. Theses positional discrepancies can often be corrected by in ArcInfo with ease, but the process can be time consuming. Second, many data layers were not generated at the same scale, and this is always problematic when doing spatial analysis. Again, some of the inaccuracies introduced by overlaying data layers at different scale can be corrected using ArcInfo.

Overall, we feel that the positional and scale accuracy problems in the data layers we used was not serious enough to eclipse our findings. Positional accuracy and polygon/polyline edge matching errors are most problematic when doing overlays in order to calculate areas of coincidence. We avoided doing overlays under these conditions. Differences of scale between data layers is usually a problem when comparing polygon perimeters and polyline lengths. We did not make such comparisons when different scales were encountered.

Another inherent problem relates to the general availability of high resolution topography data, irrespective of whether it was available in GIS. The generally low resolution for elevation data within the diked areas available for restoration prohibits resolution of critical questions such as extent (particularly undiked upland edge) tidal flooding and predictions of the likely distributions of elevation-sensitive habitats (e.g., high vs. low emergent marsh).

Alternative and Additional Assessment Criteria

The criteria that we had available or could generate to assess the potential for restoring diked estuarine wetlands for juvenile salmonid rearing habitat was limited by data availability. We encountered many data sources that were insufficient or of dubious accuracy, and we did not have the exhaustive resources required to generate new, reliable data from field verification.

Extreme caution should be used in interpreting the following data and criteria in lieu of validation or replacement with better information.

Traditional potential restoration site ranking criteria are labor intensive and dependent upon often subjective and qualitative field surveys. The intricacies of spatially explicit ecological and habitat interactions are often missed with existing ranking protocols. For example, exhaustive surveys of upstream water quality parameters over a large watershed area are cost prohibitive and time consuming. Often times (as was the case for this project) geospatial data layers are already available to resource managers that incorporate these types of information and a spatial analysis, as we have developed here, is the only way to incorporate spatially explicit environmental data.

Our methodology is also unique in that it reduces the mount of subjectivity in decision making by utilizing weighted scoring of habitat attributes controlled by the resource manager. This control makes the analysis versatile in that restoration sites can be chosen various alternative weightings of priorities and criteria. For example, the ranking can be skewed toward maximizing different ecological goals or accommodating various levels of risk in attempting to restore juvenile salmonid habitat. Finally, this system facilitates accountability on the part of resource managers in that a discreet series of decisions can be defined quantitatively.

Dikes and Upland Boundaries of Potential Restoration Sites

Despite the fortunate discovery of the 1965 U.S. Army Corps floodplain survey sheets, dikes could not be readily delineated by simple isolation of a few elevation contours. This required extensive extrapolation and subjective interpretation. It was even more of a problem to identify and delineate interior dikes and upland margins, which could dramatically alter our estimates for surface area, dike perimeter and other fundamental descriptors of the potential restoration sites.

Subsidence

A common phenomenon of diked wetlands in the Pacific Northwest and around the world is subsidence of land (historic marsh) where regular tidal inundation has been eliminated or severely reduced. The extent of subsidence (topographic elevation of diked land relative to MLLW or MSL) of these sites is an extremely important but missing criterion in this analysis. A less quantitative estimate that might serve as an analog to subsidence would be the time duration each site was diked. However, this information was not available.

Dike and Tidegate Integrity

In the absence of an extensive survey of each site we identified, we had to assume that all dikes and tidegates were intact. On-site assessment would permit direct observation and interpretation (e.g., from wetland vegetation composition and structure) of any reversal to vegetation indicative of tidal inundation. We would presumably assign higher scores and ranks to degraded dikes and tidegates on the assumption that sites with some level of tidal inundation and salinity exposure, no matter how small, was developing an estuarine wetland community appropriate to restoration goals.

Optimizing Restoration of Estuarine Rearing Habitat for Juvenile Salmonids in Tillamook Bay

This analysis demonstrated a common issue with restoration of tidal habitats in an extensively developed tidal flood plain—sites that have the most potential to benefit important resources such as salmon are often those that are the most difficult to restore. Even without taking into account the actual availability and cost of discrete tracts of land that could be restored, the difference between the potential of restoring viable estuarine rearing habitat for juvenile salmonids and our assessment of restoration feasibility and constraints was often quite polarized. The most notable sites that ranked high in potential juvenile salmon rearing and indicated high feasibility with few constraints included: (1) #4-Hall Slough, (2) #9-Nolan Slough and (3) #Kilchis River.

As mentioned earlier, some of these sites are elements of contiguous blocks that may be (or have been) integrated hydrologically, such that restoration of one site cannot necessarily be implemented without impacting or involving an adjacent site. Of the three prominent sites listed above, #4-Hall Slough is connected in some degree with #5-Wilson River, and #9-Nolan Slough is contiguous with the two Memaloose Point sites (#7, #8). While the adjacent sites may not rank as high in juvenile salmonid rearing potential, or may rank low in feasibility or high in constraints, their inclusion (as in a phased approach) in a long-term restoration strategy would be advantageous. We would anticipated that expanding the restoration area into adjacent sites would magnify a number of wetland attributes important to juvenile salmon rearing, including: (1) increased the tidal prism and associated increased tidal channel complexity; (2) increased habitat diversity; (3) increasing rearing area in contact a broader salinity gradient; and (4) expanding the sources of organic matter production contributing to the local and Bay-wide (detritus-based) food web.

Therefore, as confined by scientific and technical criteria for the potential and feasibility of restoration in this analysis, the following areas of historic tidal wetlands in Tillamook Bay would likely provide the highest function for juvenile salmon rearing habitat and would be the most feasible for restoration:

(1) #9-Nolan Slough, phased with #8-Memaloose Point South

(2) #4-Hall Slough, phased with portions or all of #5-Wilson River

(3) #3-Kilchis River

Recommendations for Future Assessments and Implementation

In addition to other, practical considerations, such as site availability and cost, that may alter ranking of the historic tidal wetland sites in Tillamook Bay, other measurements should be used to further refine the restoration assessment. Our analysis did not allow field measurements on or adjacent to the sites. However, further efforts in both the field and in refinement and expansion of the GIS database would reduce the inherent uncertainty in predicting the probability, patterns and rates of habitat restoration. These include:

1. Conduct further measurements for sites that are under serious consideration for restoration:
   - high resolution elevation/topographic survey to determine subsidence rates;
   - dike and tidegate integrity; and,
   - actual juvenile salmonid occurrence in site vicinity, with emphasis on chum, chinook and coho salmon fry (that would provide maximal utilization of tidal marshes and channels).
2. Establish estuarine wetland (high marsh, low marsh, shrub/scrub; also eelgrass?) reference site(s) to track natural changes and response to restoration.

3. Determine sediment accretion rates in natural marshes in vicinity of potential restoration sites in order to provide realistic estimates of time required to return subsided wetlands to tidal elevation that would support emergent and other natural estuarine vegetation.
4. Field survey (digitize) dike (and other habitat polygons of interest) perimeters using dual frequency, 0.5 to 1.0 m horizontal resolution, real time, differentially corrected GPS.
5. Perform edge matching and incorporate additional control points in geospatial data layers in order to improve positional, attribute, and topological accuracy.

A final recommendation would be to integrate estuarine salmonid habitat restoration assessment methods such as this with those designed for the watershed and flood plain freshwater (Bradbury et al. 1995; Nehlsen 1997; Thom and Moore 1996) in a single assessment that takes into account the continuum of salmon life history habitat transitions from freshwater spawning and rearing to estuarine rearing and ocean entry.

Restoration, Conservation and Management

Loss or degradation of the remaining viable estuarine rearing habitat for juvenile salmon should not be substituted for the uncertain promise of restoration. One of the inherent goals of this demonstration project was to provide guidance in setting priorities and objectively evaluating options for estuarine wetland restoration. However, restoration should not be uncoupled from conservation and management of remaining natural estuarine wetland resource. The still considerable scientific uncertainty surrounding estuarine habitat restoration implies that: (1) the ultimate outcome or "endpoint" is unpredictable because many ecosystem processes have been irreversibly altered; (2) the rate of recovery by a restoring wetland is dependent upon a variety of factors and is likely longer than the usual bureaucratic window that promoted the restoration activity, and most certainly longer than most monitoring and assessment windows; (3) there is little evidence of the function for juvenile salmon of interim development stages. Highest priority should be attached to the identification, assessment and conservation of existing functional estuarine rearing habitats, with the objective of building on these "core" areas with future restoration (see Salmonid Rearing Landscape metrics). In addition to serving as the last viable rearing habitats for juvenile salmon in the Bay, they have the potential (depending upon proximity) to both provide sources of fish, invertebrate and plant recruitment to restoration sites as well as serve as 'reference' sites to which the progress of restoration sites can be compared and evaluated. At the minimum, this requires concerted management and planning to couple protection of natural marsh habitats with restoration of historically-diked habitats. Optimally, both conserved and restoring marshes should be integrated into the broader context of the conserving, restoring and managing juvenile salmonid migration and rearing habitats across the entire watershed-estuary landscape.

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APPENDICES

A. Metadata for (DIKES) GIS coverage of levees bordering estuarine intertidal wetlands in Tillamook Bay, OR

B. Metadata for (HISESTUW) GIS coverage of estuarine wetland structure in Tillamook Bay, OR in 1856

C. Landscape position of fifteen potential breached-dike restoration sites in Tillamook Bay, OR. Eelgrass (primarily *Zostera marina* but also including *Z. japonica*) indicated by black (dense coverage) and light green (sparse coverage) from Strittholt and Frost (1996).

D. Tabulation of GIS-derived assessment data for fifteen potential breached-dike restoration sites in Tillamook Bay, OR. See text and appendices A and B for details on assessment metrics.

Appendix A. DIKES GIS metadata

Identification_Information:
    Citation:
        Citation_Information:
            Originator: Wetland Ecosystem Team, University of Washington
            Publication_Date: 19970900
            Title: Levees of Tillamook Bay
            Geospatial_Data_Presentation_Form: map
    Description:
        Abstract:
            Levees of Tillamook Bay, Oregon. Taken from 1964 Soil
            Conservation Service Soil Survey Publication.
        Purpose:
            Original purpose is to delineate and identify diked estuarine habitat
            for Tillamook Bay National Estuary Program.
    Time_Period_of_Content:
        Time_Period_Information:
            Single_Date/Time:
                Calendar_Date: 19640800
        Currentness_Reference: Publication Date
    Status:
        Progress: Complete
        Maintenance_and_Update_Frequency: None planned
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            East_Bounding_Coordinate: -123.850000
            North_Bounding_Coordinate: +45.400000
            South_Bounding_Coordinate: +45.600000
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            Theme_Keyword: Dike
            Theme_Keyword: Diking District
            Theme_Keyword: Flood Control
        Place:
            Place_Keyword_Thesaurus: None
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            Place_Keyword: National Estuary Program
            Place_Keyword: Kilchis River
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            Place_Keyword: Trask River
            Place_Keyword: Wilson River
            Place_Keyword: Miami river
            Place_Keyword: Tillamook

Access_Constraints: None
Use_Constraints: None
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Position: Fish Biologist IV
Contact_Address:
Address_Type: mailing and physical address
Address:
Box 357980
University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.543.7185
Contact_Facsimile_Telephone: 206.685.7471
Contact_Electronic_Mail_Address: simenstd@u.washington.edu
Hours_of_Service: 0800-1800
Data_Set_Credit:
From SOIL SURVEY, TILLAMOOK AREA, OREGON, Issued August 1964, Series 1957, No. 18. U.S. Dept. of Agriculture, Soil Conservation Service, In Cooperation with Oregon Agricultural Experiment Station.
Native_Data_Set_Environment:
Heads-up digitized in MapInfo format, converted to ArcExport format.
Data_Quality_Information:
Logical_Consistency_Report: N/A
Completeness_Report: Complete
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
The "Index to Map Sheets" map was registered in MapInfo and control points for obvious landmarks were extracted from this index map for the aerial photos of each area. Four control points were generated for each aerial photo The positional accuracy is not known and should be used for general locations of levees. The data represents a 1964 condition, and was not field checked for currentness.
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: Soil Conservation Service (comp.)
Originator: US Dept. of Agriculture w/ Oregon Agricultural Experiment Station
Publication_Date: Unpublished material
Publication_Time: Unknown

Title: Soil Survey, Tillamook Area, Oregon
Edition: Series 1957, No. 18 Issued August 1964
Geospatial_Data_Presentation_Form: map
Series_Information:
Series_Name: Series 1957
Issue_Identification: No. 18
Publication_Information:
Publication_Place: Washington, D.C.
Publisher: U.S. Goverment Printing Office
Source_Scale_Denominator: 20000
Type_of_Source_Media: paper
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 19640800
Source_Currentness_Reference: Publication Date
Source_Citation_Abbreviation: SCS
Source_Contribution: Levee locations at Tillamook Bay, Oregon
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Process_Description:
The "Index to Map Sheets" map was registered in MapInfo and control points for obvious landmarks were extracted from this index map for the aerial photos of each area. Four control points were generated for each aerial photo The positional accuracy is not known and should be used for general locations of levees. The data represents a 1964 condition, and was not field checked for currentness.
Source_Used_Citation_Abbreviation: Maps
Process_Date: 19970801
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Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Person: Blake Feist
Contact_Position: Research Assistant
Contact_Address:
Address_Type: mailing and physical address
Address:
Box 357980
University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.685.3505
Contact_Facsimile_Telephone: 206.685.7471
Hours_of_Service: 0900-1800
Cloud_Cover: 0
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:

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            Oregon_Lambert:
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                False_Northing: 0.00
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        Planar_Coordinate_Encoding_Method: row and column
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        Planar_Distance_Units: International Feet

Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Position: Fish Biologist IV
Contact_Address:
Address_Type: mailing address
Address:
Box 357980
University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.543.7185
Contact_Facsimile_Telephone: 206.685.7471
Contact_Electronic_Mail_Address: simenstad@u.washington.edu
Hours_of_Service: 0800-1800
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Distribution_Liability: None
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
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Format_Version_Number: 7.1
Format_Version_Date: 19980430
Format_Specification: .e00 Arc/Info interchange file
Format_Information_Content: Levees
File_Decompression_Technique: No compression applied

Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
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Fees:
Metadata_Reference_Information:
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Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Position: Fish Biologist IV
Contact_Address:
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Box 357980
University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.543.7185
Contact_Facsimile_Telephone: 206.685.7471
Contact_Electronic_Mail_Address: simenstad@u.washington.edu
Hours_of_Service: 0800-1800
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: June 8, 1994

B. HISESTUW GIS metadata

Identification_Information:
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    Citation_Information:
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      Publication_Date: 19970900
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      Geospatial_Data_Presentation_Form: map
  Description:
    Abstract:
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      Prepared by Kevin Coulton, P.E., Associate and Philip B. Williams,
      Ph.D., P.E., President Philip and Williams and Associates, Ltd.
      With Patricia A. Benner, Oregon State University and assistance
      from the Tillamook Pioneer Museum.
    Purpose:
      Original purpose is to assist with delineating and
      identifying diked estuarine habitat for Tillamook
      Bay National Estuary Program.

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Use_Constraints: None
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Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Position: Fish Biologist IV
Contact_Address:
Address_Type: mailing and physical address
Address:
Box 357980
University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.543.7185
Contact_Facsimile_Telephone: 206.685.7471
Contact_Electronic_Mail_Address: simenstd@u.washington.edu
Hours_of_Service: 0800-1800
Data_Set_Credit:
An Environmental History of the Tillamook Bay Estuary and Watershed. Prepared by Kevin Coulton, P.E., Associate and Philip B. Williams, Ph.D., P.E., President Philip and Williams and Associates, Ltd. With Patricia A. Benner, Oregon State University and assistance from the Tillamook Pioneer Museum.
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Heads-up digitized in MapInfo format, converted to ArcExport format.
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Attribute_Accuracy_Report: unknown
Quantitative_Attribute_Accuracy_Assessment:
Attribute_Accuracy_Value:
Attribute_Accuracy_Explanation:

Logical_Consistency_Report: N/A
Completeness_Report: Complete
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
The map was registered in ArcInfo® from four control points. The positional accuracy is not known and should be used for general locations of historical habitat types. The data represents an 1856 condition, and was not field checked for currentness.
Lineage:

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            Originator: General Land Office
            Publication_Date: Unpublished material
            Publication_Time: Unknown
            Title: Unknown
            Edition: 1856
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Process_Step:
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The map was registered in ArcInfo® using four control points. The positional accuracy is not known and should be used for general locations of historical habitat types. The data represents an 1856 condition, and was not field checked for currentness.

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                Contact_Person: Blake Feist
            Contact_Position: Research Assistant
            Contact_Address:
                Address_Type: mailing and physical address
                Address:
                    Box 357980
                    University of Washington
                City: Seattle
                State_or_Province: WA
                Postal_Code: 98195-7980
                Country: USA
            Contact_Voice_Telephone: 206.685.3505

Contact_Facsimile_Telephone: 206.685.7471
Hours_of_Service: 0900-1800
Cloud_Cover: 0
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Latitude_of_Projection_Origin: +41.75
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False_Northing: 0.00
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Attribute_Label: -
Attribute_Definition: polygon attribute table
Attribute_Definition_Source: generated
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: -
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown
Attribute:
Attribute_Label: AREA
Attribute_Definition: Degenerate area of polygon
Attribute_Definition_Source: Assigned
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: 0
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown

Attribute:
Attribute_Label: PERIMETER
Attribute_Definition: Degenerate perimeter of polygon
Attribute_Definition_Source: Assigned
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: 0
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown
Attribute:
Attribute_Label: HISESTUW#
Attribute_Definition: Internal feature number
Attribute_Definition_Source: Computed
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: Sequential unique positive integer
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown
Attribute:
Attribute_Label: HISESTUW-ID
Attribute_Definition: User-assigned feature number
Attribute_Definition_Source: User-defined
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: Integer
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown
Attribute:
Attribute_Label: HABITAT
Attribute_Definition: Historical Landscape Type
Attribute_Definition_Source: designated
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: multiple characters
Attribute_Value_Accuracy_Information:
Attribute_Measurement_Frequency: Unknown

Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
Contact_Position: Fish Biologist IV
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City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
Country: USA
Contact_Voice_Telephone: 206.543.7185
Contact_Facsimile_Telephone: 206.685.7471
Contact_Electronic_Mail_Address: simenstad@u.washington.edu
Hours_of_Service: 0800-1800
Resource_Description: Arc/Info Coverage of 1856 General Land Office Original Survey
Distribution_Liability: None
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARCE
Format_Version_Number: 7.1
Format_Version_Date: 19980430
Format_Specification: .e00 Arc/Info interchange file
Format_Information_Content: landscape types
File_Decompression_Technique: No compression applied
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name:
Access_Instructions:
Online_Computer_and_Operating_System:
Fees:
Metadata_Reference_Information:
Metadata_Date: 19970828
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Charles A. Simenstad
Contact_Organization: Wetland Ecosystem Team, University of Washington
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City: Seattle
State_or_Province: WA
Postal_Code: 98195-7980
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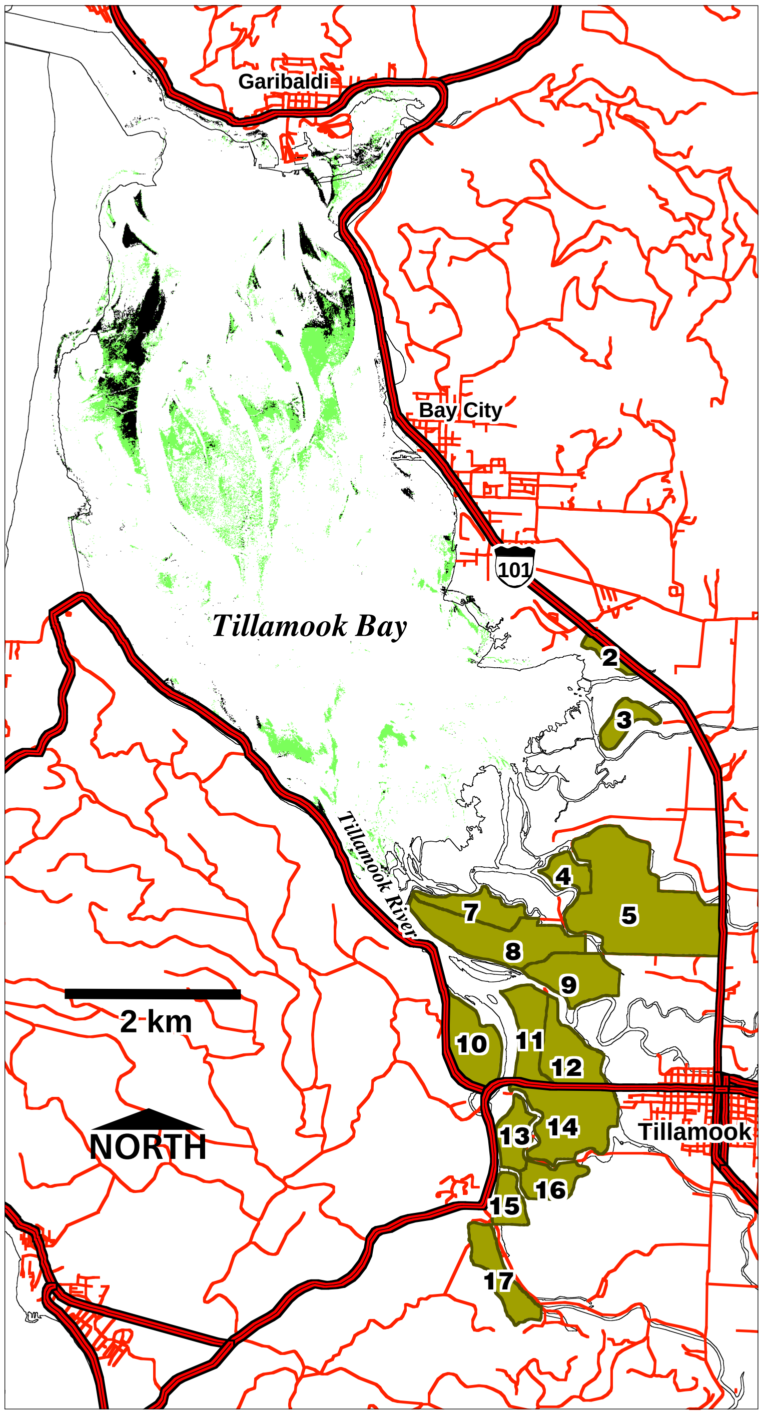
Hours_of_Service: 0800-1800
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: June 8, 1994

Appendix C. Landscape position of fifteen potential breached-dike restoration sites in Tillamook Bay, OR. Eelgrass (primarily Zostera marina but also including Z. japonica) indicated by black (dense coverage) and light green (sparse coverage) from Strittholt and Frost (1996).



Appendix D. Tabulation of GIS-derived assessment data for fifteen potential breached-dike restoration sites in Tillamook Bay, OR. See text and appendices A and B for details on assessment metrics.