[Online Appendix for "Conservation priorities and environmental offsets: Markets for Florida Wetlands," by Daniel Aronoff and Will Rafey]

Online Appendix – Data and Estimation Details

A Details of primary data sources

A.1 Wetland offsets

A.1.1 Wetland bank entry, size, and location

Entry into offsets production requires that the private landowner producing offsets obtain certification. To identify the locations of existing banks and their service areas, we use administrative data containing all mitigation bank permits issued under Ch. 373.4136, Florida Statutes by either the Florida Department of Environmental Protection (FDEP) or a Water Management District.

We obtained our data from FDEP in July 2020. For each bank, these data includes the entry date, total capacity (lifetime offsets), a map of the wetland bank project site, and a map of the service area delineating the hydrological region(s) where the bank can sell its offsets.

A.1.2 Wetland offset production and trades

Offsets trades are recorded by the regulator in order to verify each wetland permittee's compliance with conservation laws and ensure that offsets used for compliance are retired from each bank's store of available offsets. In practice, these records are dispersed across state and various local agencies.

We assemble a comprehensive ledger for each bank that includes the date of the transaction, quantity of offsets released (if produced), and quantity of offsets deducted (if sold). We use these transaction-level data to assemble a ledger of wetland offsets transactions from 1995–2018.

A.2 Offset transaction prices

We obtain transaction-level prices from 1998–2020 for a subset of transactions described below. We match these prices to banks, then deflate all nominal prices to real (2020 USD) values with the consumer price index defined in A.13.

The transaction price for each offset trade are privately negotiated and not reported to the regulator. To the best of our knowledge, there has been no previous systematic effort to compile this data. We obtain information from a large private broker and public infrastructure project.

Cross-sectionally, our price data covers banks comprising nearly two-thirds of production (63%) and trades (67%) from 1995–2018. The main missing areas are Palm Beach and the upper panhandle.

1/ NDA with private broker. Through a nondisclosure agreement, we access all private transactions brokered by a large intermediary from 2004–2018, who provided us with the date, quantity, price, and wetland bank of each transaction.

2/ FOIA, FDOT. Public infrastructure projects such as highways can require offsets. We issued FOIA requests to the infrastructure team at the Florida Department of Transportation (FDOT). FDOT has different districts that collect different data, but we obtained data from Districts 2, 5, 7, 1.

3/ FOIA, counties. Florida's counties also occasionally engage in infrastructure and other development that require wetland offsets. We issued FOIAs to major Florida counties. Not all counties maintained complete records, but we obtained records from Brevard County, Lee County, and Orange County ranging variously from 1998–2020, which typically include the date or year of the transaction, the price paid, and number of offsets.

A.3 Wetland bank costs

We obtain cost data by hand from wetland bank contracts, which we match to the banks in our data.

We observe two categories of costs:

Restoration costs

Restoration costs are measured as the sum of directly reported restoration costs and the total amount put in escrow in the Long-Term Maintenance Trust Fund.

Land costs

We obtain the baseline assessed value of the parcel as well as, where possible, the purchase value.

We deflate nominal values in the entry year to real (2020 USD) values.

A.4 Hydrological boundaries

We use the U.S. Geological Survey (USGS) Watershed Boundary Dataset to define local watersheds as 12-digit hydrological units or HUC12s (USGS, 2013), depicted in Figures A1 and A2.

This data is produced by the USGS for the U.S. Department of the Interior and consists of 7,700 polygons. We last downloaded the most recent version on 13 February 2023.

We construct our map for Florida by dropping HUC12 units not overlapping with Florida, i.e., where the "states" field equals (FL), (AL,FL), (FL,GA) or (AL,FL,GA).

1,378 HUC12s (watersheds) satisfy this criterion.

A.5 Hydrological flow network

In robustness, we inspect the flow network across watersheds, also constructed from the WBD introduced in A.4. Figure A1 shows this hydrological network.

We build two adjacency matrices for the hydrological graph.

First, an inflow matrix, where row h (corresponding to a watershed h) has entries of 0 except for columns h' such that h' flows into h. The rows of this matrix can sum to more than 1 because some HUC12s have more than one upstream HUC12.

Second, an outflow matrix where row h has entries of 0 except for columns h' such that h flows to h'. The rows of this matrix sum to no more than 1, because each HUC12 flows to at most one HUC12, with some rows summing to zero when a HUC12 is isolated or flows to the ocean.

A.6 Water management districts

Florida has five water management districts, which collaborate with the Florida Department of Environmental Protection (FDEP) under the Florida Water Resources Act (Chapter 373, Florida Statutes).

We use FDEP's Water Management District Boundaries Dataset.

This dataset contains the extent of all five water management districts in Florida. Because the WMD boundaries closely align with HUC4s, we match HUC4s to WMDs and use this approximation to match markets (via the first four digits of their primary HUC8 code) and watersheds (via the first four digits of the HUC12) to water management districts.

Water Management District	HUC4	Number of HUC12s
Southwest Florida	0310	248
St. John's River	0307, 0308	322
South Florida	0309	239
Northwest Florida	0312, 0313, 0314	369
Suwannee	0311	200

A.7 Land cover

We use land cover data from the Coastal Change Analysis Project (C-CAP) from the National Oceanic and Atmospheric Administration (NOAA), from 1996, 2001, 2006, 2011, and 2016.

Work by Brody *et al.* (2015) used earlier versions of this dataset (the 2001 and 2006 editions). We are unaware of work in economics using this data other than us, but surely someone has.

The raw data has pixels at $30\times30\text{m}^2$ resolution and contains twenty-five land use categories (listed in Appendix D). Six categories are wetlands.

We define three principal land use categories from the raw data: developed land (c2–c5) and wetland (c13–c18), and other (c6–c12, c19–c23). We also measure highly-developed land (c2). We also track agricultural land (c6–c8) and forest land (c9–c12), though we do not use this in our main analysis.

Appendix B describes the several steps we take to distill useful features from the resulting data.

A.8 Land ownership

We obtain two Florida administrative datasets to track land ownership over time. The data is produced by Florida Department of Environmental Protection, in collaboration with the Florida Department of Management Services (DMS) and housed in the Florida State Owned Lands and Records Information System (FL-SOLARIS), authorized by Sections 216.052, 253.0325, and 253.87 Florida Statutes.

We are unaware of prior work in economics using this data.

1. We obtain state-owned conservation land from the Florida Land Inventory Tracking System (LITS), introduced in 2013 and updated annually. Our version contains 71,531 polygons. LITS is preferable because it has the date of acquisition, unlike CLEAR described below.

2. We obtain federally-owned conservation land, as well as locally-owned land (land owned by a special district, county, municipality, or a water management district) from Conservation Lands, Easements, and Recreation (CLEAR), introduced in September 2017, as specified in 253.87 FS, and updated every five years. Our version has 162,900 polygons.

3. We construct a map of all pre-1995 conservation land as the union of all state parcels in 1 and federal and local parcels in 2, dropping state lands from LITS acquired after 1995. We use this map primarily to identify private wetlands in each watershed using the techniques described in B.1.1–B.1.2.

4. We build an annual panel from 1995–2020 of conservation land purchases from LITS by identifying polygons acquired under either Preservation 2000 or Florida Forever or both programs in each of these year. As described in B.1.4, we use this data to construct our conservation lands cost shifter.

A.9 Demographics

A.9.1 Census

We use standard demographic data at the zip code level (Zip Code Tabulation Area, ZCTA5) on population, housing units, median home value, and median income, in particular using the same variables as Taylor and Druckenmiller (2022) for comparability.

The Census data includes the 2000 Census and then American Community Survey decennial observations centered in 2009, 2014, and 2019 (i.e., from 2007–2011, 2012–2016, and 2017–2021).

Variables	ACS codes (sf3)	Census 2000 codes
population	B01003_001	P001001
median income	B19013_001	P053001
housing units	B25001_001	H001001
median home value	B25077_001	H085001

We linearly interpolate the observed values in 1999 (2000 Census), 2009, 2014, and 2019, censoring interpolated values at zero where required, to obtain annual demographic data for each zip code from 1995–2020. Observations for 1995–1998 are assumed to grow at the 1999–2009 rate. The observation for 2020 is assumed to grow at the 2014–2019 rate.

A.9.2 Zillow

We use Zillow, Inc.'s Home Value Index (ZHVI), which is commonly used by economists.

This is a smoothed, seasonally adjusted measure of the typical home value and market changes across a given region and housing type, derived from over 100 million homes, including new construction homes and/or homes that have not traded on the open market in many years.

Our version is monthly from 1996–2020 for each Florida zip code. We use the "ZHVI All Homes (SFR, Condo/Co-op) time series, smoothed, seasonally adjusted" that we downloaded in October 2020.

A few zips do not appear in the data until after 1996. For 1995, and for zip codes missing observations after 1995, we linearly interpolate price indices to build a balanced panel.

We then aggregate monthly values by year to construct zip code level home prices from 1995–2020.

A.10 Flood insurance claims

We use redacted administrative data from the National Flood Insurance Program (NFIP) from FEMA, which has been used in several studies (Brody *et al.*, 2015; **?**; Taylor and Druckenmiller, 2022), particularly since its public release in 2019.

Our version of the FEMA National Flood Insurance Program (NFIP) Redacted Claims dataset, downloaded 16 January 2023, includes new data relative to the research cited (as well as relative to a previous draft of this paper), particularly for the years 2019 and 2020.

We primarily use four fields from this data:

Date

We assign claims to calendar years using the recorded date of claim.

For Florida, the data ranges from 1975-2022, but with only a few observations before 1978 (1 claim in 1975, 0 claims in 1976, and 54 claims in 1977) and for our version, 2021, 2022 appear incomplete (1177 claims in 2021, 72 claims in 2022), so we use data from 1985–2020, primarily focusing on data from 1990–1995 and 2016–2020 as we describe below.

Amount

We define the total claim as the sum of contents and building payments.

We omit "Increased Cost of Compliance" (ICC) coverage, which is included after 1997. No ICC claims occur prior to 1997, and they comprise less than one percent (0.568%) of overall payments.

Location

We restrict to claims occurring in Florida, which drops the dataset from 2,570,089 claims to 312,306. We then drop 3 claims that have negative amounts (repayments), and keep the remaining 312,303 claims. Many have zero values for payments, resulting in the sample size recorded in Table 1.

We also observe the latitude and longitude (redacted to one decimal place), the census tract, and the zip code (ZCTA5). We describe how we make use of this in B.4.3.

Year structure built

Our regressions focus on claims for structures built pre-1995, as described in B.4.3.

A.11 Flood insurance policies

We obtained FEMA flood insurance policies on record from a Freedom of Information Act request that we filed in September 2021 (2021-FEFO-00054) and obtained a response in February 2022.

Year

The data covers 1975-2019, but is missing some of year 2014 and all of years 2016, 2017 due to data corruption (CD-ROM #6 appeared to have been damaged in the mail by a rainstorm).

Amount

Like claims, we sum coverage for contents and coverage for buildings to obtain total insured value.

Location

Like NFIP claims, the data includes latitude and longitude, redacted to the first decimal place, and zip code, but not census tract.

Appendix B.4.4 describes how we make use of this data in our analysis.

A.12 Flood risk maps

We use FEMA's National Flood Hazard Layer (NFHL, v3) to calculate baseline flood exposure based on elevation and other hydrological variables.

The NFHL are detailed maps of flood risk used by FEMA to price flood insurance at the city-block-level. These maps cover nearly all locations, whether or not they have purchased insurance.

We extract v3 for Florida (approx 8 GB), which consists of a very large number of polygons, labeled by flood zone type. We follow Brody *et al.* (2015) to concentrate on two categories of flood risk: storm surge or "V" flood zones (V and VE in the raw data), and 100-year or "A" flood zones (consisting of A, AE, AO, AH). Most of the remaining area in Florida lies in X zones (500-year flood zones).

Appendix B.1.7 describes how we make use of this data.

A.13 Price deflator

We use the U.S. Bureau of Labor Statistics' core consumer price index (**?**) to convert dollar values in earlier years (e.g., offset prices, flood insurance claims and policies) to 2020 USD for comparability between years and clarity in interpreting our dollar estimates.

B Details of data construction

We build four main datasets for our analysis:

1. watershed-by-period panel for five-year periods between 1996–2016, used to estimate demand
2. market-by-year panel from 1995–2020, used to estimate supply
3. firm-by-year panel from 1995–2020, used to estimate supply
4. watershed-level long difference from 1990–2020, used to estimate flood protection functions

Let us explain each in turn.

B.1 Watershed panel (used to estimate demand)

B.1.1 Initial land use

We use the CCAP data described in A.7 to track watershed-level wetlands, developed land, and highly-developed land at baseline and over time.

All initial values are calculated from the first CCAP map in 1996.

1/ We calculate the area of each HUC12 as the sum of pixels. A pixel is $900m^2$ (900/4047 acres).

2/ We intersect each HUC12 with land ownership boundaries from 1995 (Appendix A.8) to partition each HUC12 into public and private land.

For each HUC12,

2a/ We calculate the area of public and private land.

2b/ We calculate the area of public wetland as the number of wetland pixels on public land.

2c/ We calculate the area of private wetland as the number of wetland pixels on private land.

2d/ We calculate the area of all wetlands as the number of wetland pixels in the HUC12.

3/ We calculate developed land and highly-developed land for each HUC12.

In addition to baseline land cover (1996), we build land cover stocks (1996, 2001, 2006, 2011, 2016) using the same steps.

B.1.2 Conditional choice probabilities

For each HUC12, and for each period 1996–2001, 2001–6, 2006–11, and 2011–16, we also use CCAP data calculate within-pixel transitions of interest for our analysis.

We define four transition types:

1. wetland to developed
2. other to developed
3. wetland to other
4. developed to not developed

The last, developed to not developed, never occurs in the data.

For each watershed-period, we calculate the total number of pixels experiencing each type of transition.

For each watershed-period, we then define the conditional choice probability by dividing the number of conversions in each transition type by the total area of private wetland at the start of the period

Online Appendix – Supplementary Tables

Table A1. Summary of Primary Data Sources

data	obs (≈)	range	frequency	geography	primary source
1. wetland offsets					
wetland bank contracts	100	1995–2020	monthly	parcel-level	FDEP
offset trades	7,000	1995–2018	monthly	bank-level	various
offset prices	1,200	1998–2018	monthly	bank-level	various
2. land use					
wetlands	134m×5	1996–2016	bidecadal	30m×30m	NOAA
developed lands	134m×5	1996–2016	bidecadal	30m×30m	NOAA
within-pixel changes	134m×4	1996–2016	bidecadal	30m×30m	NOAA
3. hydrology					
hydrological local areas	1,378	–	–	polygons	USGS
hydrological sub-basins	50	–	–	polygons	USGS
water management districts	5	–	–	polygons	FDEP
hydrological flow network	1,378×1,378	–	–	polygons	USGS
4. demographics					
population, income, etc		2000–2019	bidecadal	zip	Census
home price indices	$800 \times 12 \times 20$	1995–2018	monthly	zip	Zillow
5. floods					
flood insurance claims	300,000	1978–2020	daily	lat/lon×zip×tract	NFIP
flood insurance policies	$> 10^7$	1978–2020	annual	lat/lon×zip	FEMA
flood zone maps	450,000	–	–	polygons	NFHL
6. land ownership					
state-owned land	71,500	–	–	polygons	FDEP
federal, local conservation land	162,900	–	–	polygons	FDEP
state conservation purchases	$\approx 20,000$	1990–2020	daily	polygons	FDEP

Appendix A describes these data sources in more detail.

Acronyms:
FDEP – Florida Department of Environmental Protection
NOAA – National Oceanic and Atmospheric Administration
USGS – United States Geological Survey
NFIP – National Flood Insurance Program
FEMA – Federal Emergency Management Agency
NFHL – National Flood Hazard Layer

Table A2. New Data on Wetland Offsets in Florida

	N	avg	sd	q0	q25	q50	q75	q100
Initial wetland (pct/pixels)	136,302,645	36.5	48.1	0	0	0	100	100
Initial developed land (pct/pixels)	136,302,645	12.0	32.5	0	0	0	0	100
Hydrology								
Area ('000 pixels/watershed)	1,004	135.8	168.6	27.7	79.0	109.7	146.1	2,753.8
Area ('000 acres/watershed)	1,004	30.2	37.5	6.2	17.6	24.4	32.5	612.4
Land Ownership								
Private land ('000 acres/watershed)	1,004	25.3	23.9	0	14.7	20.9	29.9	388.9
Public land ('000 acres/watershed)	1,004	4.8	27.5	0	0	0.5	3.8	564.2
Percent public land (watershed)	1,004	12.5	21.8	0	0	2.1	14.7	100
Initial Conditions								
Initial wetlands ('000 acres/watershed)	1,004	11.0	30.6	0.001	4.1	7.2	11.6	542.3
Initial wetlands (pct/watershed)	1,004	34.0	20.1	0.002	20.0	30.8	44.0	99.6
Initial private wetlands ('000 acres/watershed)	1,004	7.7	13.8	0	3.2	5.7	9.3	387.3
Initial public wetlands ('000 acres/watershed)	1,004	3.3	25.0	0	0	0.3	1.9	528.1
Pct public wetland (pct/watershed)	1,004	17.2	24.7	0	0	4.8	25.0	100
Initial developed land ('000 acres)	1,004	3.6	5.8	0	0.4	1.2	4.5	49.7
Initial developed land (pct)	1,004	13.8	19.1	0	1.8	4.7	18.2	92.8
Wetlands Development and Restoration								
Wetlands developed, 1996-2016 (acres/watershed)	1,004	207.5	483.4	0	2.4	16.3	186.7	4,908.3
Private wetlands developed, 1996-2016 (acres/watershed)	1,002	206.2	481.3	0	2.0	15.9	186.1	4,812.2
Public wetlands developed, 1996-2016 (acres/watershed)	731	2.4	8.4	0	0	0	1.1	96.1
$\mathbb{P}(\text{develop}\|\text{wet}) \times 100^a$	1,000	3.7	7.3	0	0.04	0.3	3.9	57.0
$\ln \frac{\mathbb{P}(\text{develop}\|\text{wet})}{1-\mathbb{P}(\text{develop}\|\text{wet}))}$	912	−5.3	2.6	−12.0	−7.3	−5.4	−3.0	0.3
Area of wetland banks, 2016 (acres/watershed)	1,378	132.2	663.9	0	0	0	0	9,518.7
Market Structure								
Area ('000 acres/market)	30	1,153.3	800.4	264.0	516.8	863.4	1,520.4	3,993.5
Area (watersheds/market)	30	33.5	18.0	11	18.2	27.5	49	70
Initial private wetlands ('000 acres/market)	30	257.5	215.6	43.5	100.1	188.5	355.8	912.9
Entry[b] (market-year)	780	11.7	32.1	0	0	0	0	100
Number of banks (market-year)	530	2.6	2.3	1	1	2	3	16
Lagged capacity[c] (credits/market-year)	780	556.9	1,214.7	0	0	0	535	7,137
Annual trades (credits/market-year)	381	41.7	67.3	0.02	2.9	11.7	50.6	516.0

Descriptive statistics for Florida, 1995–2020.

[a] $\mathbb{P}(\text{develop}|\text{wet})$ defined as the within-pixel probability that a wetland pixel in 1996 becomes developed in 2016.
[b] Wetland bank entry indicator equals 1 if a wetland mitigation bank enters in market m in year t and 0 otherwise.
[c] Historical capacity defined as lifetime offset production authorized to all banks in market m that entered $k = 5$ or more years prior to t.

Table A2 (cont'd): New Data on Wetland Offsets in Florida

	N	avg	sd	q0	q25	q50	q75	q100
Demand Shifters								
Other land developed, 1996-2016 (acres/watershed)	1,004	518.9	985.9	0	43.8	142.4	522.9	9,400.3
Average annual home price ('000$ per watershed)	999	143.2	65.2	47.2	98.4	135.6	172.8	868.0
Endogenous State Variables								
Wetlands stock ('000 acres/watershed/period)	5,020	10.8	30.6	0.001	4.0	6.9	11.4	542.5
Private wetlands ('000 acres/watershed/period)	5,020	7.5	13.7	0	3.1	5.6	9.1	387.5
Public wetlands ('000 acres/watershed/period)	5,020	3.3	25.0	0	0	0.3	1.9	528.1
Developed land stock ('000 acres/watershed/period)	5,020	4.1	6.4	0	0.5	1.4	5.4	56.5
Offset Credit Release and Sales								
Bank entry year	107	2,008.1	7.5	1,995	2,003	2,009	2,014.5	2,020
Bank size (acres/bank)	107	1,866.1	2,680.0	66	428.5	1,049	2,157.5	22,805
Bank size (credits/bank)	106	410.0	566.1	13	85.2	203	521.8	4,345
Acres per credit	106	5.9	4.5	1.1	3.1	5.1	6.9	29.4
1(credits released) per bank per year	1,209	0.3	0.4	0	0	0	1	1
Credits released per bank per year (pct total)	343	15.3	16.2	0.05	5	10.0	20.0	96.8
Annual sales (credits/bank-year)	981	15.5	31.4	0	0	1.8	15.4	236.4
Bank reserves[d] (pct/bank-year)	967	51.8	33.6	0	18.3	54.7	82.0	100
Acre wetland developed per credit sold	5,512	8.8	2.8	4.8	8.1	8.2	11.6	12.6
Credit price ('000$/credit), all transactions	1,432	87.5	61.7	1.0	38.6	63.4	137.2	785.3
Credit price ('000$/credit), average per market per year	151	98.8	50.5	5.5	62.0	93.9	127.2	306.2
Credit price ('000$/credit), average per market per year, sd	61	51.2	36.5	1.0	24.3	49.3	73.0	203.0
Flood Risks								
Flood zone (pct/watershed)	1,004	41.7	23.8	0	23.9	37.3	56.1	100
Zone V (storm surge) (pct)	1,004	2.4	9.8	0	0	0	0	99.8
Zone A (100-yr) (pct)	1,004	39.4	22.5	0	23.0	35.6	51.7	100
Flood insurance claims[e] ('000$/claim)	188,368	31.3	71.1	0.000	3.3	10.5	32.9	9,139.5
Flood insurance claims, 1991-1995 ('000$/claim)	29,599	27.4	56.3	0.000	3.1	11.4	31.2	1,845.9
1991-1995 flood claims ('000$/year/watershed)	1,004	241.9	1,508.3	0	0	0.7	14.3	20,640.9
1991-1995 flood claims, nonzero ('000$/year/watershed)	635	382.5	1,882.9	0.000	1.1	6.0	49.0	20,640.9
Flood insurance claims, 2016-2020 ('000$/claim)	41,348	50.0	79.8	0.004	7.3	23.4	64.4	3,000
2016-2020 flood claims ('000$/year/watershed)	1,004	337.4	1,411.2	0	0.1	6.2	75.7	24,121.5
2016-2020 flood claims, nonzero ('000$/year/watershed)	785	431.5	1,583.3	0.000	2.0	19.2	135.5	24,121.5
Flood insured value, 1991-1995 ('000'000$/watershed)	1,004	7.2	37.0	0	0.01	0.1	1.2	757.6
Flood insured value, 2016-2020 ('000'000$/watershed)	1,004	147.3	438.5	0	0.8	8.5	77.6	5,070.1

Descriptive statistics for Florida, 1995–2020.

[d] Bank reserves defined as 1 − (total number of offsets sold)/(total number of offsets released).
[e] All flood insurance claims from 1985–2020.

Table A3. Watershed-Level Differences by Offset Trade Status

	N	avg	sd	q0	q25	q50	q75	q100
Wetlands developed (acres)								
With wetland bank[a]	96	54.0	72.7	0	4.8	17.9	70.8	239.1
With high development[b]	179	859.5	770.7	253.7	390.3	580.7	958.7	4,812.2
$\mathbb{P}$(develop|wet) $\times$ 100								
With wetland bank	96	0.8	1.1	0	0.1	0.2	1.0	4.9
With high development	179	15.1	10.1	0.4	7.0	14.2	20.8	57.0
Initial Conditions[c]								
Initial wetlands ('000 acres/watershed)								
With wetland bank	96	23.1	76.1	1.4	7.6	10.5	15.9	542.3
With high development	179	10.1	13.8	0.7	3.5	7.0	11.2	140.6
Initial wetlands (pct/watershed)								
With wetland bank	96	44.5	19.4	4.9	29.9	43.3	58.1	95.7
With high development	179	31.0	18.4	5.3	17.8	28.4	39.4	93.5
Initial developed land ('000 acres)								
With wetland bank	96	1.7	2.0	0.03	0.3	0.9	2.1	9.9
With high development	179	10.5	8.8	0.2	5.1	7.7	13.9	49.7
Initial developed land (pct)								
With wetland bank	96	5.7	6.6	0.2	1.2	3.0	8.0	33.1
With high development	179	37.6	23.0	1.5	19.1	32.5	55.7	87.5
Land Ownership								
Watersheds (pct public)								
With wetland bank	96	15.4	21.6	0	0.01	4.5	24.8	95.7
With high development	179	7.1	11.5	0	0.6	2.0	9.7	73.1
Initial public wetlands ('000 acres)								
With wetland bank	96	13.7	74.1	0	0	0.6	3.9	528.1
With high development	179	2.0	6.3	0	0.1	0.4	1.6	68.7
Initial private wetlands ('000 acres)								
With wetland bank	96	9.4	5.5	1.0	5.8	8.4	11.2	31.6
With high development	179	8.1	8.8	0.7	3.3	6.0	9.6	71.9
Flood Risks								
Flood zone (pct/watershed)								
With wetland bank	96	45.8	20.9	0	30.3	46.6	56.7	100.0
With high development	179	33.8	19.8	0.5	20.7	30.6	43.9	99.4
Pre-1996 flood claims[d] ('000$/yr)								
With wetland bank	96	314.6	2,345.2	0	0	0.1	4.7	22,624.2
With high development	179	412.7	1,552.4	0	0.8	10.7	99.4	13,660.8
Pre-1996 flood insurance (MM$)								
With wetland bank	96	10.1	77.5	0	0.01	0.1	0.5	757.6
With high development	179	18.8	51.1	0.001	0.6	2.2	9.9	390.6
Post-2015 flood claims[e] ('000$/yr)								
With wetland bank	96	161.5	541.2	0	0.7	7.1	49.6	3,866.6
With high development	179	798.2	2,445.0	0	24.1	97.3	361.1	24,184.6
Post-2015 flood insurance (MM$)								
With wetland bank	96	66.0	251.5	0.01	3.7	13.5	32.3	2,267.9
With high development	179	496.4	752.7	3.2	88.2	212.8	522.1	5,070.1

Additional watershed-level comparisons between wetland bank locations and wetland development. See Table A2 for all data.

[a] Watersheds with at least 100 acres of a wetland bank site and fewer than 250 acres of developed wetlands.
[b] High-development watersheds defined as those with greater than 250 acres of developed wetland from 1996–2016 and fewer than 100 acres of a wetland bank site.
[c] Initial measures correspond to 1996 values.
[d] Pre-1996 flood insurance claims and coverage in 2020 USD, calculated over 1991–1995.
[e] Post-2015 flood insurance claims and coverage in 2020 USD, calculated from 2016–2020.

Table A4. Wetland Acreage to Offset Ratios

A. Development on Wetlands

	Developed acres	Developed acres (post)	Credits sold	Acres/credit
Southwest Florida	270,144.8	62,249.4	1,098.1	12.6
St. Johns River	226,249.4	156,505	7,206.2	4.8
South Florida	413,900	292,433	5,625.1	11.6
Northwest Florida	33,950.2	14,708.8	400.7	8.2
Suwannee	5,085	60	35.8	8.1
All Florida	949,329.4	525,956.2	14,365.9	8.1

B. Wetland Banking

	Banked acres	Credits authorized	Credits produced	Acres/credit
Southwest Florida	10,294	2,821	2,312.1	3.6
St. Johns River	90,553	19,805	11,616.6	4.6
South Florida	54,231	13,167	8,795.5	4.1
Northwest Florida	18,746	3,511	1,521.9	5.3
Suwannee	8,336	1,160	388.6	7.2
All Florida	182,160	40,464	24,634.6	4.5

Panel A. Acres of wetlands converted to development, 1996–2016, by water management district. Developed acres (post) is all wetlands developed from t_m to 2016, where t_m is the year in which the first bank produces offsets in market m, summed over all markets m in the water district. Offsets sold are measured from 1995–2016. Acres/offset ($\tilde{v}_h$ in the model) is column two divided by column three, except for Suwannee, where we use the Florida-wide ratio, so that Suwanne's acres/offset equals the sum of column two divided by the sum of column three.

Panel B. Acres of land committed to wetland banks, 1995–2016. Credits authorized reports all offsets authorized for lifetime production by these banks. Credits produced are offsets released by 2016. Acres/credit ($\tilde{v}_f$ in the model) is banked acres divided by offsets authorized.

See Figure A3 for a map of wetland acres developed with offsets by watershed and Figure 4 for a map of wetland bank project sites.

Table A5. Demand for Development on Wetlands — Sources of Heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Credit price coefficient[a] (θ_P)	−0.342	−1.292	−0.977	−1.103	−1.454	−2.316	−1.063
	(0.145)	(0.278)	(0.264)	(0.380)	(0.601)	(0.583)	(0.385)
factor(wmd)South Florida	−0.456	−0.204	−0.457	1.380		2.962	
	(0.352)	(0.357)	(0.371)	(1.349)		(2.246)	
factor(wmd)Southwest Florida	−0.461	−0.048	−0.332	−0.252	−1.904	0.544	−1.651
	(0.354)	(0.374)	(0.384)	(0.597)	(1.457)	(0.675)	(1.148)
factor(wmd)St. Johns River	−0.327	−0.027	−0.406	−2.783	−5.699	−2.990	−5.068
	(0.344)	(0.352)	(0.371)	(0.842)	(2.000)	(0.986)	(1.524)
factor(wmd)Suwannee	−2.799	−2.670	−2.529	−1.459	−3.360	−0.777	−3.047
	(0.467)	(0.501)	(0.496)	(0.558)	(1.493)	(0.616)	(1.172)
Development on non-wetlands	0.552	0.571	0.516	0.534	0.543	0.528	0.545
	(0.024)	(0.027)	(0.029)	(0.030)	(0.034)	(0.034)	(0.033)
Baseline development density (%)	4.684	4.246	3.802	3.776	3.932	3.761	3.936
	(0.261)	(0.299)	(0.346)	(0.334)	(0.438)	(0.376)	(0.423)
Baseline high-development share (%)	5.352	7.217	6.086	4.744	6.694	4.685	6.671
	(1.467)	(1.799)	(1.608)	(1.700)	(1.876)	(1.978)	(1.799)
Flood Zone V (storm surge) (%)	1.884	1.598	1.074	1.683	2.451	1.973	2.306
	(0.719)	(0.885)	(0.791)	(0.785)	(1.087)	(0.986)	(0.962)
Flood Zone A (100-yr) (%)	0.239	0.007	−0.123	−0.080	−0.278	−0.221	−0.218
	(0.261)	(0.281)	(0.271)	(0.299)	(0.368)	(0.350)	(0.345)
period ≤ 2011	1.110	0.910	1.199	1.113	1.119	0.966	1.167
	(0.132)	(0.154)	(0.156)	(0.146)	(0.163)	(0.174)	(0.149)
period ≤ 2006	−0.310	−0.533	−0.304	−0.130	−0.123	−0.402	−0.056
	(0.126)	(0.144)	(0.139)	(0.153)	(0.195)	(0.195)	(0.174)
period ≤ 2001	0.134	−0.204	0.036	0.019		0.035	
	(0.212)	(0.224)	(0.221)	(0.218)		(0.228)	
Lagged population			0.113	0.086	−0.005	0.091	−0.003
			(0.061)	(0.060)	(0.095)	(0.065)	(0.091)
Lagged median income			1.225	1.269	1.331	1.296	1.325
			(0.273)	(0.295)	(0.354)	(0.342)	(0.336)
Instruments							
Historical sunk capacity		✓	✓	✓			✓
Hausman cost shifters					✓		✓
Government conservation land purchases						✓	✓
First-stage F-stat		115.8	117.3	49.8	8.3	21.3	14.3
Observations	758	758	758	758	629	758	629
Adjusted R^2	0.704	0.676	0.704	0.715	0.677	0.637	0.697

All coefficient estimates for Table 2. Omitted water management district factor is Northwest Florida (columns 1–4, 6) and South Florida (columns 5, 7). Columns (4)–(7) include HUC8 fixed effects which remain omitted.

Table A6. Entry Policy Function Estimates

	(1)	(2)	(3)	(4)
Market state variables				
Total market-level reserves, asinh(number of credits)	−0.043	−0.070	−0.077	−0.132
	(0.037)	(0.038)	(0.039)	(0.048)
Number of incumbents	0.013	−0.021	−0.010	−0.153
	(0.039)	(0.041)	(0.041)	(0.058)
At least one incumbent	0.015	−0.100	−0.129	−0.201
	(0.214)	(0.221)	(0.221)	(0.256)
ln(Private wetland area)	0.130	0.351	0.350	−7.421
	(0.125)	(0.142)	(0.144)	(5.451)
ln(Public wetland area)	−0.026	−0.109	−0.106	−1.086
	(0.088)	(0.108)	(0.109)	(1.925)
ln(Population)	0.208	0.238	0.235	−0.013
	(0.083)	(0.102)	(0.102)	(1.343)
ln(Median Income)	−0.478	−0.416	−0.479	0.864
	(0.493)	(0.542)	(0.518)	(1.321)
Flood Zone V (storm surge) (%)	−2.962	−1.408	−1.174	
	(1.715)	(1.821)	(1.831)	
Flood Zone A (100-yr) (%)	0.097	0.170	0.187	
	(0.758)	(0.804)	(0.808)	
Controls				
Linear time trend	✓	✓	✓	✓
Water district fixed effects		✓	✓	✓
Period fixed effects			✓	✓
Market fixed effects				✓
Observations	780	780	780	780
McFadden pseudo-R^2	0.041	0.067	0.073	0.134
McKelvey-Zavoina pseudo-R^2	0.076	0.136	0.152	0.265
Veall-Zimmermann pseudo-R^2	0.069	0.110	0.120	0.210
Log Likelihood	−269.429	−262.195	−260.403	−243.280
Akaike Inf. Crit.	560.858	554.391	554.806	566.561
Prob $> \chi^2$	0.0104	0.0006	0.0005	0.0004

Estimated probit coefficients for entry policy at the market×year level. The outcome is 1 if there is an entrant in the market in that year and 0 otherwise.

Paper uses column (3).

McFadden pseudo-R^2 is defined as the ratio of the difference in log likelihoods between the fitted model and a constant probit model (−280.978).

χ^2-squared test statistic p-value based on a likelihood ratio test rejecting the null hypothesis of a constant probit model.

Table A7. Trading Policy Function Estimates

	(1)	(2)	(3)	(4)
Bank state variables				
Own cumulative sales (share of lifetime capacity)	−2.150	−2.720	−2.781	−3.586
	(0.672)	(0.654)	(0.649)	(0.618)
Own reserves (share of lifetime capacity)	3.943	3.832	3.817	4.293
	(0.476)	(0.463)	(0.446)	(0.501)
Bank age	−0.033	−0.009	−0.006	0.023
	(0.035)	(0.032)	(0.031)	(0.034)
Market state variables				
ln(Private wetland area)	0.386	0.492	0.463	−4.475
	(0.321)	(0.312)	(0.301)	(9.433)
ln(Public wetland area)	−0.160	−0.073	−0.052	−1.672
	(0.203)	(0.209)	(0.199)	(1.897)
ln(Population)	0.231	−0.032	−0.010	−2.699
	(0.134)	(0.142)	(0.140)	(3.109)
ln(Median Income)	0.233	−0.594	−1.197	0.372
	(0.961)	(0.912)	(0.976)	(3.920)
Is single-firm market	−0.167	−0.149	0.003	0.485
	(0.353)	(0.348)	(0.352)	(0.473)
Number of active banks	0.035	0.072	0.087	0.085
	(0.046)	(0.052)	(0.051)	(0.080)
Controls				
Linear time trend	✓	✓	✓	✓
Water district fixed effects		✓	✓	✓
Period fixed effects			✓	✓
Market fixed effects				✓
Observations	208	208	208	208
Adjusted R^2	0.306	0.385	0.405	0.461

Estimates for the logit trading policy function used to predict (11) at the bank×period (f, τ) level.

Coefficients estimated via linear regression with the outcome defined as $\ln(y/(1-y))$, where $y = q_{f\tau}/\tilde{v}_f$ is the share of credits traded by bank f in quinquennial period τ. Note that the time trend is collinear with the period fixed effects in columns (2)–(4).

Paper uses column (3).

Robust (HC1) standard errors clustered at the bank-period level in parentheses.

Table A8. Estimated Wetland Bank Costs – Additional Parameters

	N	mean	sd	q10	q25	q50	q75	q90
First-stage entry probabilities								
$p_{\{\text{enter}\}}$, firm 1	27	0.08	0.06	0.02	0.03	0.06	0.11	0.15
$p_{\{\text{enter}\}}$, firm 1, duopoly	6	0.07	0.03	0.04	0.06	0.08	0.09	0.09
$p_{\{\text{enter}\}}$, firm 2, duopoly	6	0.10	0.07	0.04	0.06	0.09	0.10	0.16
$p_{\{\text{enter}\}}$, firm 1, oligopoly, at least three firms	13	0.12	0.07	0.05	0.06	0.12	0.15	0.16
$p_{\{\text{enter}\}}$, firm 2, oligopoly, at least three firms	17	0.14	0.08	0.06	0.09	0.10	0.18	0.23
$p_{\{\text{enter}\}}$, firm 3+	56	0.14	0.06	0.06	0.11	0.14	0.17	0.19
Value functions								
$\mathbb{E}[V]$, firm 1	27	18.60	25.32	1.60	2.73	6.60	24.46	46.50
$\mathbb{E}[V]$, firm 1, duopoly	6	28.08	28.67	5.60	6.92	18.01	39.80	60.62
$\mathbb{E}[V]$, firm 2, duopoly	6	4.31	4.48	0.86	1.26	3.06	4.96	9.00
$\mathbb{E}[V]$, firm 1, oligopoly, at least three firms	13	16.97	27.88	1.80	2.55	5.48	16.63	35.68
$\mathbb{E}[V]$, firm 2, oligopoly, at least three firms	17	30.57	41.78	1.29	5.76	7.09	36.14	102.17
$\mathbb{E}[V]$, firm 3	56	15.14	28.75	0.38	0.86	2.67	12.52	48.06
Parameter estimates								
$\mu_\kappa(s_{mt})$, firm 1	27	16.81	2.77	14.83	15.34	15.96	16.53	22.95
$\sigma_\kappa(s_{mt})$, firm 1	27	1.40	1.96	0.12	0.12	0.94	1.06	5.91
$\mu_\kappa(s_{mt})$, firm 1, duopoly	6	17.77	4.32	14.78	14.87	15.19	21.31	23.34
$\mu_\kappa(s_{mt})$, firm 2, duopoly	6	14.74	0.79	14.16	14.40	14.51	14.83	15.57
$\sigma_\kappa(s_{mt})$, duopoly	12	1.22	2.21	0.12	0.12	0.12	0.94	5.41
$\mu_\kappa(s_{mt})$, firm 1, oligopoly, at least three firms	13	16.23	2.06	14.93	15.45	15.96	16.07	16.24
$\mu_\kappa(s_{mt})$, firm 2, oligopoly, at least three firms	17	16.54	3.15	14.38	14.60	15.05	16.02	22.15
$\mu_\kappa(s_{mt})$, firm 3	56	15.55	2.26	13.92	14.07	15.00	15.72	16.98
$\sigma_\kappa(s_{mt})$, oligopoly, at least three firms	86	1.14	1.60	0.12	0.12	0.94	1.19	1.19
Implied costs								
Realized entry cost estimate (MM/bank)	106	7.01	10.71	0.06	1.06	2.85	6.85	62.44
Est entry costs per credit ('000/bank)	106	29.93	41.97	0.25	5.79	13.66	35.53	231.21
Comparison with contract data								
Observed entry costs (MM/bank)	79	5.29	6.09	0.26	1.42	2.86	7.18	36.16
Observed entry costs per credit ('000/bank/credit)	79	23.95	23.27	1.76	9.20	15.99	31.17	116.67
Observed construction costs (MM/bank)	86	1.61	2.50	0.04	0.36	0.97	1.81	16.16
Observed land costs (MM/bank)	95	5.05	10.53	0.02	0.57	1.89	5.53	89.19
Implied markup	106	2.12	1.51	1.01	1.19	1.45	2.22	8.66
Rate of return on capital (pct)	106	6.08	5.97	0.05	1.79	3.81	8.30	24.10
Rate of return on capital (pct), firm 1	27	5.99	5.49	0.05	2.62	3.89	7.05	16.22
Rate of return on capital (pct), firm 2	23	5.74	5.74	0.06	0.41	3.79	8.55	17.61

Expanded version of Table 3.

Table A9. Wetland Flood Protection Function — Sources of Heterogeneity

	(1)	(2)	(3)	(4)
Development on wetlands (ζ_d)	0.428	0.245	0.243	0.147
	(0.077)	(0.083)	(0.084)	(0.085)
Wetland bank area (ζ_b)	−0.083	−0.093	−0.093	−0.108
	(0.042)	(0.036)	(0.036)	(0.034)
factor(wmd)South Florida	0.043	0.273	0.274	−0.292
	(0.626)	(0.683)	(0.687)	(0.552)
factor(wmd)Southwest Florida	−1.132	−0.880	−0.881	−1.711
	(0.395)	(0.361)	(0.362)	(0.570)
factor(wmd)St. Johns River	0.044	0.280	0.283	−3.111
	(0.366)	(0.390)	(0.391)	(0.621)
factor(wmd)Suwannee	−1.975	−1.466	−1.460	−0.694
	(0.356)	(0.356)	(0.355)	(0.553)
Baseline development density (%)	0.064	0.113	0.112	1.141
	(0.862)	(1.141)	(1.144)	(0.482)
Baseline high-development share (%)	11.146	3.435	3.430	1.876
	(1.927)	(1.984)	(1.985)	(2.325)
Development on non-wetlands, squared	−0.0002	−0.0001	−0.0001	−0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Development on non-wetlands	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Baseline population (1995)		0.00001	0.00001	0.00001
		(0.00001)	(0.00001)	(0.00000)
Baseline population (1995), squared		−0.000	−0.000	−0.000
		(0.000)	(0.000)	(0.000)
Baseline median income (1995)		0.0001	0.0001	−0.00002
		(0.0001)	(0.0001)	(0.0001)
Baseline median income (1995), squared		−0.000	−0.000	0.000
		(0.000)	(0.000)	(0.000)
Additional controls				
Demographic controls		✓	✓	✓
HUC8 FEs				✓
Implied damages ($/acre)				
0%	135.7	6.7	9.7	0.000
10%	5,625.1	873.6	1,065.1	124.2
25%	16,624.0	2,977.9	3,533.3	589.1
50%	54,315.2	10,145.9	12,746.6	2,614.4
75%	184,120.7	39,954.6	52,343.7	11,588.8
90%	391,284.0	151,036.6	184,177.3	38,930.7
95%	574,790.8	275,008.5	369,786.0	89,572.5
97.5%	744,815.1	501,671.4	576,853.7	195,402.1
99%	797,514.3	754,819.5	855,061.2	336,950.8
99.9%	1,076,979.0	4,792,847.0	5,256,975.0	1,531,050.0
100%	10,579,423.0	5,380,962.0	5,369,403.0	2,257,844.0
Observations	1,226	1,226	1,015	1,226

Additional coefficient estimates for Table 4. Omitted water management district factor is Northwest Florida. As in Table 4, all columns include water district fixed effects and controls for baseline development density and other development on non-wetlands. Flood zone and baseline flood claims coefficients reported in the main Table 4 are omitted here for space.

Table A10. Robustness of Wetland Flood Protection — Functional Form

	(1)	(2)	(3)	(4)	(5)	(6)
Development on wetlands (ζ_d)	0.492	0.271	0.258	0.261	0.209	0.205
	(0.122)	(0.109)	(0.110)	(0.118)	(0.104)	(0.131)
Wetland bank area (ζ_b)	0.121	0.046	0.046	0.021	−0.021	0.016
	(0.044)	(0.039)	(0.038)	(0.039)	(0.054)	(0.041)
Baseline flood claims (1991-95)		0.441	0.421	0.424	1	0.379
		(0.028)	(0.029)	(0.031)		(0.034)
Identifying assumption	OLS	AR(1)	AR(1)	AR(1)	LD	AR(1)
Controls						
Water district fixed effects	✓	✓	✓	✓	✓	✓
Baseline flood risk	✓	✓	✓	✓	✓	✓
Baseline dev density	✓	✓	✓	✓	✓	✓
Other development	✓	✓	✓	✓		✓
Demographic controls	✓		✓	✓	✓	✓
HUC8 FEs				✓	✓	✓
Estimation sample						
Wetland development	✓	✓	✓	✓	✓	✓
Baseline insurance					✓	✓
Implied damages						
0%	0.8	0.2	0.1	0.1		0.2
10%	28.4	5.5	5.3	3.9		4.3
20%	55.3	9.0	9.7	9.6		12.3
30%	83.0	16.6	17.5	19.0		26.0
40%	122.0	44.7	44.2	42.6		56.1
50%	186.9	141.4	137.8	109.6		133.7
60%	296.9	328.4	332.1	328.0		330.7
70%	546.5	717.9	720.1	836.6		786.8
80%	1,290.0	1,772.9	1,702.1	2,216.3		2,031.4
90%	4,869.6	5,811.9	6,310.3	10,584.9		8,071.0
95%	14,748.8	14,370.8	13,564.9	38,411.1		23,435.1
97.5%	51,592.3	36,069.2	35,733.3	93,660.8		65,777.4
99%	274,530.5	200,411.8	263,903.5	505,385.0		402,800.1
99.9%	8,779,438.0	2,237,612.0	1,364,001.0	3,002,401.0		1,633,139.0
100%	63,403,238.0	12,031,498.0	3,986,859.0	4,816,523.0		2,321,241.0
Observations	1,052	1,059	1,052	1,052	870	900
Adjusted R^2	0.433	0.533	0.533	0.594	0.268	0.553

Alternative functional forms for (20) at the local watershed level for watersheds with nonzero development on wetlands.

Robust (HC1) standard errors clustered at the HUC12 level in parentheses.

Table A11. Robustness of Wetland Flood Protection Functions

	(1)	(2)	(3)	(4)	(5)	(6)
Local development on wetlands (ζ_d)	0.245	0.261	0.137	0.205	0.271	0.263
	(0.083)	(0.078)	(0.098)	(0.094)	(0.077)	(0.078)
Wetland bank area (ζ_b)	−0.093	−0.099	−0.118	−0.098	−0.060	−0.100
	(0.036)	(0.036)	(0.040)	(0.034)	(0.032)	(0.036)
Nonzero baseline flood claims (1991-95)	3.069	3.094	3.864	3.040		3.094
	(0.417)	(0.441)	(0.430)	(0.444)		(0.436)
Baseline flood claims (1991-95)	0.236	0.231	0.151	0.229		0.403
	(0.097)	(0.077)	(0.061)	(0.087)		(0.139)
Baseline flood claims (1991-95) squared	−0.009	−0.008	−0.003	−0.008		−0.024
	(0.007)	(0.005)	(0.002)	(0.006)		(0.016)
Nonzero baseline flood claims (1985-95)					2.847	
					(0.403)	
Baseline flood claims (1985-95)					0.764	
					(0.141)	
Baseline flood claims (1985-95) squared					−0.056	
					(0.018)	
Estimation sample	Baseline	Match Tract	Binary Match	geq1-acre	10-yr	Nominal
Implied damages						
0%	0	0	0	0	0	0
10%	0	0	0	0	0	0
20%	149.7	189.8	35.2	0	123.8	188.7
30%	1,251.0	1,523.5	410.3	566.9	931.7	1,508.0
40%	3,247.0	3,606.8	1,004.8	1,819.7	2,092.9	3,589.5
50%	5,876.6	6,480.1	2,164.5	3,625.0	3,832.6	6,498.5
60%	10,675.5	12,234.0	3,799.3	6,721.5	6,976.5	12,126.6
70%	19,674.6	21,388.8	7,033.1	13,212.2	12,920.7	21,427.7
80%	41,004.3	46,536.0	14,049.7	25,052.6	27,486.0	46,523.5
90%	115,482.3	134,016.4	46,701.3	77,979.9	73,222.2	131,532.7
95%	234,652.8	252,112.7	123,293.3	180,185.4	152,573.5	256,338.9
97.5%	444,396.1	457,910.3	246,651.1	291,363.0	294,088.6	453,717.3
99%	714,247.9	819,761.8	512,701.0	437,467.8	447,643.1	827,094.4
99.9%	3,754,954.0	3,525,599.0	1,407,460.0	3,470,109.0	1,473,871.0	3,562,016.0
100%	5,380,962.0	5,548,918.0	1,596,509.0	5,149,647.0	2,464,015.0	5,422,225.0
Total Damages						
Development	2.315	2.418	1.569	2.073	1.349	2.401
Restoration	−0.435	−0.499	−0.593	−0.467	−0.150	−0.499
All	1.880	1.919	0.977	1.606	1.200	1.902
All (below 99%-ile)	1.767	1.790	0.945	1.395	1.189	1.776
Observations	1,226	1,226	1,226	1,052	1,226	1,226

Estimates of (20) with some alternative variable definitions. All regressions are at the local watershed level and include all controls from Table 4 (column 2). (1) Baseline specification (Table 4, column 2). (2) Interpolate flood insurance claims to watersheds with only latitude, longitude, and census tract instead of the baseline which also uses zip code (ZCTA5). (3) Baseline spatial interpolation with binary matching (assign claims to watershed with maximal area overlap) rather than continuous allocation. (4) Drops watersheds with wetland development less than one acre. (5) Use ten year window to build pre- and post-claims (1986–1995 and 2011–2020) instead of the baseline five years (1991–1995 and 2016–2020). (6) Annual flood claims constructed with nominal rather than deflated claims. Damages reported in 2020 USD using the average CPI from 2016–2020. Robust (HC1) standard errors clustered at the HUC12 level in parentheses.

Table A12. Wetland Flood Protection Function — Channels

	(1)	(2)	(3)	(4)	(5)
Local development on wetlands (ζ_d)	0.245	0.208	0.236	0.201	0.0003
	(0.083)	(0.190)	(0.103)	(0.071)	(0.0005)
Wetland bank area (ζ_b)	−0.093	−0.051	−0.083	0.003	−0.00003
	(0.036)	(0.042)	(0.036)	(0.015)	(0.0002)
Nonzero baseline flood claims (1991-95)	3.069	2.629	2.961	1.445	0.006
	(0.417)	(0.432)	(0.401)	(0.195)	(0.001)
Baseline flood claims (1991-95)	0.236	0.159	0.224	−0.093	0.002
	(0.097)	(0.130)	(0.096)	(0.075)	(0.001)
Baseline flood claims (1991-95) squared	−0.009	−0.005	−0.008	0.003	−0.0001
	(0.007)	(0.009)	(0.007)	(0.003)	(0.0001)
Baseline flood insurance (1991-95)				0.000	−0.000
				(0.000)	(0.000)
Baseline flood insurance (1991-95) squared				−0.000	0.000
				(0.000)	(0.000)

Outcome	Baseline	post-95	all	insurance	claims/insured
Implied damages					
0%	0	0	0		
10%	0	0	0		
20%	149.7	27.8	199.1		
30%	1,251.0	243.1	1,608.2		
40%	3,247.0	612.7	3,902.2		
50%	5,876.6	1,488.8	7,553.4		
60%	10,675.5	2,756.7	13,731.2		
70%	19,674.6	5,307.8	24,675.0		
80%	41,004.3	11,613.9	52,339.6		
90%	115,482.3	32,475.7	146,866.0		
95%	234,652.8	82,813.3	322,536.8		
97.5%	444,396.1	149,521.6	596,381.5		
99%	714,247.9	260,402.6	970,784.9		
99.9%	3,754,954.0	593,630.1	4,352,697.0		
100%	5,380,962.0	1,155,052.0	6,634,406.0		
Total Damages					
Development	2.315	2.334	1.866		
Restoration	−0.435	−0.461	−0.879		
All	1.880	1.874	0.987		
All (below 99%-ile)	1.767	1.756	0.961		
Observations	1,226	1,226	1,226	1,226	1,209
Adjusted R^2					0.065

Channels underlying (20). All regressions are at the local watershed level and include all controls from Table 4 (column 2).
(1) Baseline specification (Table 4, column 2).
Outcome is average annual flood claims from 2016–2020 on structures built after 1995
(2) Outcome is average annual flood claims from 2016–2020 on structures built after 1995.
(3) Outcome is average annual flood claims from 2016–2020 on all structures.
(4) Outcome is average annual flood insured value from 2016–2020 for all structures.
(5) Outcome is annual flood claims per dollar insured from 2016–2020 for all structures.
Robust (HC1) standard errors clustered at the HUC12 level in parentheses.

Table A13. Assessing Network Spillovers in Wetland Flood Protection

	(1)	(2)	(3)	(4)	(5)
Local development on wetlands	0.245	0.236	0.223	0.210	0.212
	(0.083)	(0.094)	(0.111)	(0.092)	(0.104)
Wetland bank area	−0.093	−0.103	−0.095	−0.121	−0.096
	(0.036)	(0.036)	(0.033)	(0.038)	(0.029)
Hydrological Network					
Upstream area		0.019	0.196	−0.009	0.126
		(0.018)	(0.050)	(0.022)	(0.057)
Downstream area		0.342	0.308	0.349	0.301
		(0.231)	(0.138)	(0.184)	(0.132)
Upstream wetland development			0.042		0.038
			(0.099)		(0.100)
Downstream wetland development			0.076		0.053
			(0.070)		(0.065)
Upstream wetland bank area				0.166	0.113
				(0.050)	(0.032)
Downstream wetland bank area				−0.069	−0.057
				(0.044)	(0.039)
Total Damages					
Development	2.315	2.335	2.029	2.156	1.973
Restoration	−0.435	−0.500	−0.448	−0.631	−0.452
Indirect			0.517	0.723	1.214
All	1.880	1.836	2.098	2.249	2.735
Observations	1,226	1,226	1,226	1,226	1,226

Enriching the flood protection function to include hydrological network spillovers across local watersheds.

(1) Baseline specification (Table 4, column 2).
(2) Same as (1), with controls for total area of upstream and downstream watersheds.
(3) Model with spillovers from upstream and downstream wetland development.
(4) Model with spillovers from upstream and downstream wetland bank area.
(5) Model with spillovers from upstream and downstream wetland development and bank activity.

Robust (HC1) standard errors clustered at the HUC12 level in parentheses.

Table A14. Benchmarking Flood Protection Estimates

	ΔDamages	ΔWetland	ΔD/ΔW	$\widehat{\Delta D}/\Delta W$	$\frac{\widehat{\Delta D}/\Delta W}{\Delta D/\Delta W}$
All watersheds					
This paper	310,593	56,922	5,456	1,661	30
Brody et al (2015)	252,830	57,127	4,426	384	9
Taylor and Druckenmiller (2022)	254,070	86,020	2,954	4,514	153
Only developed					
This paper	255,129	48,650	5,244	1,645	31
Taylor and Druckenmiller (2022)	143,710	56,700	2,535	8,290	327
Only coastal					
This paper	83,518	1,163	71,803	14,417	20
Sun and Carson (2020)	164,162	3,432	47,828	18,000	38

Columns:

(1) ΔDamages: observed outcome calculated from our data, '000$/year.
(2) ΔWetland: observed treatment calculated from our data, hectares.
(3) ΔD/ΔW: average observed outcome per observed treatment, $/year/ha.
(4) $\widehat{\Delta D}/\Delta W$: average estimated effect, $/year/ha.
(5) Percent of observed outcome attributable to predicted treatment effect.

Comparisons with prior literature:

All watersheds
This paper: observed outcome is annual flood claims from 2016–2020 in watersheds with offsets; observed treatment is all wetlands developed from 1996–2016 in watersheds with offsets; $\widehat{\Delta D}/\Delta W$ ($/ha/yr) is annual estimated flood damage from offsets divided by observed treatment.

Brody *et al.* (2015): observed outcome is annual flood claims from 2001–2008, observed treatment is the net change in palustrine wetlands from 2001–2006; $\widehat{\Delta D}/\Delta W$ ($/ha/yr) is the paper's average estimate ($13,975/watershed/1pp) multiplied by the percent change in palustrine wetlands from 2001–2006 (−1.14%) and the number of watersheds (1368) divided by observed treatment.

Taylor and Druckenmiller (2022): observed outcome is the increase in annual (nominal) flood claims from 1991–1995 to 2016–2020; observed treatment is all wetland pixels converted to development from 1996–2016; $\widehat{\Delta D}/\Delta W$ is the average $/ha/year for these wetland pixels calculated from TD's Florida grid-level estimates based on code provided to the authors by TD.

Developed watersheds only
This paper: same, calculated only for watersheds with at least 10% of area developed in 1996.

Taylor and Druckenmiller (2022): same as above for the outcome, calculated only for watersheds with at least 10% of area developed in 1996. Observed treatment is calculated as in TD, as the positive part of net change in wetland acres from 2001–2016. $\widehat{\Delta D}/\Delta W$: $8,290/ha/yr (DT, p. 1336).

Coastal watersheds only
This paper: same, calculated only for storm surge watersheds (defined as those with at least 10% of area classified as a storm surge flood zone by FEMA).

Sun and Carson (2020): observed outcome is annual flood claims from 2016–2020 in storm surge watersheds; observed treatment is net change in wetland + water hectares in these watersheds from 1996–2016; $\widehat{\Delta D}/\Delta W$ is $18,000/ha/yr (from their average estimate of $1.8m/km^2/yr).

Table A15. Overlapping Federal Offsets

	N	p_fed	q_fed	pq_fed	p_state	q_state	pq_state	fed_share
2006	9	6.81	834.40	5.68	48.80	1,274.90	62.22	0.08
2007	10	9.31	667	6.21	60.61	1,136.90	68.91	0.08
2008	1	7	591.80	4.14	58.70	795.10	46.68	0.08
2009	4	7.57	270.80	2.05	68.48	677.50	46.40	0.04
2010	1	20	304.80	6.10	75.79	571.90	43.34	0.12
2011	2	78.47	304.40	23.89	78.51	691.60	54.30	0.31
2012	6	20.83	392.20	8.17	85.36	724.90	61.88	0.12
2013	4	24.33	653.70	15.91	91.31	662.50	60.50	0.21
2014	14	29.28	699.60	20.49	98.90	880.90	87.12	0.19
2015	7	24.68	561.40	13.86	89.29	701.90	62.68	0.18
2016	15	35.54	576	20.47	89.57	869.90	77.91	0.21
2017	11	42.89	833.80	35.76	103.13	760.80	78.46	0.31
2018	9	14.96	947.40	14.17	107.94	607.70	65.60	0.18
2006–2018	93		7,637.40	176.89		10,356.50	815.97	0.18

Columns:

(1) Number of federal offset transactions in Florida with observed prices.
(2) Estimated average federal offset price in Florida, nominal '000$/offset.
(3) Total federal offsets sold in Florida (all, not just those with prices).
(4) Estimated federal offset transaction volume, nominal MM$.
(5) Estimated average state offset price, nominal '000$/offset.
(6) Total state offsets sold in Florida.
(7) Estimated state offset transaction volume, nominal MM$.
(8) Column (4) divided by the sum of (4) and (7).

Source. Authors' calculations from ledger and price data.

Table A16. Estimated Marginal Damages — Additional Details

	Per acre	Per credit
0%	−14,800.68	−120,828.80
5%	−2,483.87	−14,210.87
10%	−481.93	−5,150.65
15%	0	0
20%	0	0
25%	170.01	1,700.01
30%	776.35	6,592.48
35%	1,422.43	12,462.93
40%	2,271.52	18,845.44
45%	3,303.32	27,966.32
50%	4,782.01	39,039.04
55%	6,574.71	52,931.00
60%	8,807.56	73,054.87
65%	11,839.17	96,159.14
70%	16,648.43	139,533.60
75%	22,466.57	192,945.50
80%	31,403.34	287,192.40
85%	60,206.46	439,870.00
90%	98,911.34	791,940.80
95%	204,614.00	1,606,385.00
97.5%	324,080.90	2,320,047.00
99%	490,202.20	4,095,167.00
99.9%	4,328,164.00	22,776,278.00
100%	5,380,962.00	66,680,328.00

Watershed-level estimated marginal flood protection values from Table 4 (column 3) for watersheds with nonzero wetland development from 1996–2016. Negative values correspond to net flood protection benefits due to wetland bank protection.

Calculated as the expected net present discounted value (NPDV) of marginal insured flood damage from permanently developing an acre of wetland and restoring a wetland in that market (column 1) or using a wetland offset (column 2), discounted to current 2020 USD with a 5% real discount rate. See Section 5.2 for details.

Table A17. Welfare and Passthrough of Pigouvian Taxation

	Market	Pigou	Pigou (CP)
Wetlands developed (acres)	141,606.2	120,097.6	112,457.1
Wetlands offsets used (credits)	16,694.3	14,256.0	13,429.2
Passthrough			
Average price ('000$/credit)	70,233.4	67,486.2	71,349.3
Average price + tax ('000$/credit)	70,233.4	80,451.1	83,225.8
Total transaction volume (MM)	1,172.5	962.1	958.2
Producer price change (%)		−3.9	1.6
Consumer passthrough (%)		78.8	109.4
Gains from trade			
Developer values (MM)	2,850.6	2,486.2	2,363.9
Supply costs (MM)	440.3	421.4	396.9
Private gains from trade (MM)	2,410.3	2,064.9	1,967.0
Distributional outcomes			
Consumer surplus (MM)	1,678.1	1,339.3	1,246.3
Producer surplus (MM)	732.2	540.7	561.2
Producer surplus (%GFT)	30.4	26.2	28.5
Tax revenue (MM)	0	184.8	159.5
Externalities			
Flood damage (MM)	−1,888.1	−282.1	−235.1
damages (% pre-reform)		14.9	12.5
below 99.9%-ile	−1,888.1	−282.1	−235.1
below 99%-ile	−1,719.5	−282.1	−235.1
below 97.5%-ile	−1,702.4	−284.9	−237.8
7% discount rate	−1,132.9	−169.2	−141.1
3% discount rate	−2,643.4	−394.9	−329.1
Welfare (MM)	522.2	1,782.8	1,731.9

Version of Table 5 with alternative passthrough assumptions. Market outcomes from 1995–2020 in millions of 2020 USD at observed offset prices (column 1, "Market"), offset prices with local Pigouvian taxes (column 2, "Pigou"), and offset prices with a local Pigouvian tax and complete passthrough (column 3, "Pigou (CP)"). Average passthrough is slightly below 100% in the full passthrough scenario because some watershed-periods have zero trade under the vector of Pigouvian taxes. Flood damage (%) reports counterfactual flood damage as a percent of flood damage in column (1). Net present discount values calculated using a 5% real discount rate.

Online Appendix – Supplementary Figures

FIGURE A1. FLORIDA WATERSHEDS AND HYDROLOGICAL FLOW NETWORK

Flow network across the 1,378 watersheds (white borders) or HUC12 USGS (2013) units, in Florida. See Figure A2 and Appendix A.5 for more details.

Arrowed dotted line indicates flow from the centroid to the centroid of another HUC12. **Dark blue** boundaries indicate HUC8 boundaries.

White boundaries (gray polygons) are watersheds. Isolated arrowheads indicate watersheds that are closed basins. Unarrowed coastal watersheds flow to the ocean.

Authors' calculations from the USGS (2013) National Watershed Boundary Dataset.

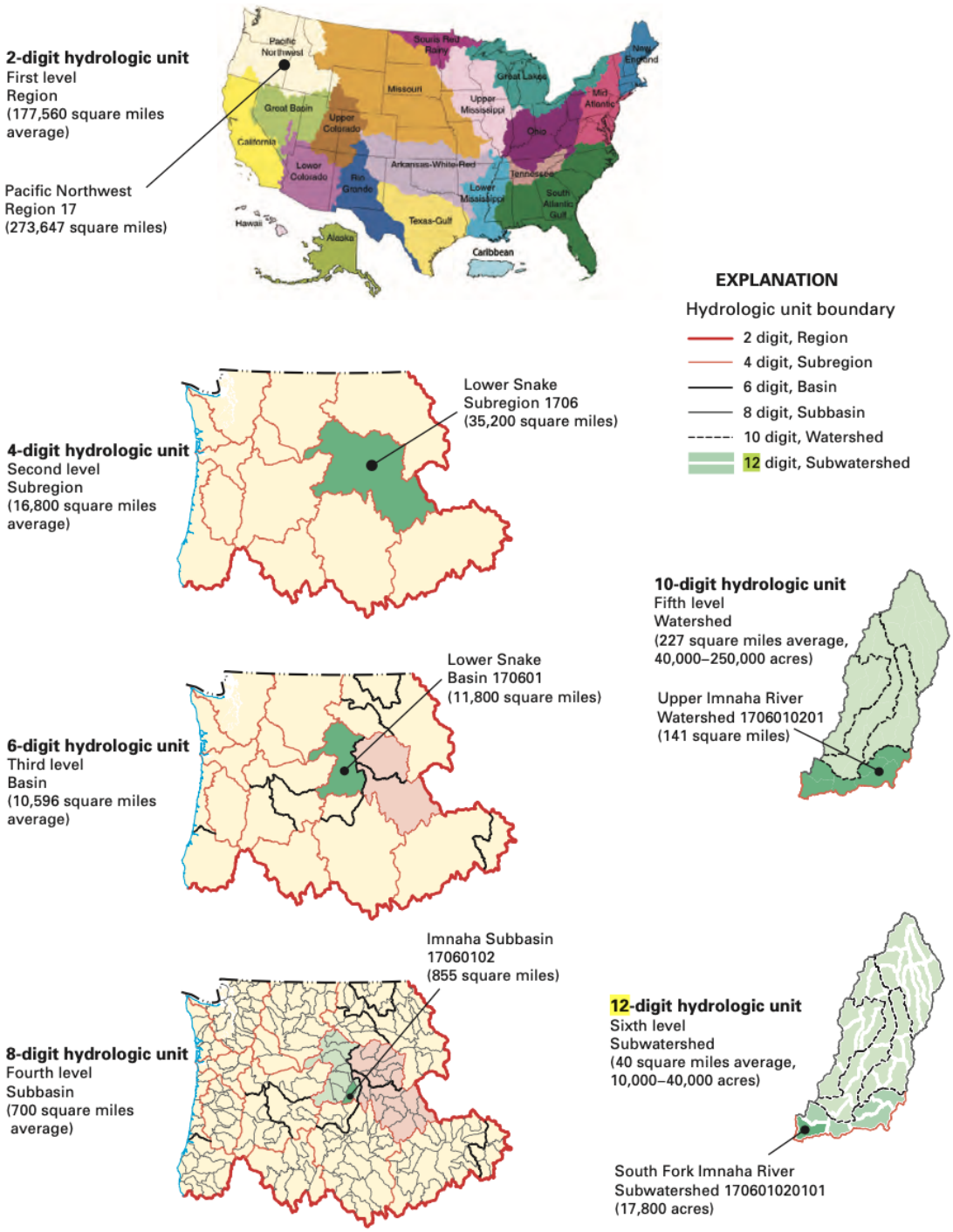


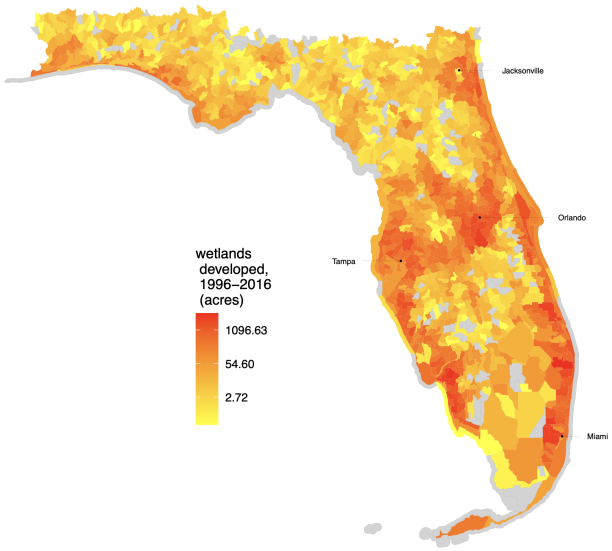
Figure 3. Hierarchy and areas for the six nested levels of hydrologic units are shown in the above example. As they are successively subdivided, the numbering scheme of the units increases by two digits per level.

Figure A2. Explanation of Hydrological Units

Watershed Boundary Dataset structure visualization

Source: USGS (2013, p. 7).

A. All Development on Wetlands



B. Development in Offsets Markets

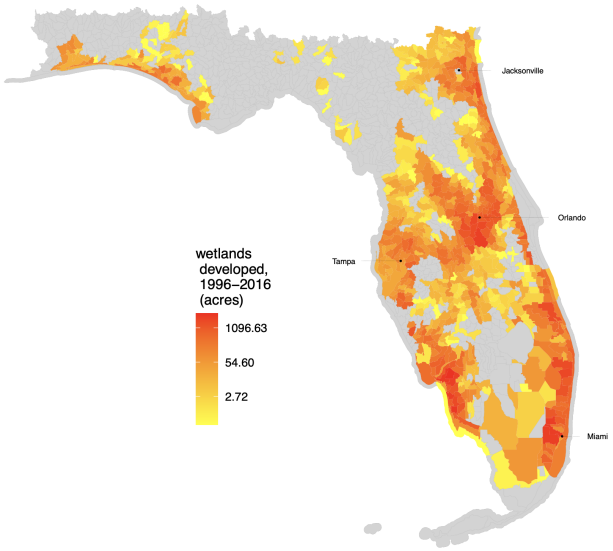


FIGURE A3. DEVELOPMENT ON FLORIDA WETLANDS

A. Map of local wetland development between 1996–2016.

B. Map of local wetland development occurring in active offset markets between 1996–2016. See Table A4 for more details.

Local watersheds colored by decile of ln(acres of wetlands developed).

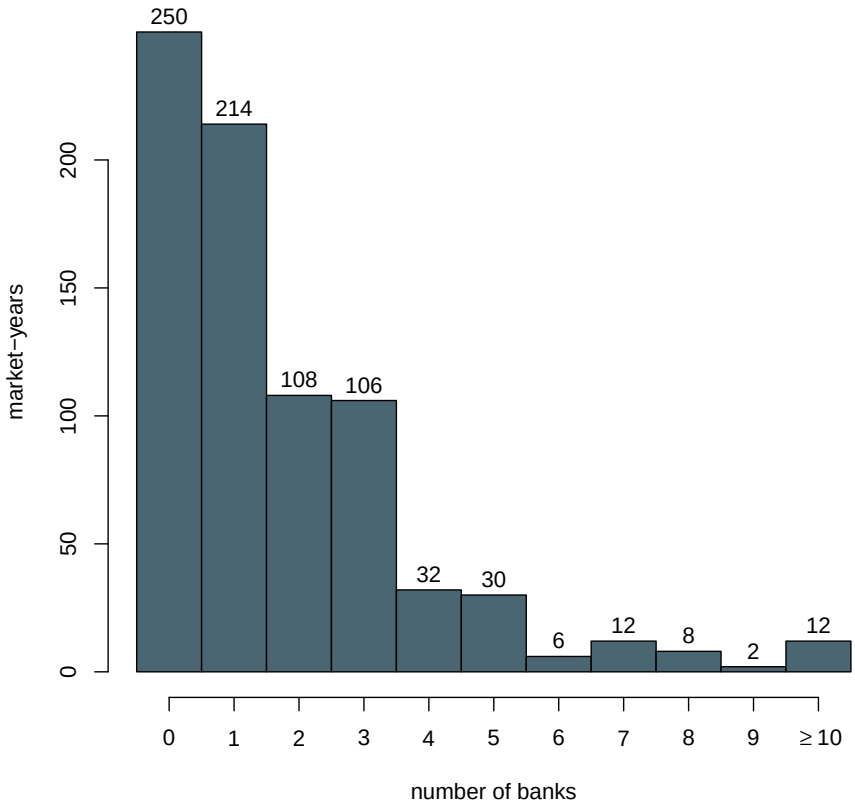


FIGURE A4. VARIATION IN NUMBER OF BANKS PER MARKET-YEAR

This figure reports the distribution of the market-level count of incumbent wetland mitigation banks over market-years from 1995–2020. See Figure 1 for market boundaries and Figure 4 for cross-market variation in average entry rates from 1995–2020.

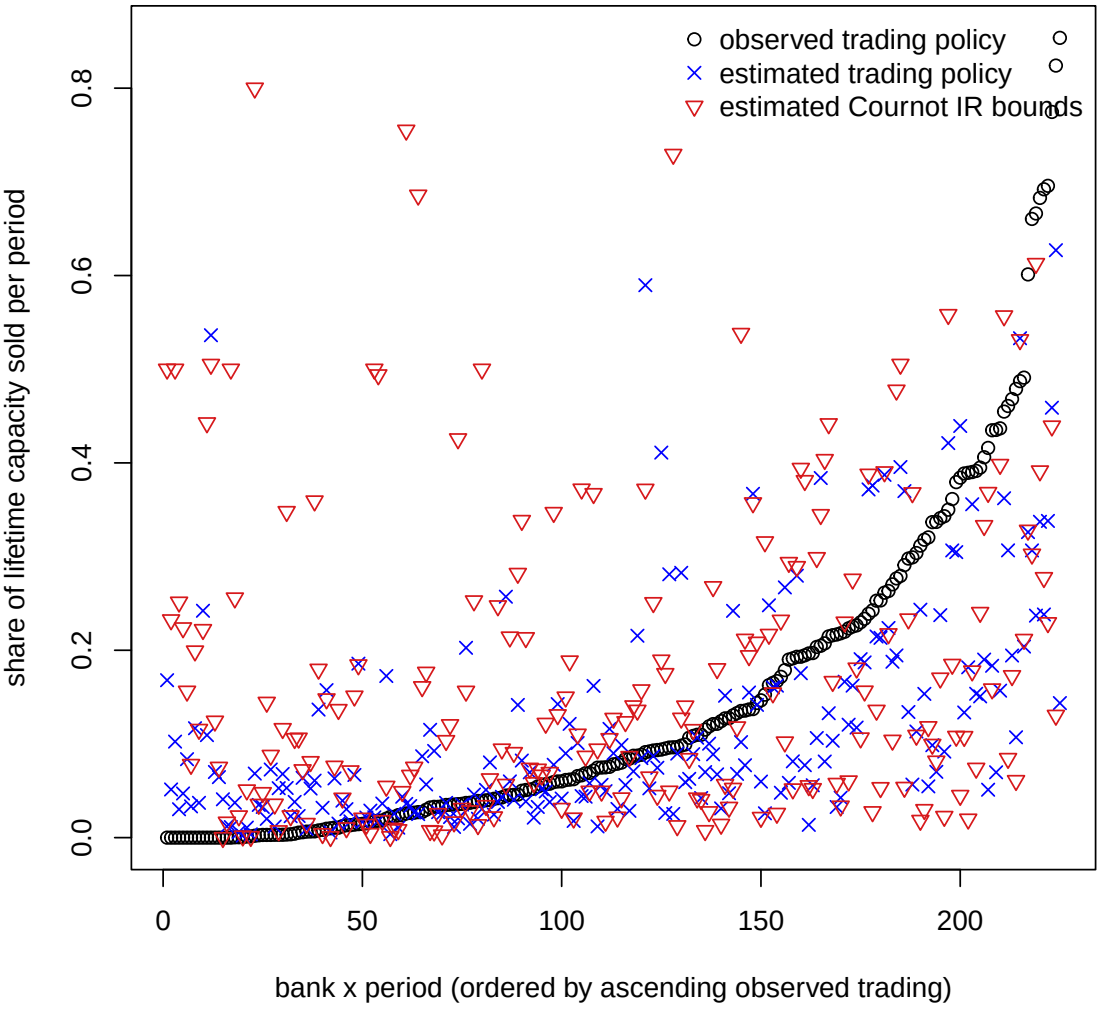


FIGURE A5. OBSERVED AND PREDICTED VARIATION IN BANK TRADING STRATEGIES

This figure reports (i) observed trading decisions by banks over five-year periods, (ii) fitted values for the unconstrained trading policy function, and (iii) implied Cournot individual rationality constraints. All three statistics are ordered by ascending observed trade share.

(∘) Black circles correspond to observed bank trade ratios, $q_{f\tau}/\tilde{v}_f$, for all bank-periods (f, τ) where banks trade nonzero quantities, ordered by ascending trade share.

(×) Blue crosses correspond to estimated trade policies, $\hat{\chi}$, predicting offset sales $q_{f\tau}$ (as a share of lifetime capacity, $\tilde{v}_f$) using a logit regression the controls for bank age, cumulative share sold, balances on issue, water management district and period fixed effects, and the extent of public and private wetland, population, median income, and the number of firms in the market.

(▽) Red inverted triangles denote myopic Cournot individual rationality constraints, q^{IR}, calculated for each bank-period in the observed equilibrium.

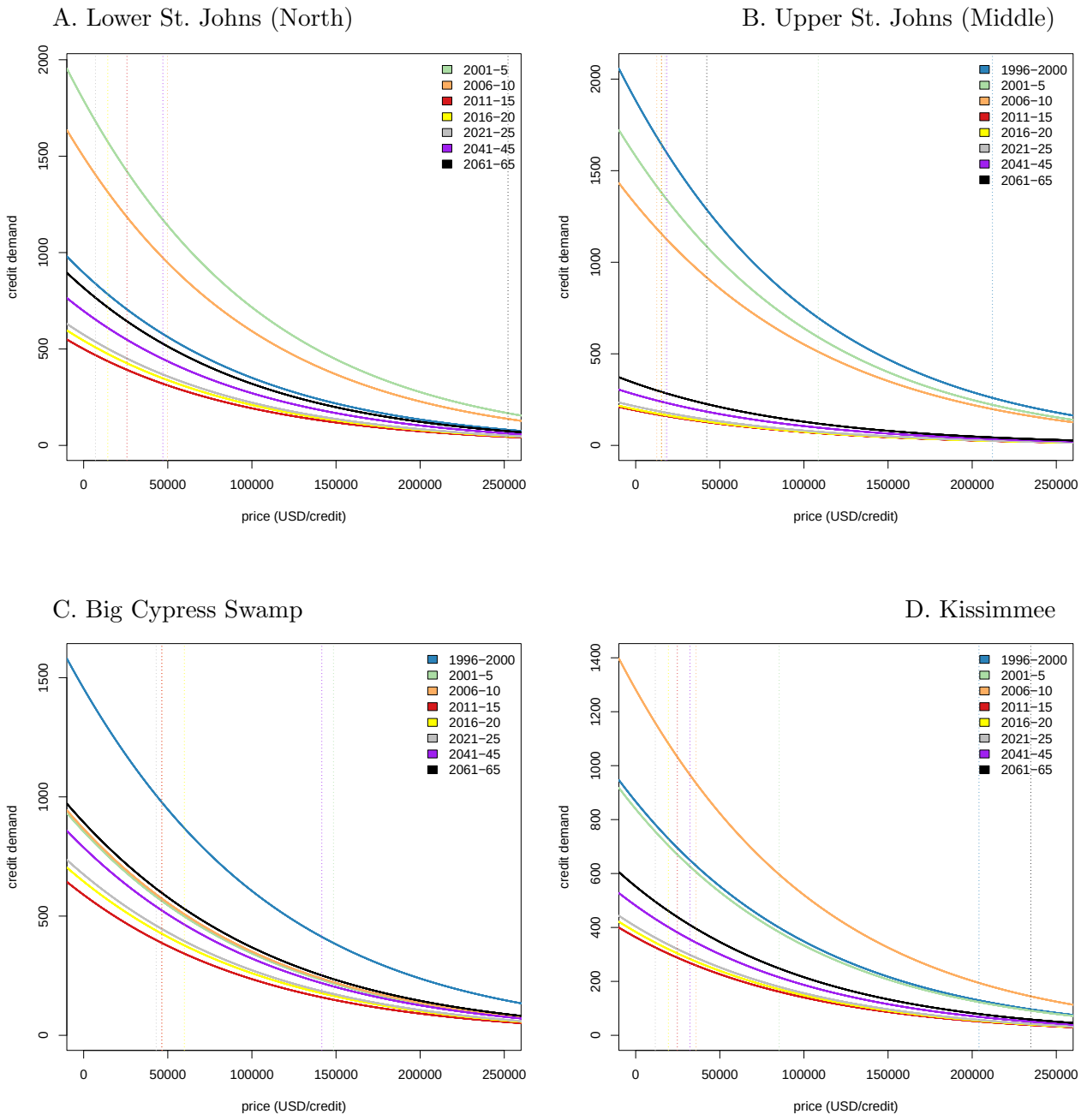


FIGURE A6. SOME AGGREGATE DEMAND CURVES OVER TIME

This figure plots aggregate estimated market-period-level demand curves for the four largest Florida offset markets by trade volume.

Each colored curve corresponds to a different period in which banks traded offsets, with dashed vertical lines corresponding to equilibrium offset prices.

Curves beyond the data (2021–25, 2041–45, 2061–65) involve simulations from the observed trading equilibrium.

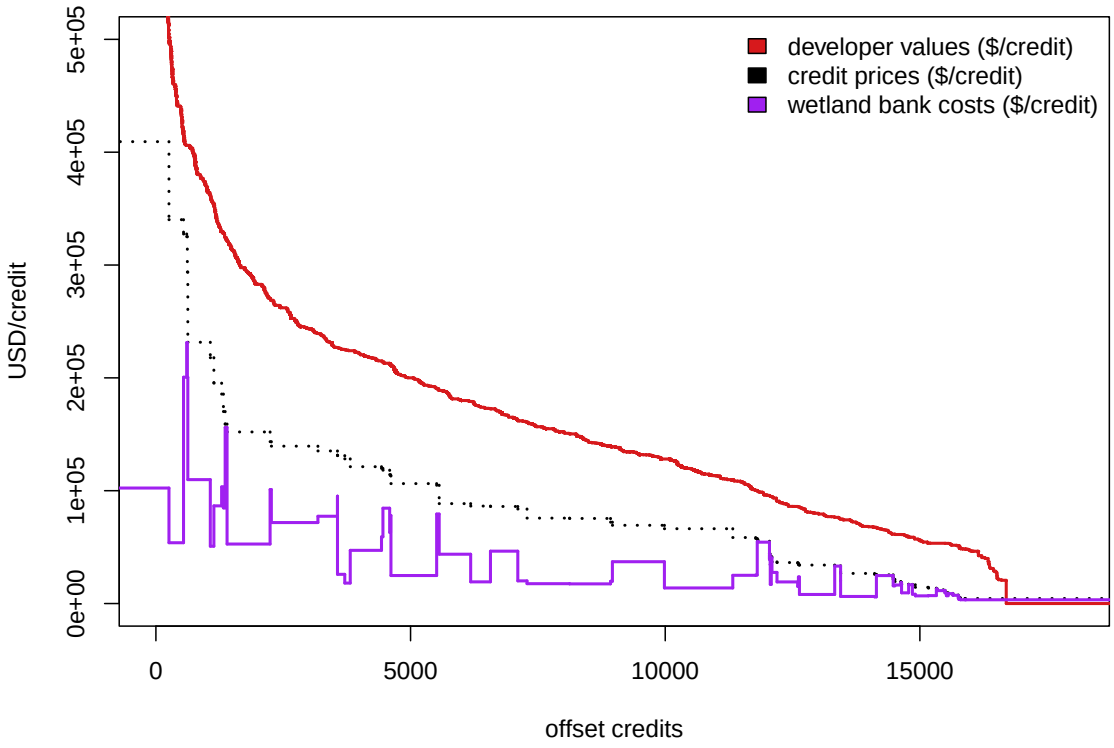


FIGURE A7. REALIZED PRIVATE GAINS FROM TRADE

Land developers' private values, transaction prices, and wetland banks' private costs.

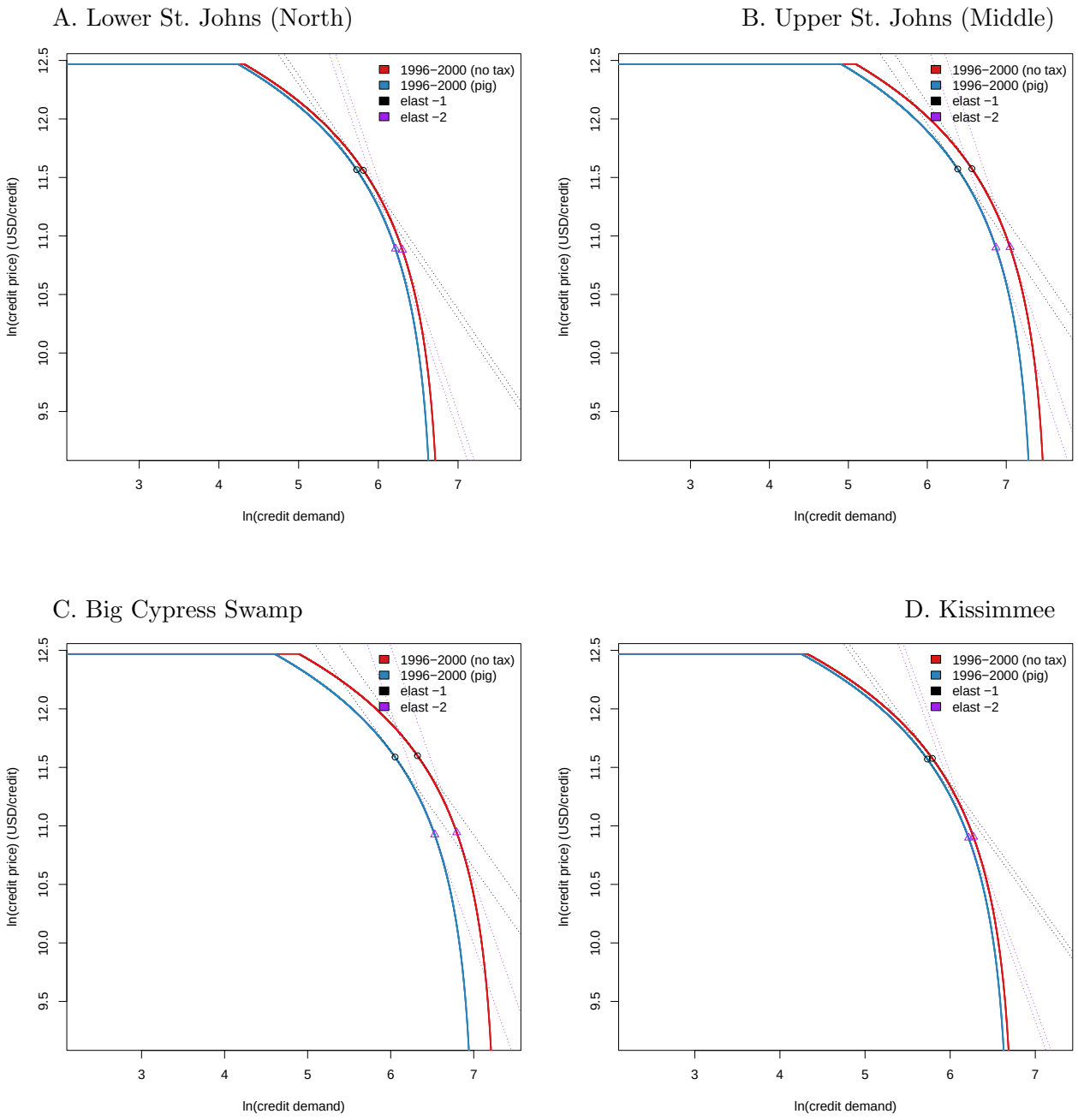


FIGURE A8. GEOMETRIC INTUITION FOR PASSTHROUGH OF PIGOUVIAN TAX

This figure plots aggregate (market-level) demand curves for the 1996–2000 period for the same four largest Florida offset markets by trade volume depicted in Figure A6, without (**red**) and with (**blue**) the local-watershed-level vector of Pigouvian taxes.

Identically-colored, dashed diagonal lines are tangencies to the points at which demand elasticities are -1 and -2, respectively (the optimal price in the myopic monopoly and symmetric duopoly games, respectively).

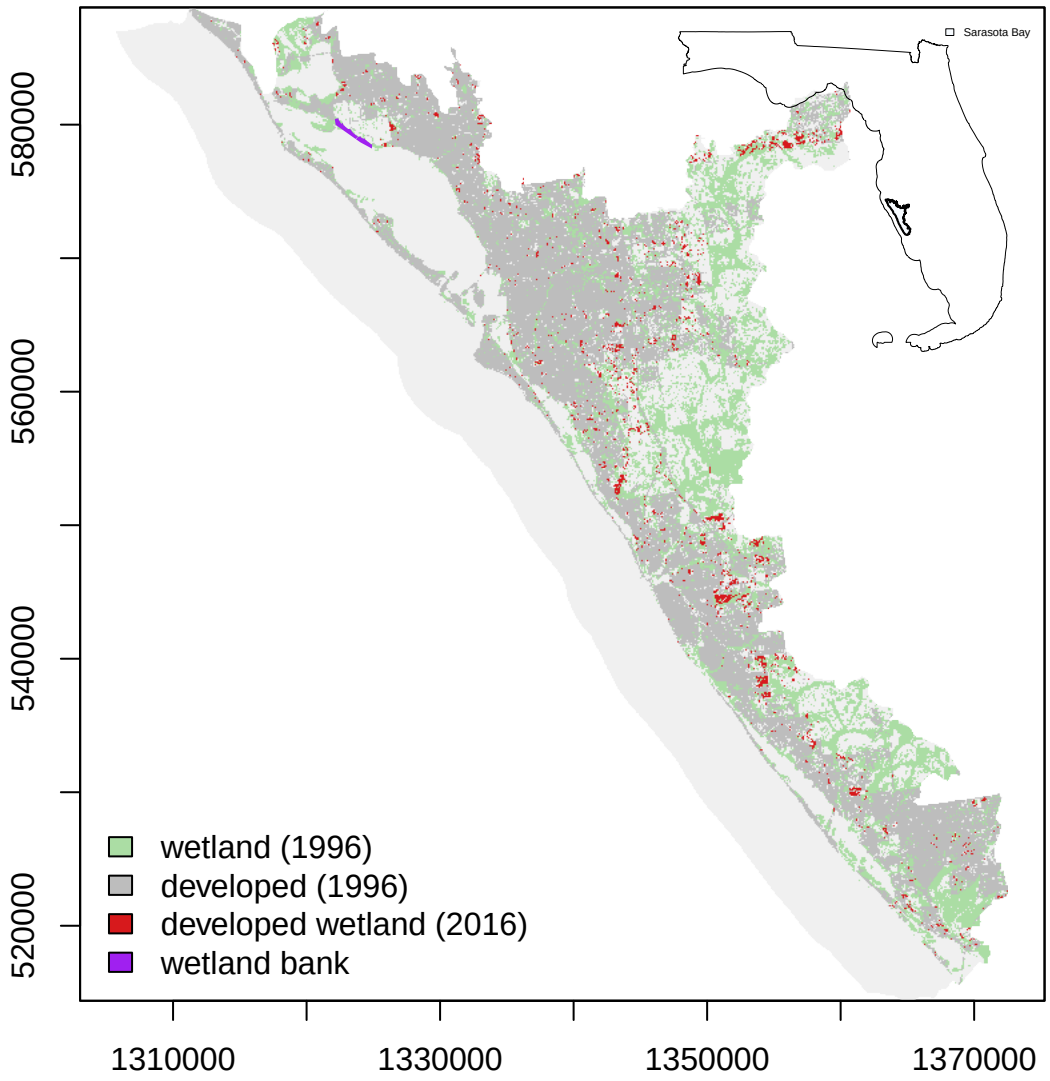


FIGURE A9.1. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

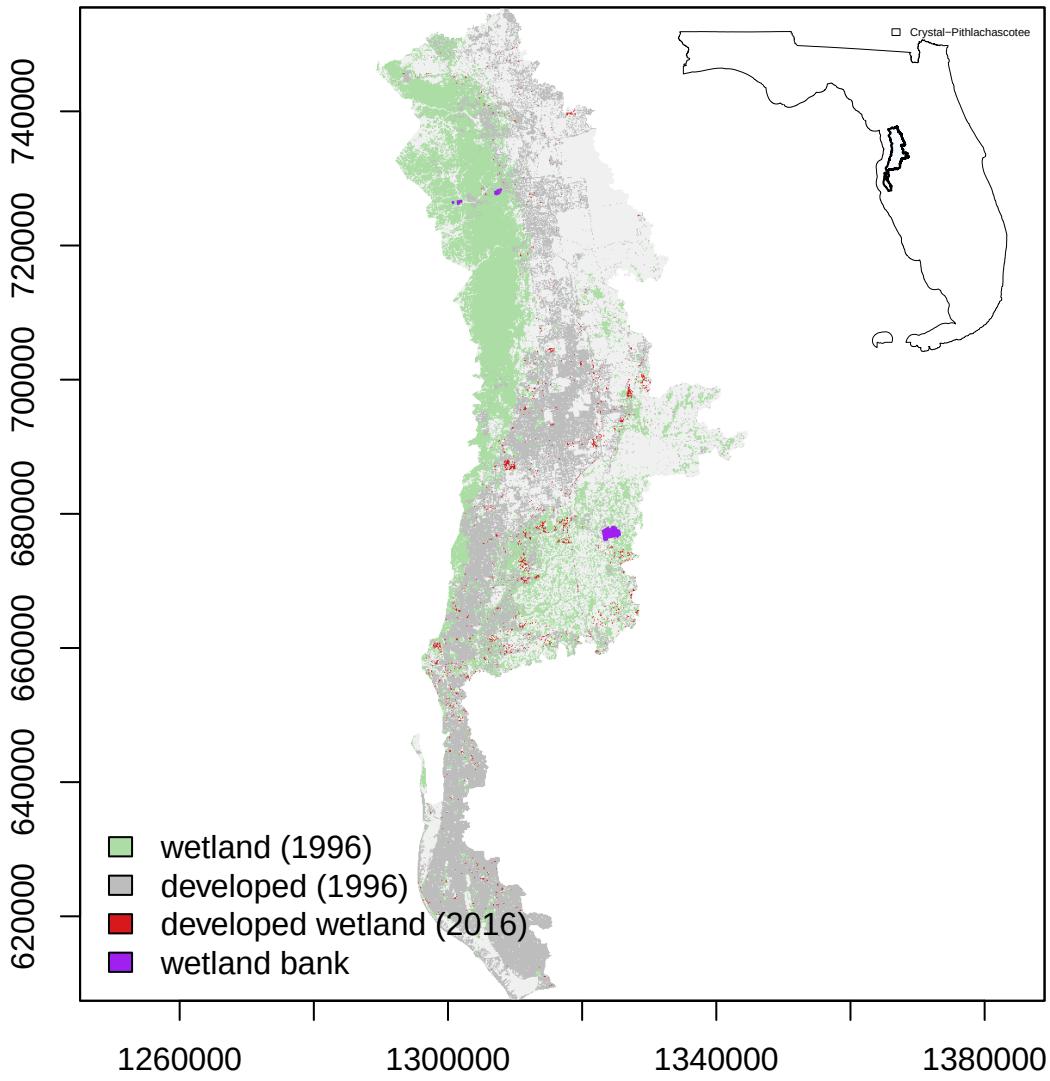


FIGURE A9.2. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

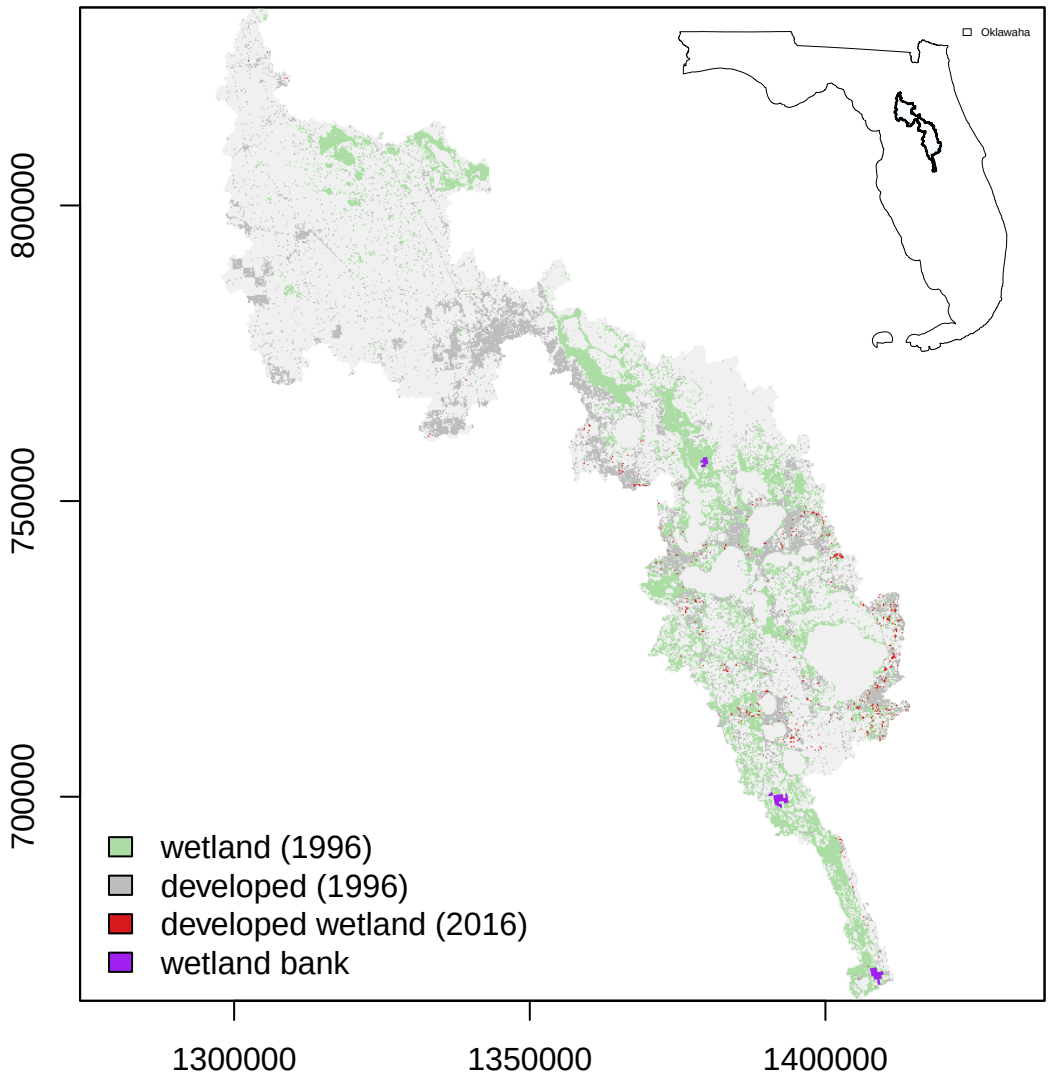


FIGURE A9.3. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

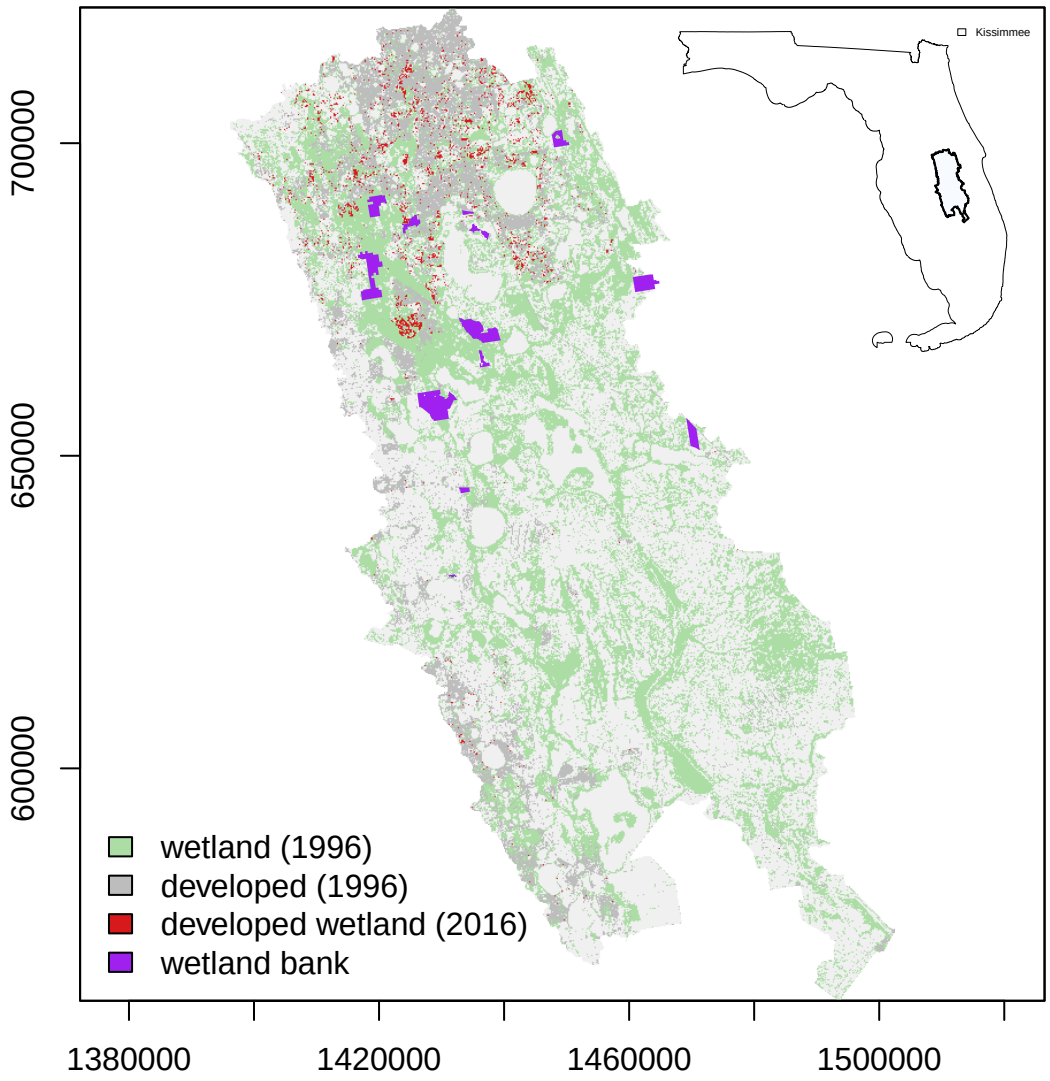


FIGURE A9.4. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

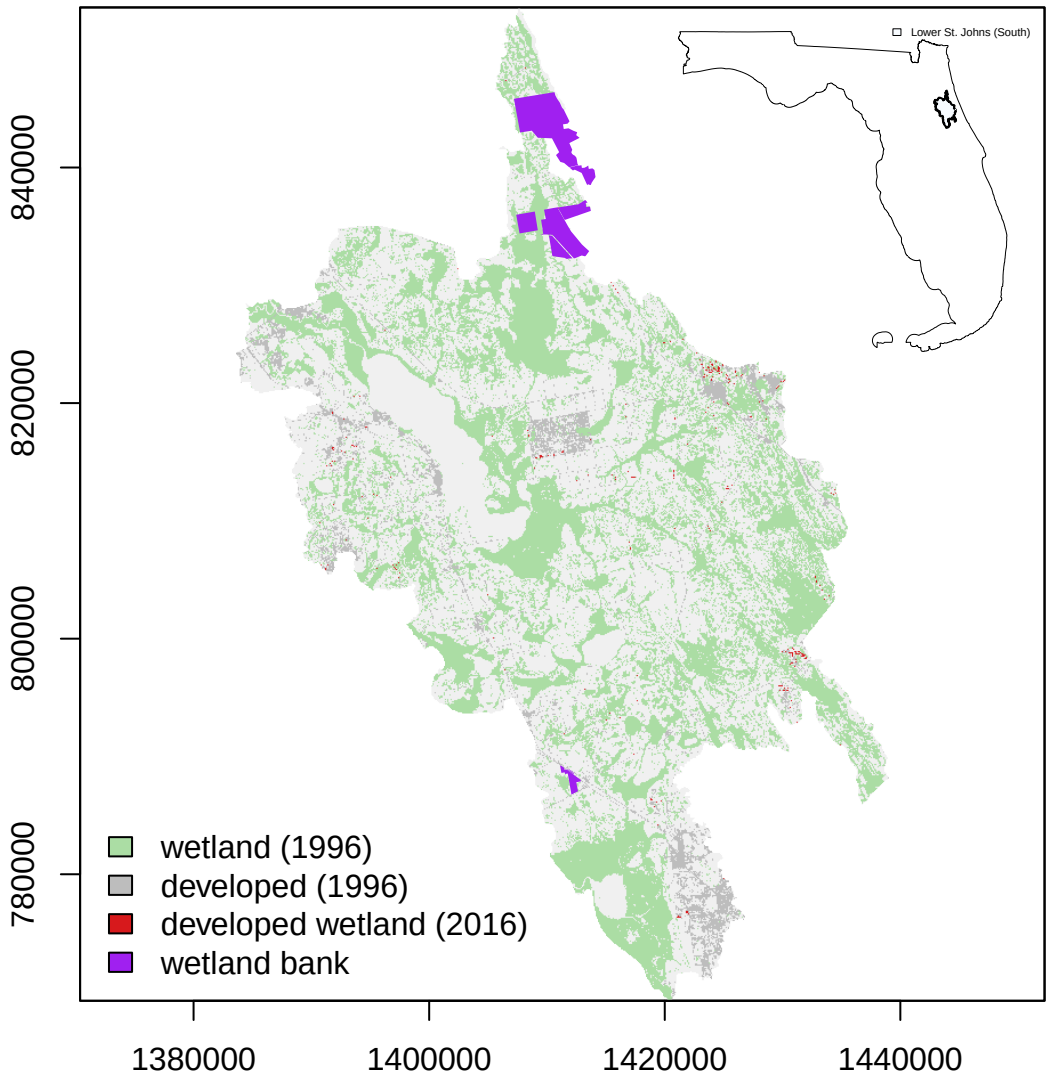


FIGURE A9.5. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

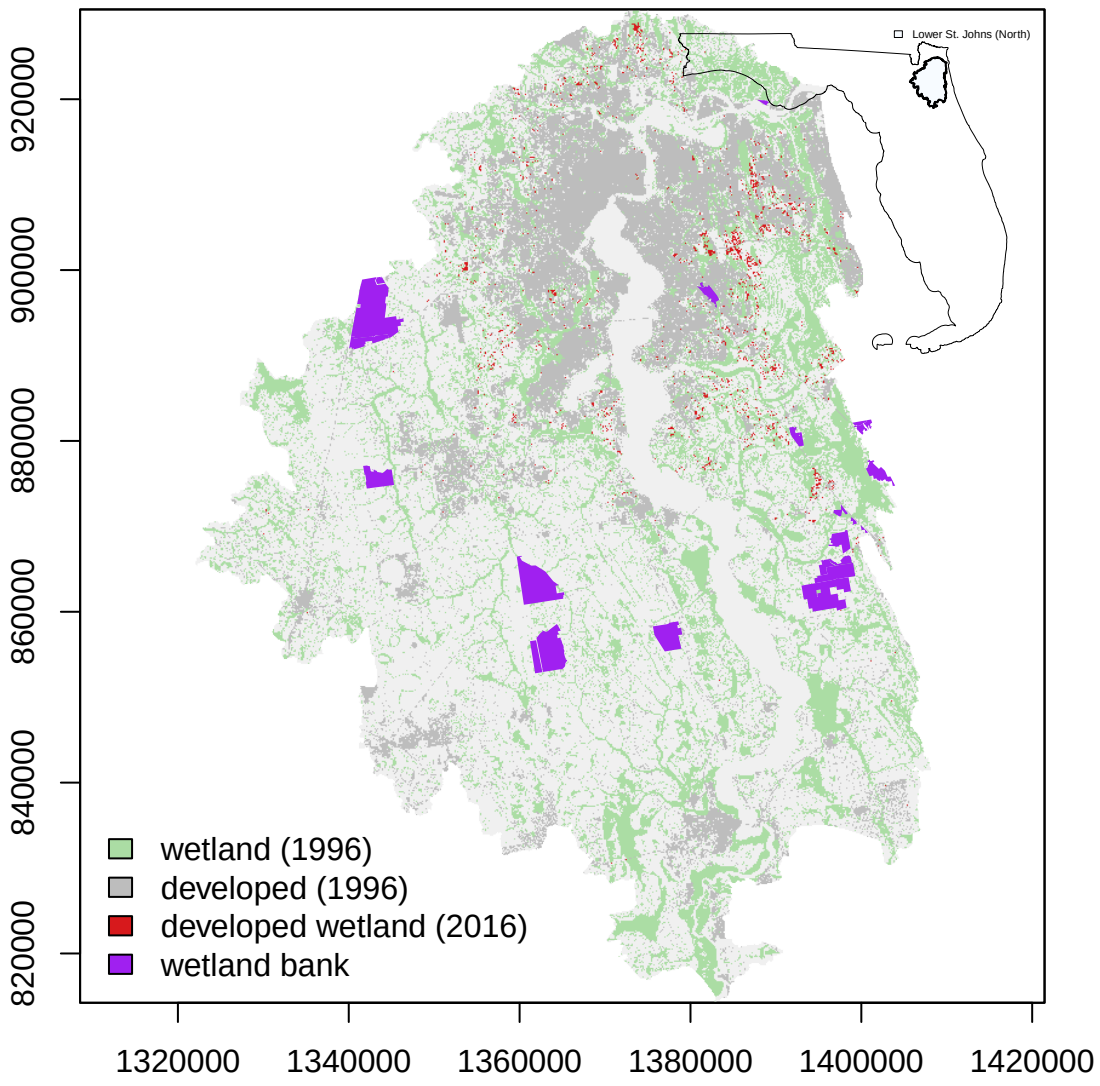


FIGURE A9.6. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

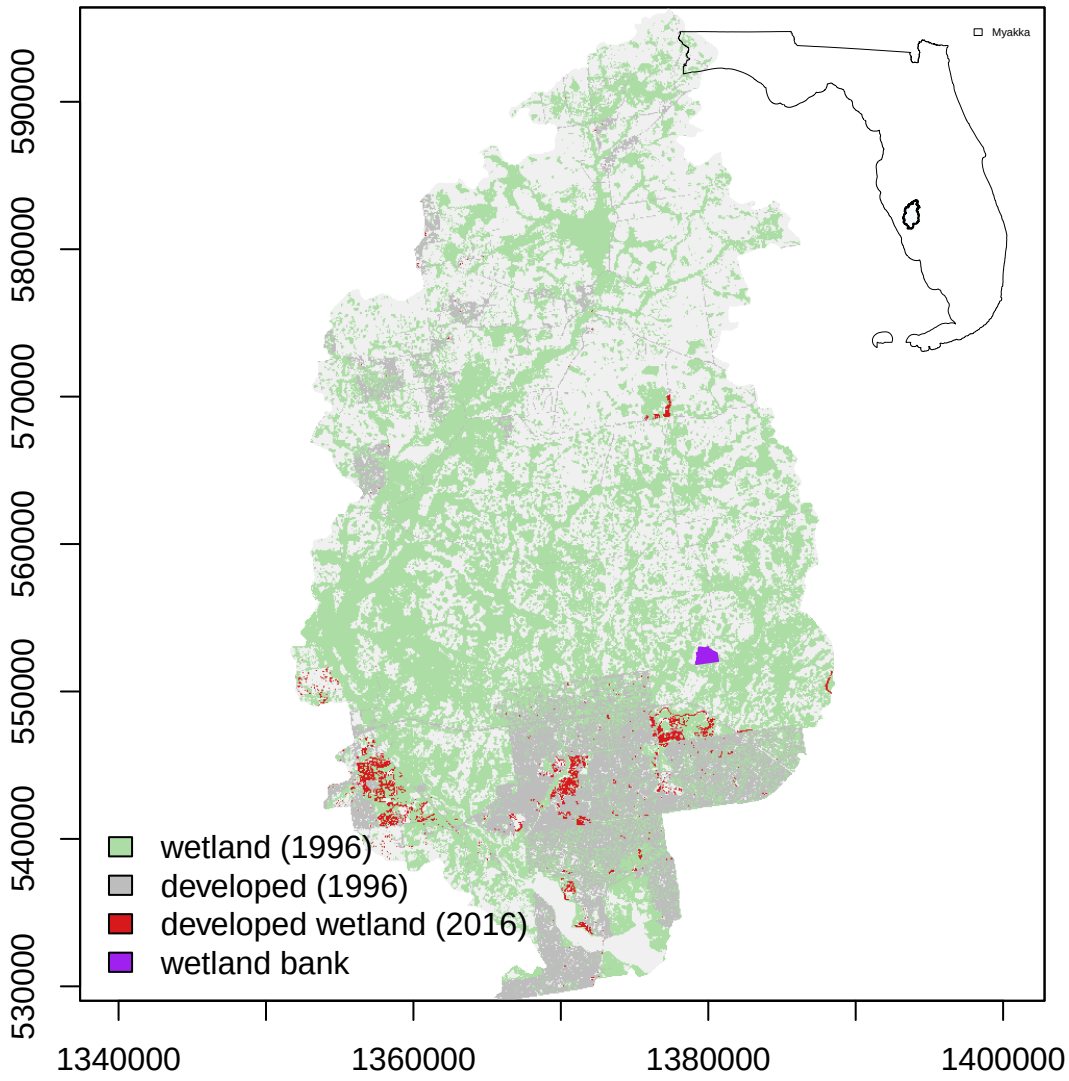


FIGURE A9.7. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

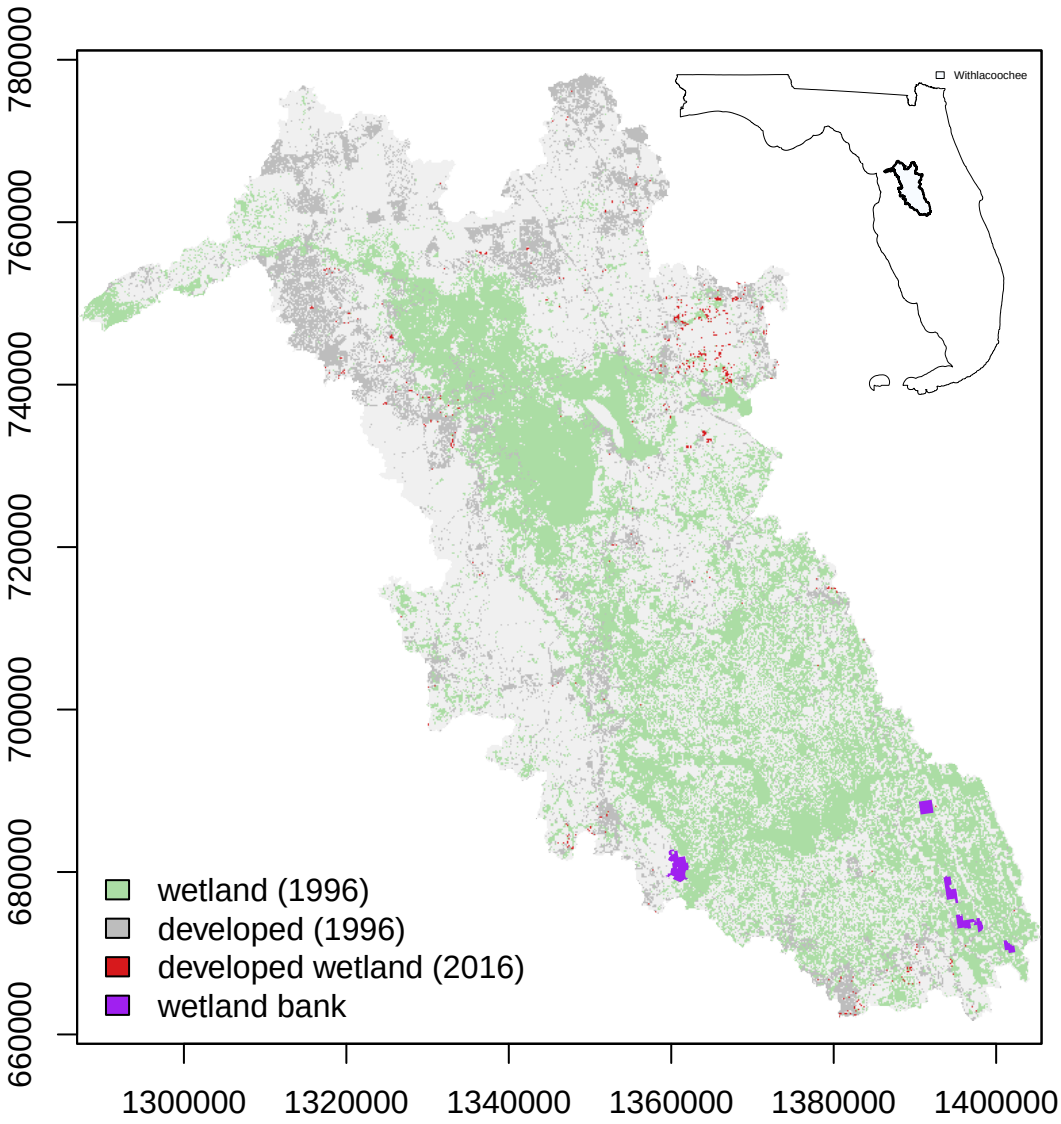


FIGURE A9.8. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

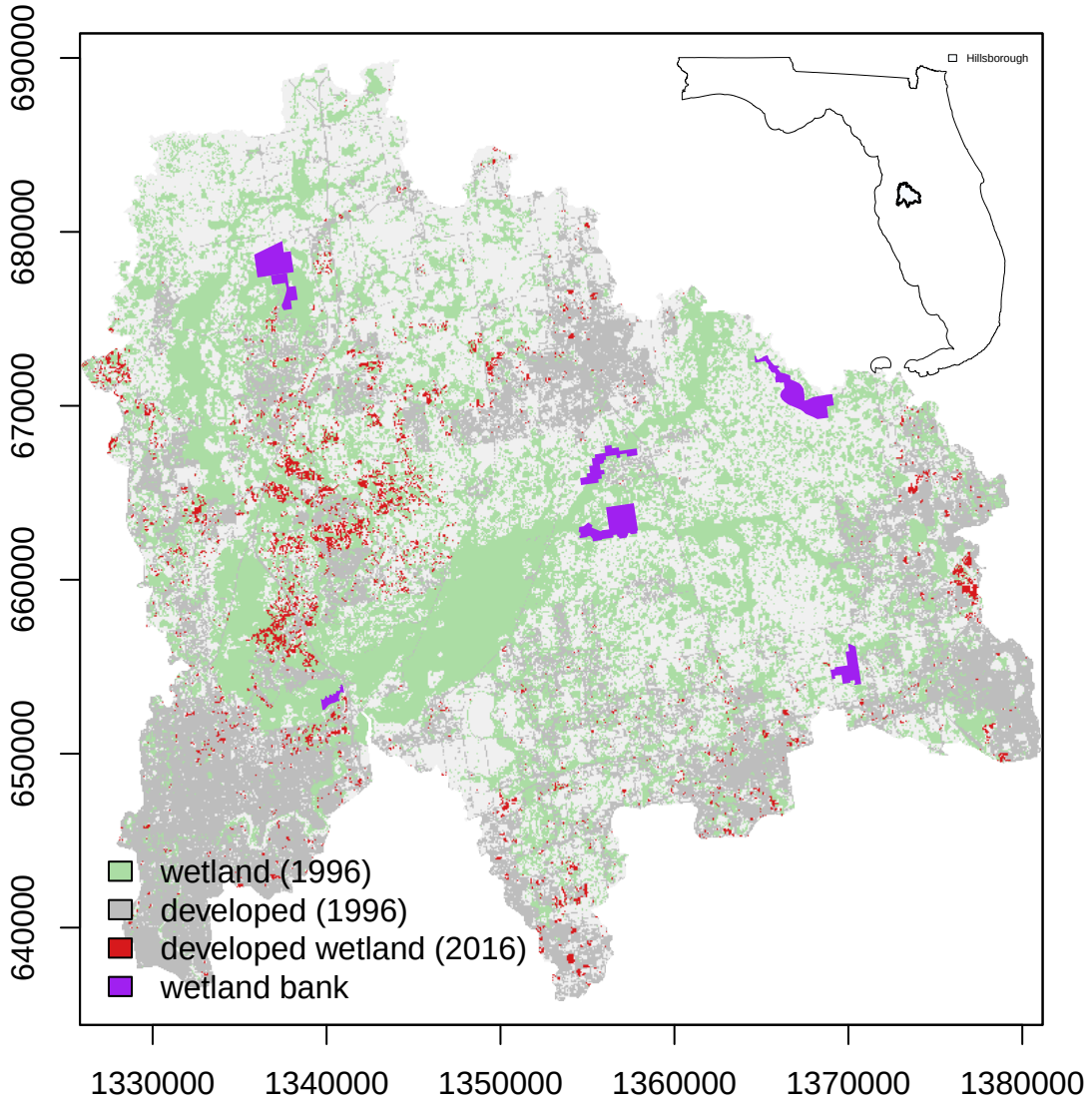


FIGURE A9.9. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

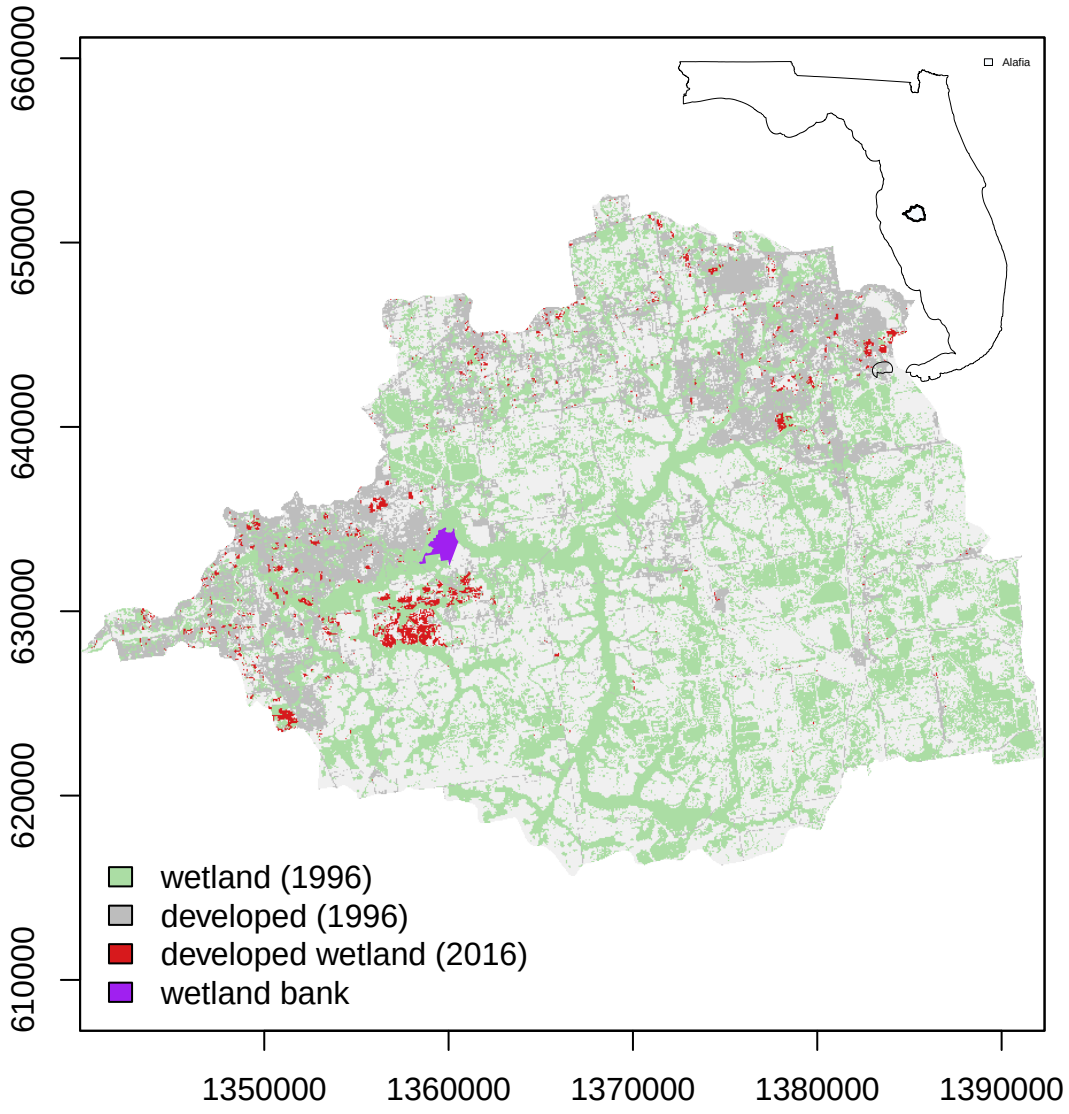


FIGURE A9.10. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

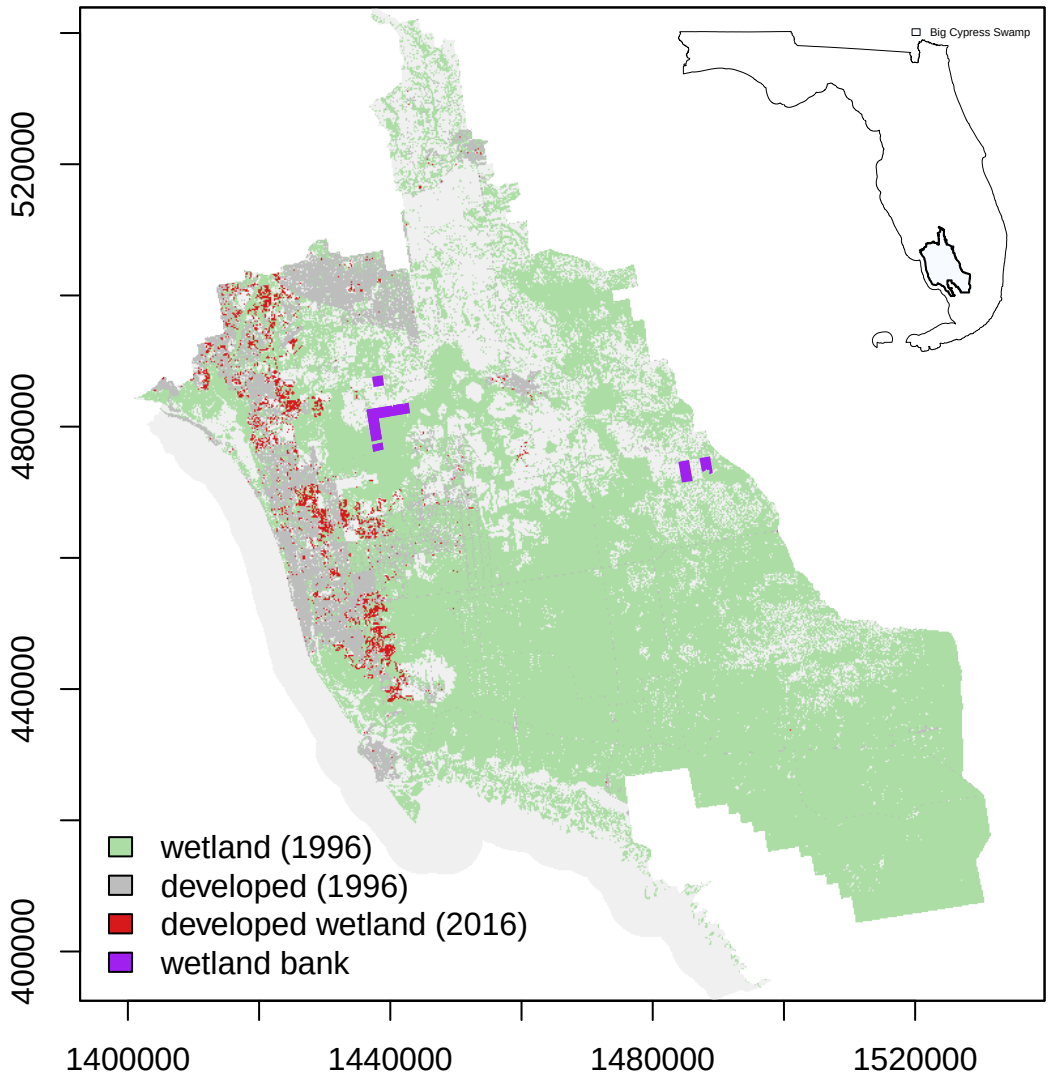


FIGURE A9.11. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

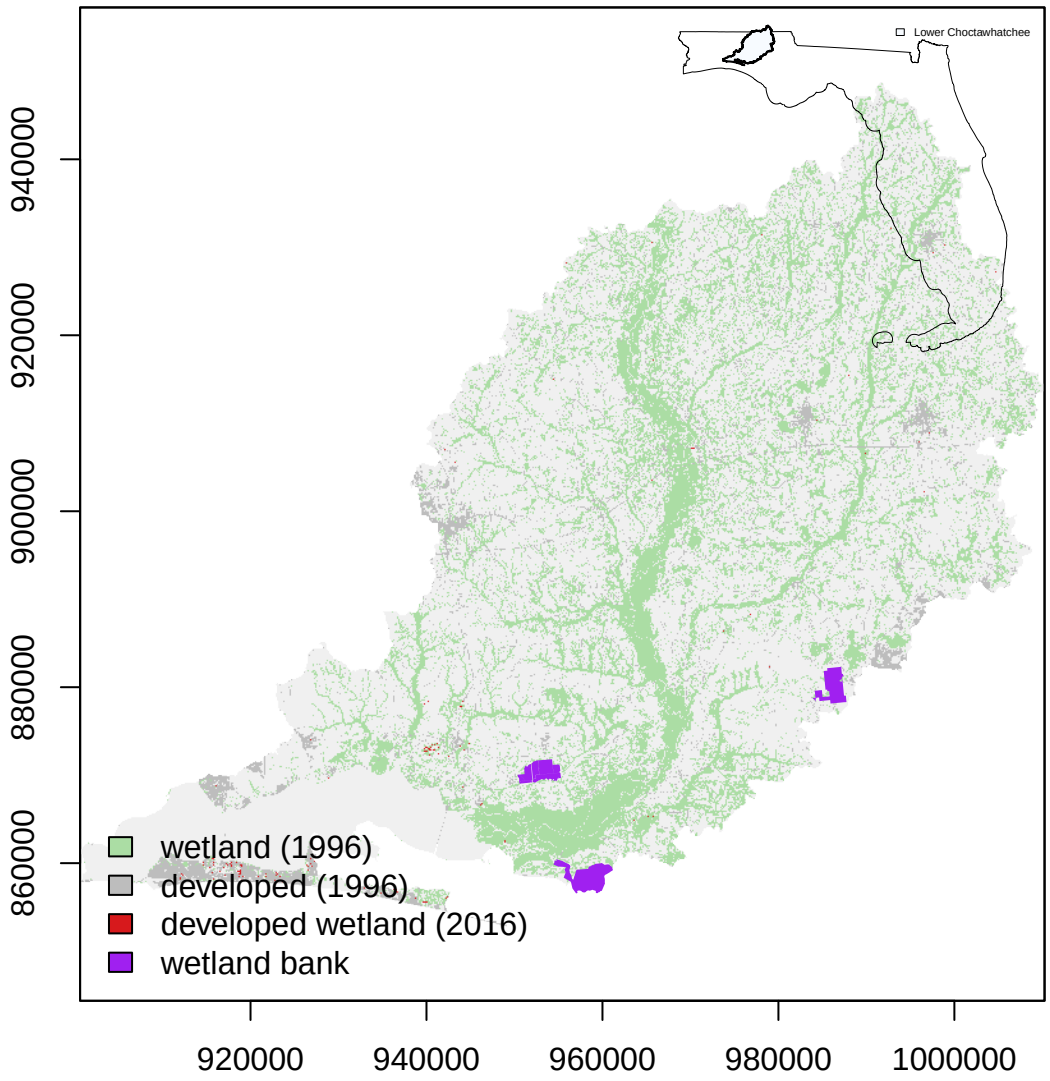


FIGURE A9.12. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

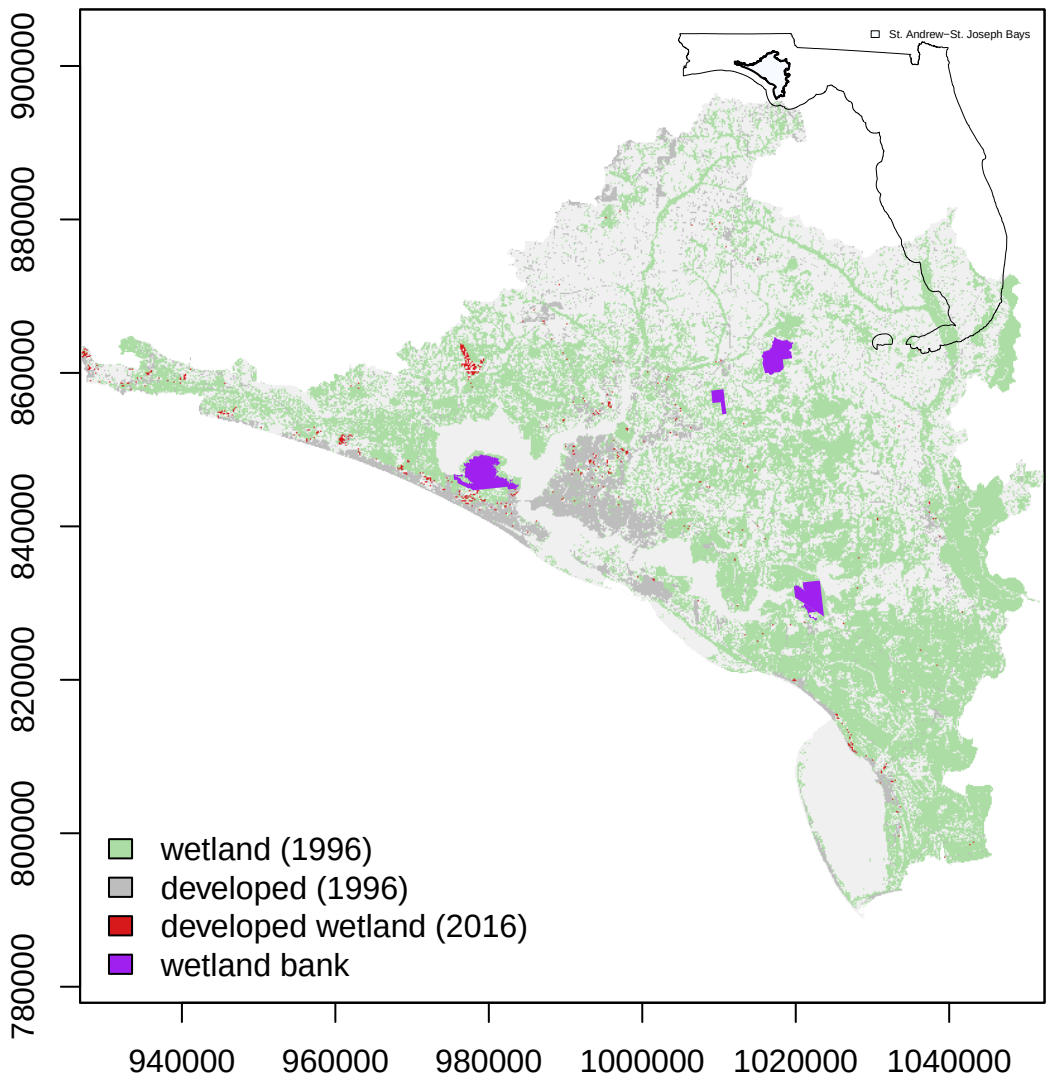


FIGURE A9.13. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

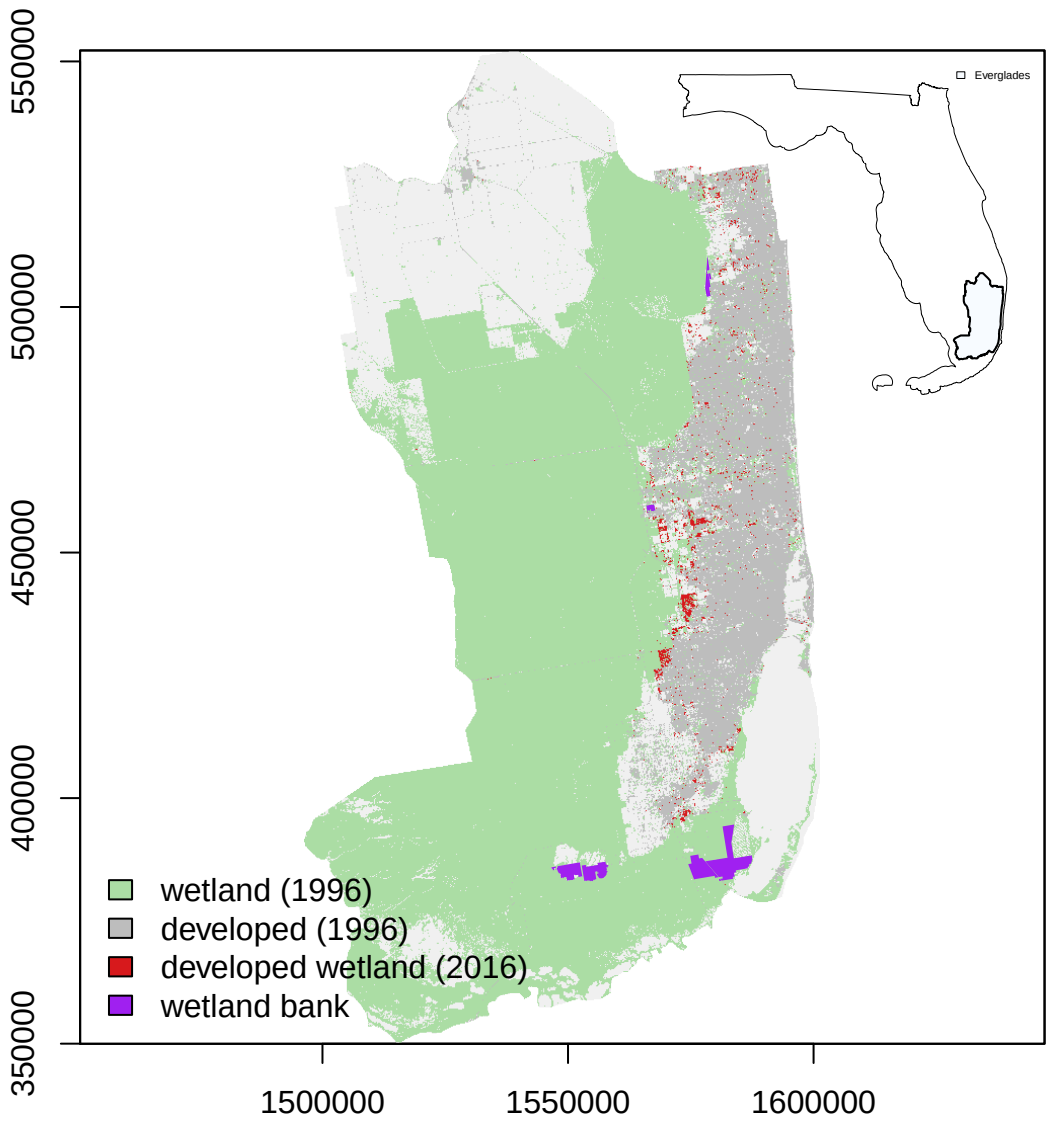


FIGURE A9.14. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

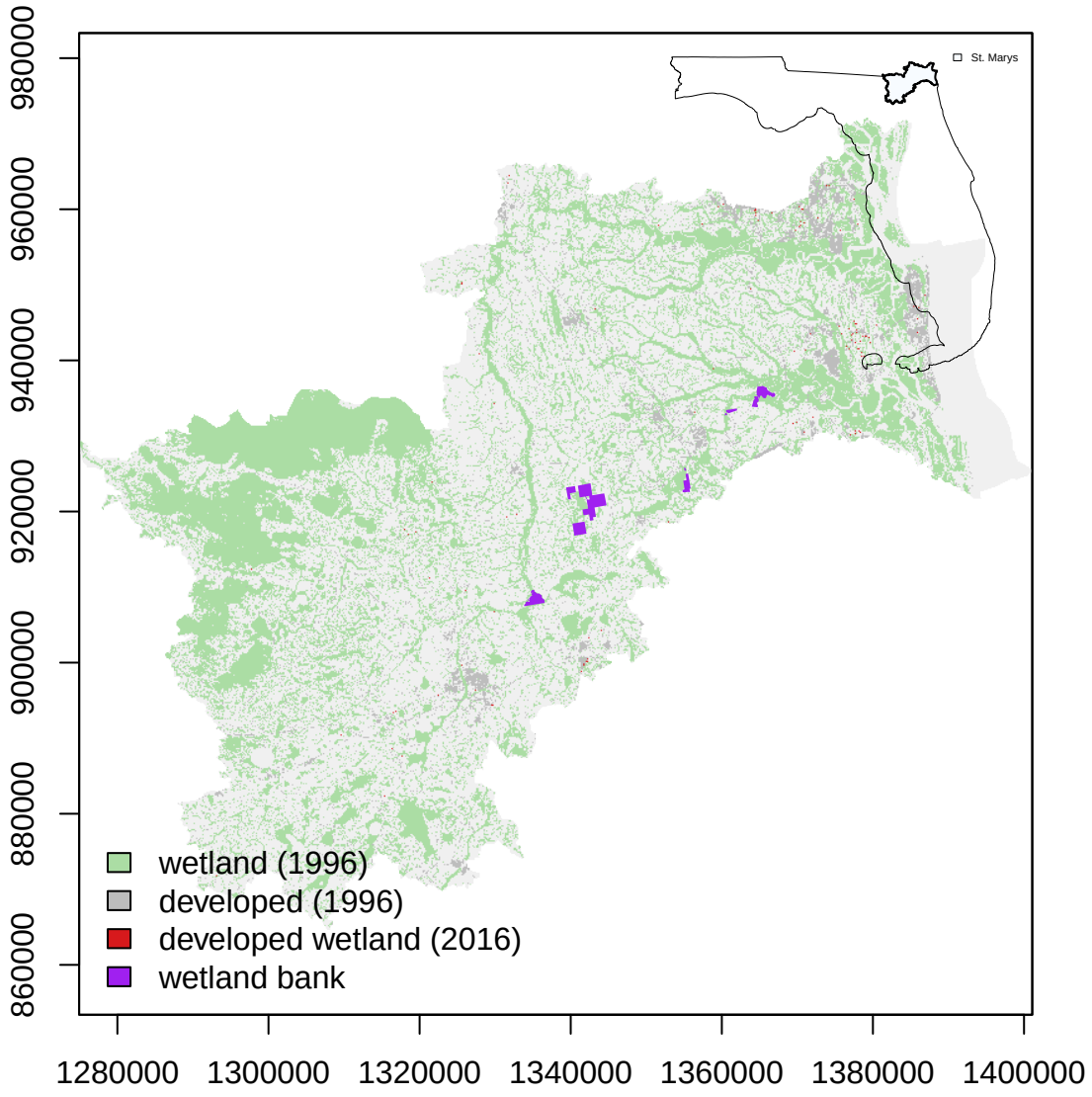


FIGURE A9.15. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

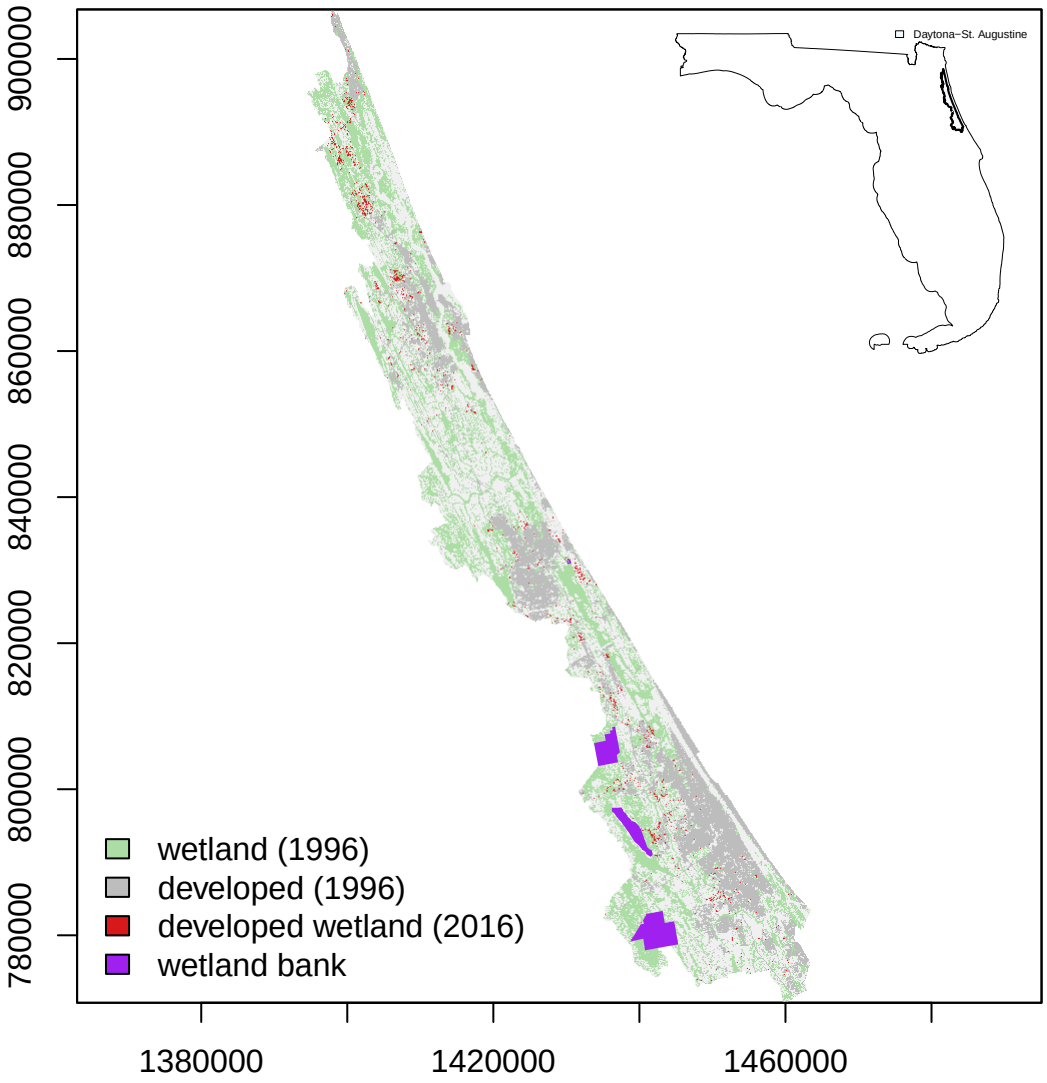


FIGURE A9.16. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

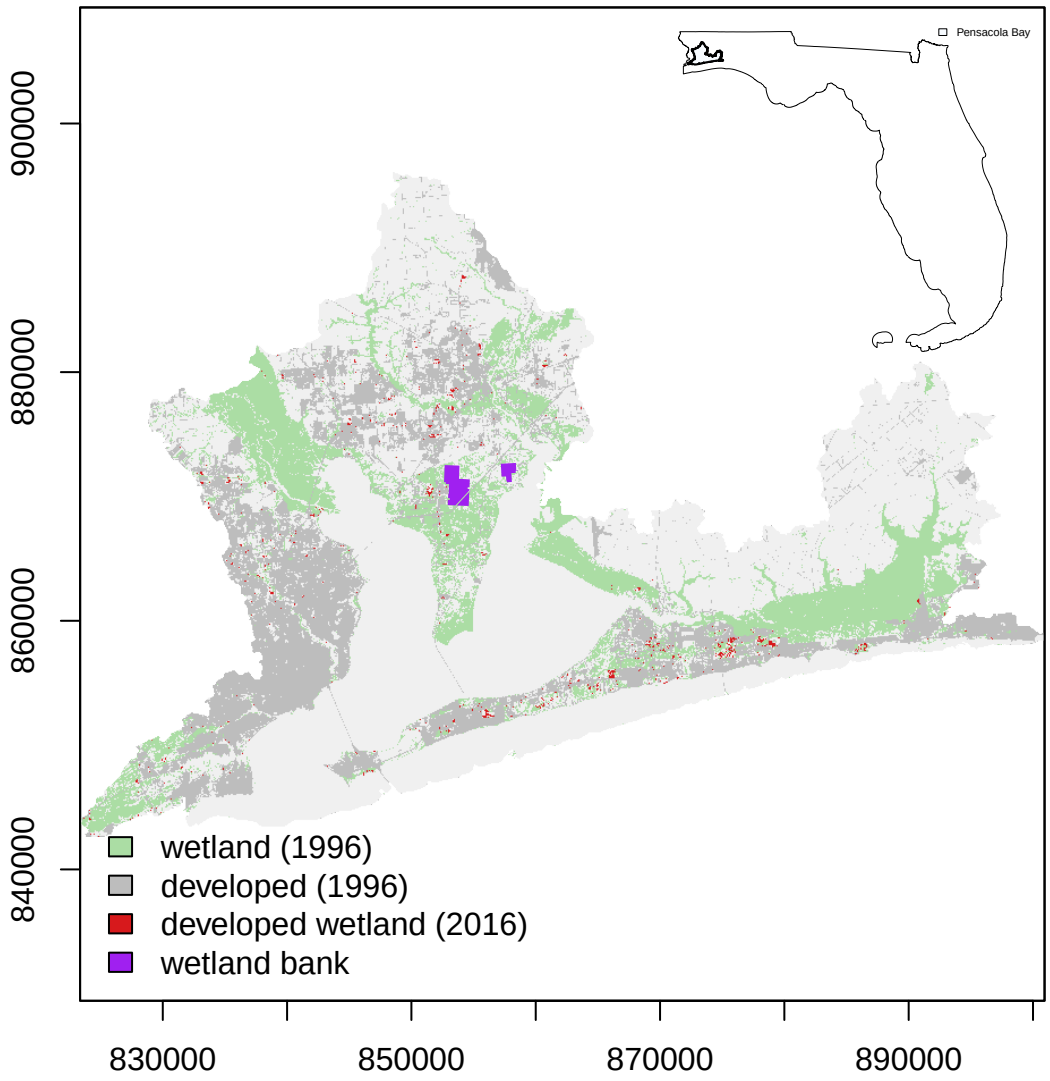


FIGURE A9.17. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

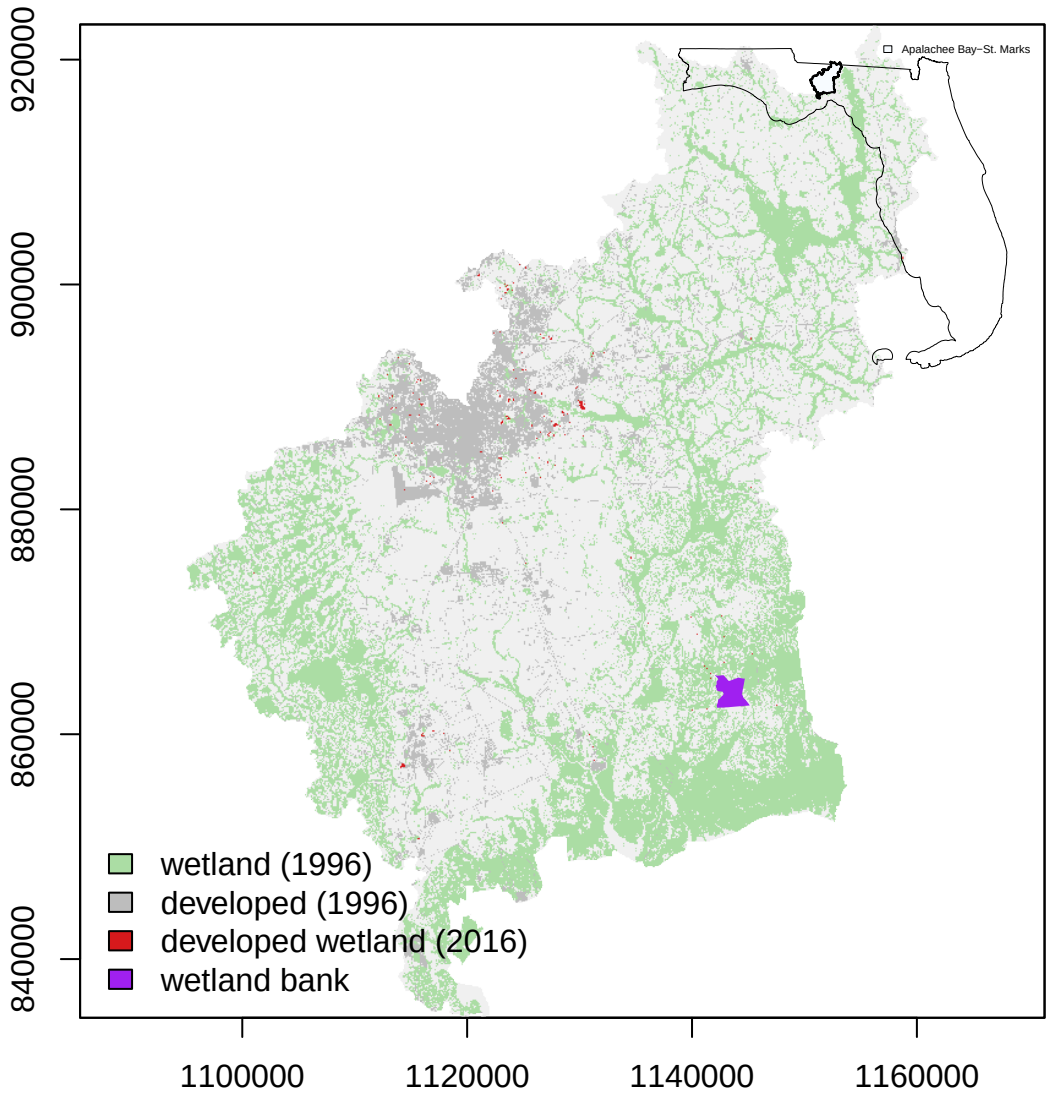


FIGURE A9.18. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

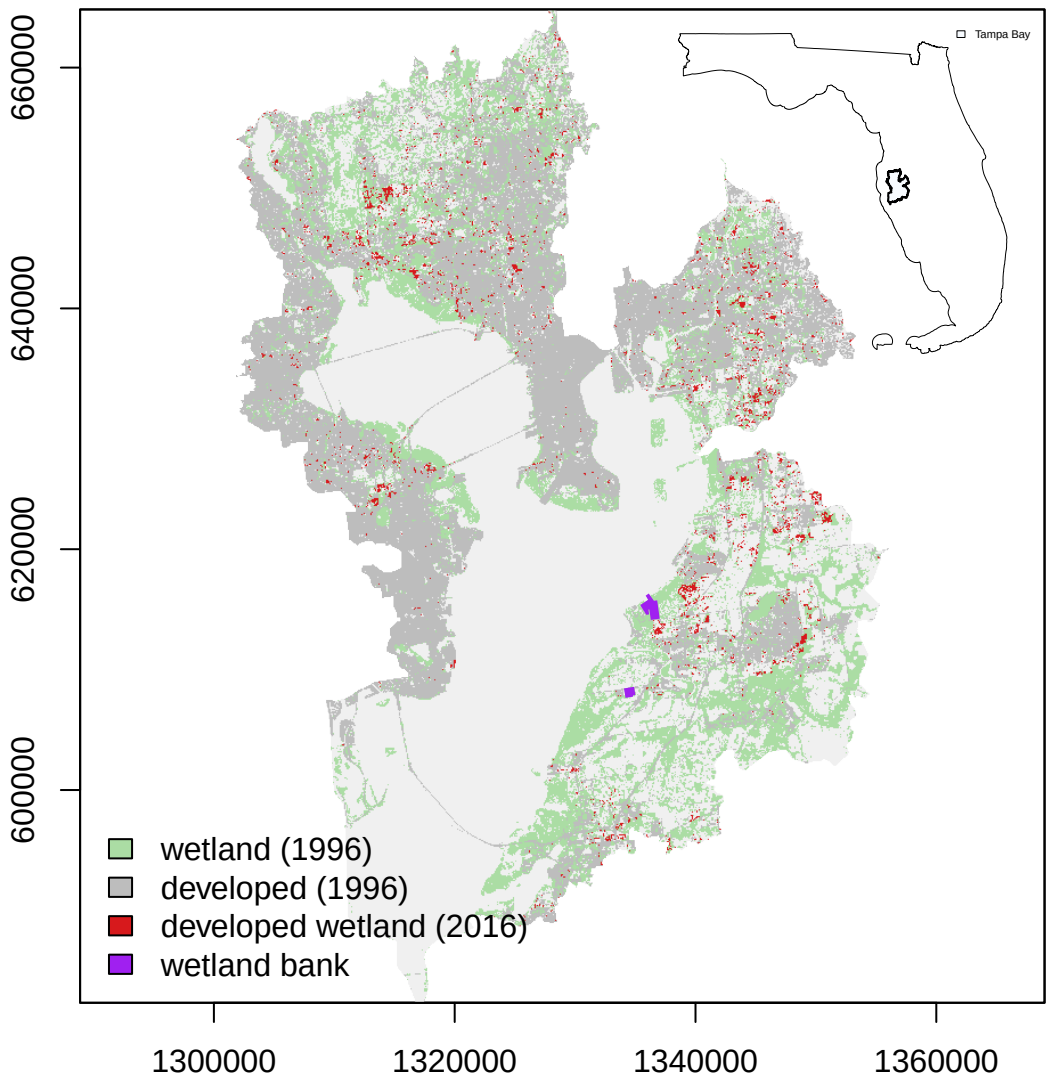


FIGURE A9.19. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

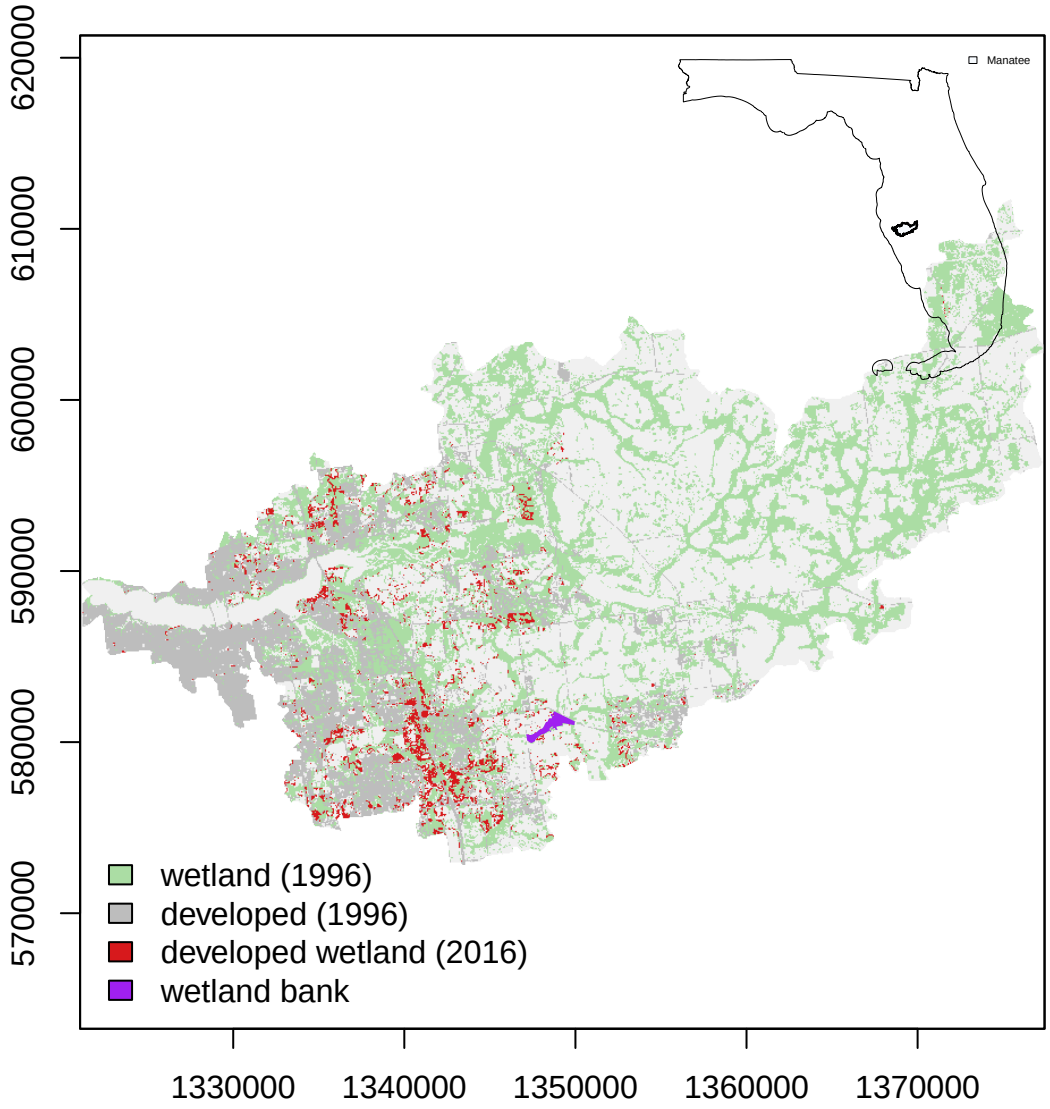


FIGURE A9.20. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

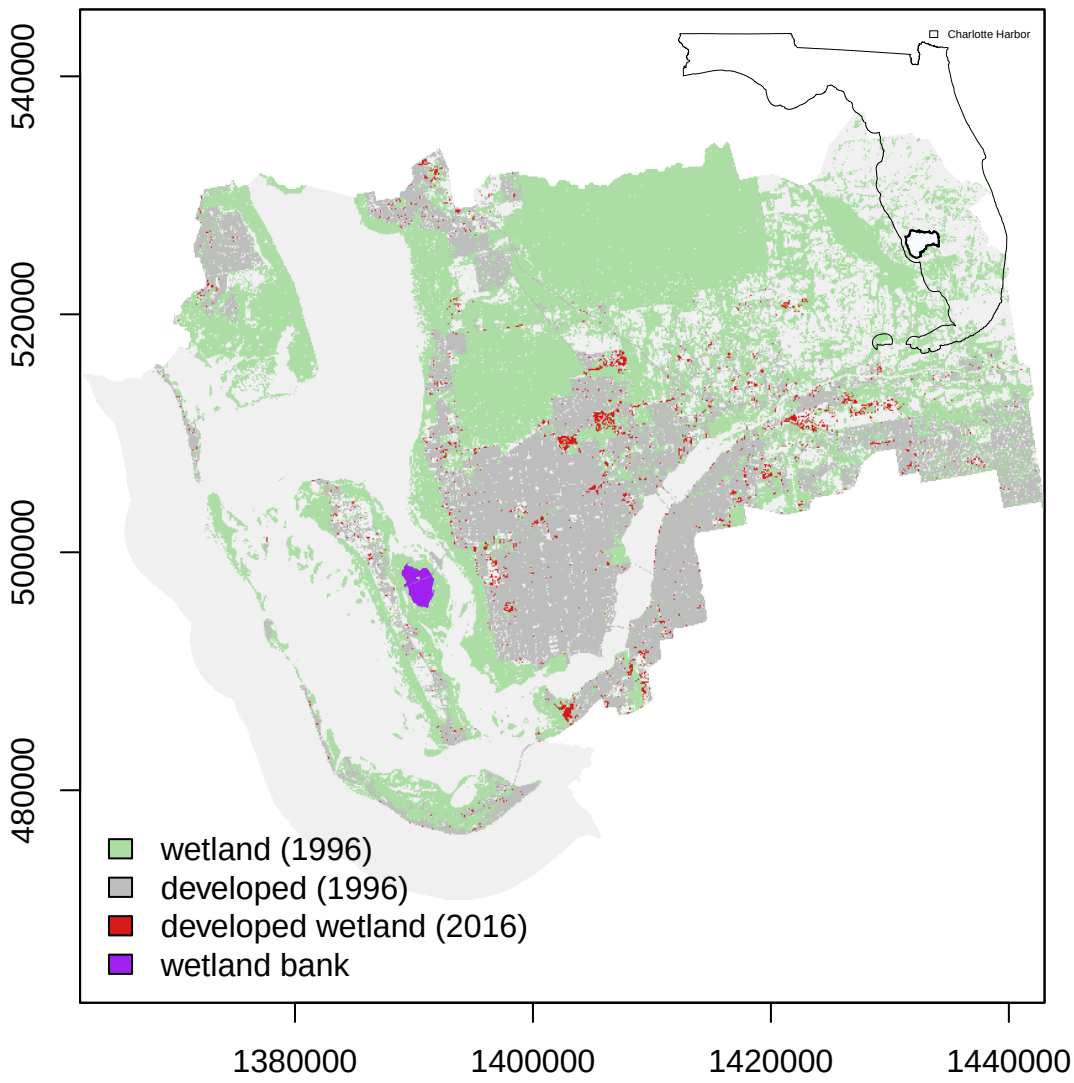


FIGURE A9.21. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

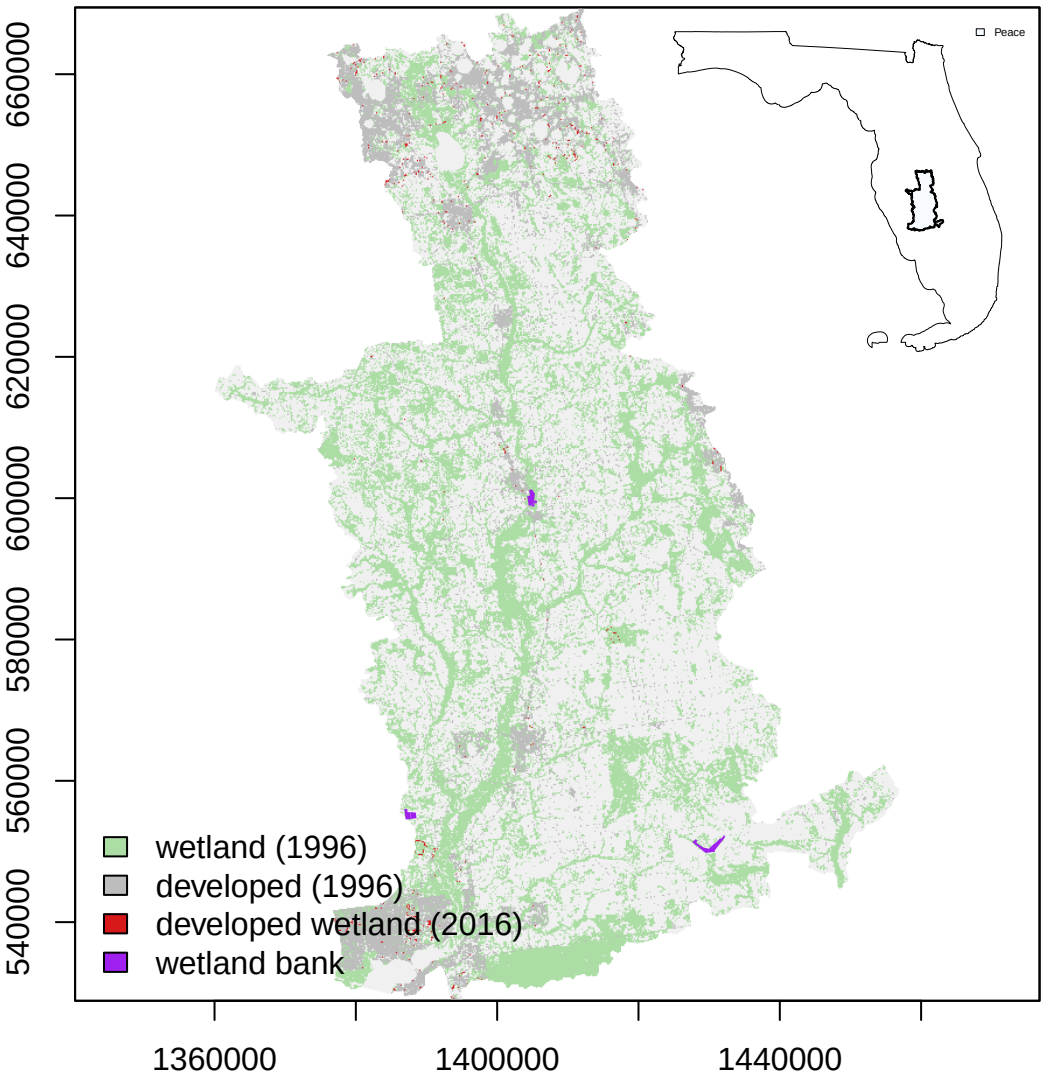


FIGURE A9.22. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

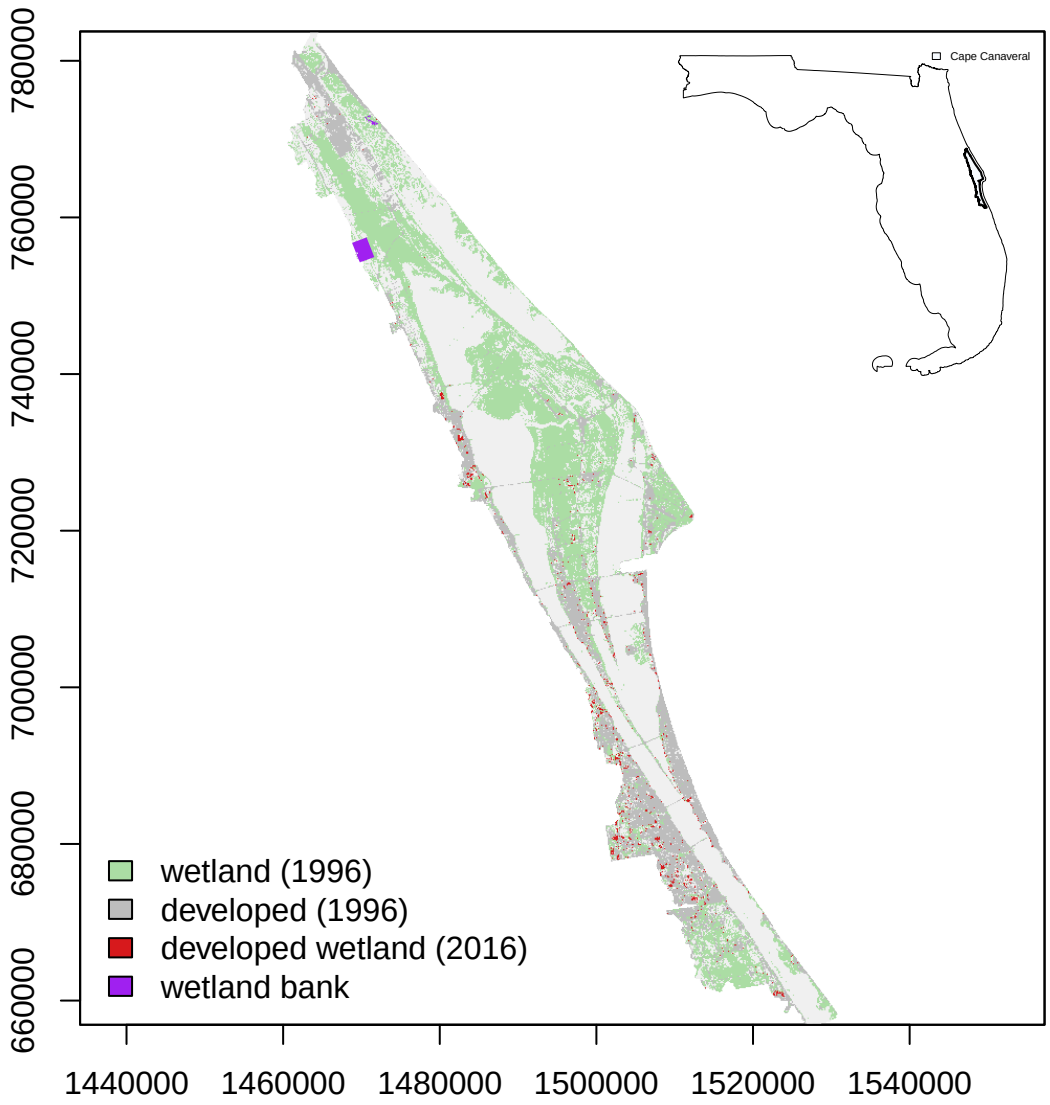


FIGURE A9.23. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

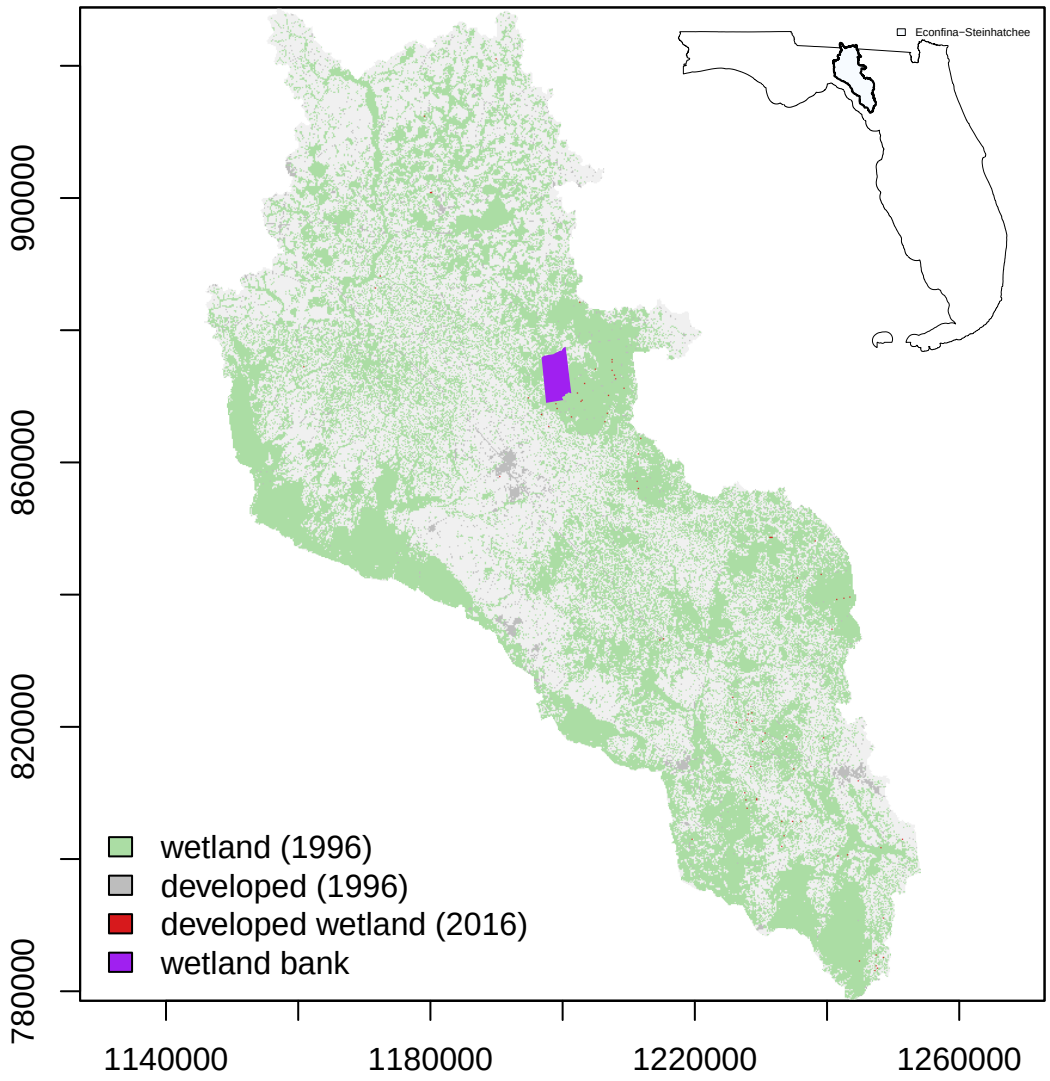


FIGURE A9.24. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

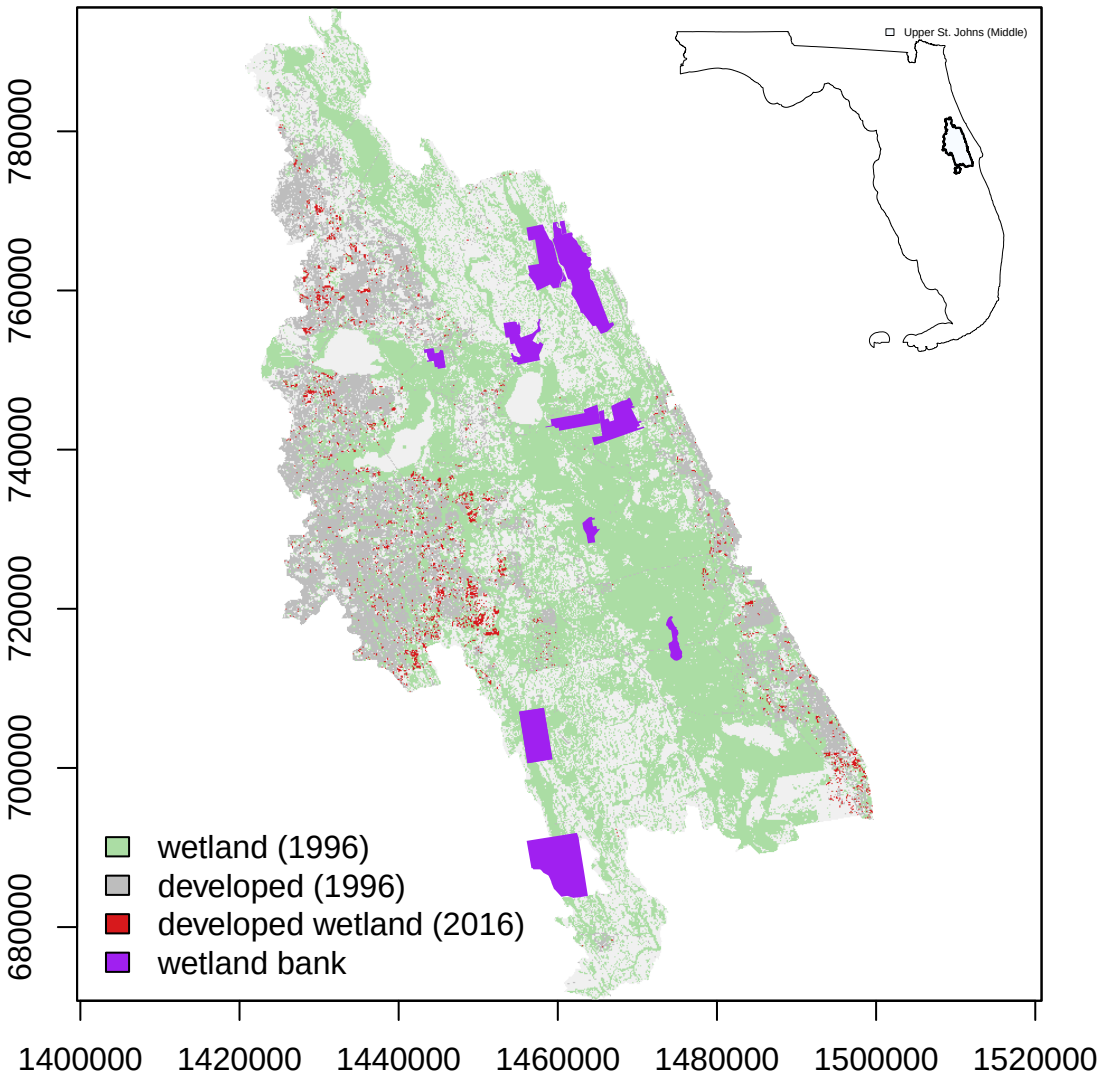


FIGURE A9.25. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

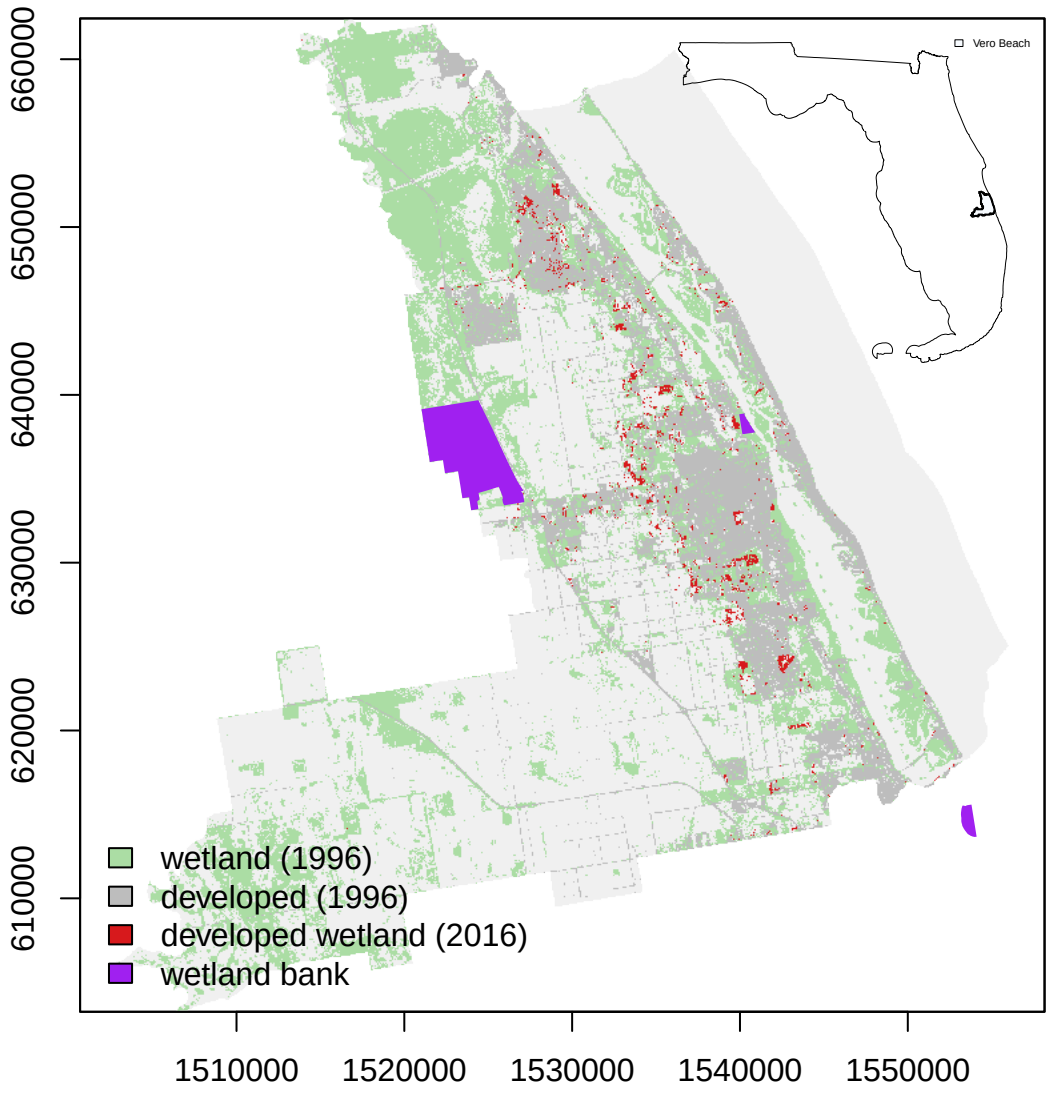


FIGURE A9.26. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

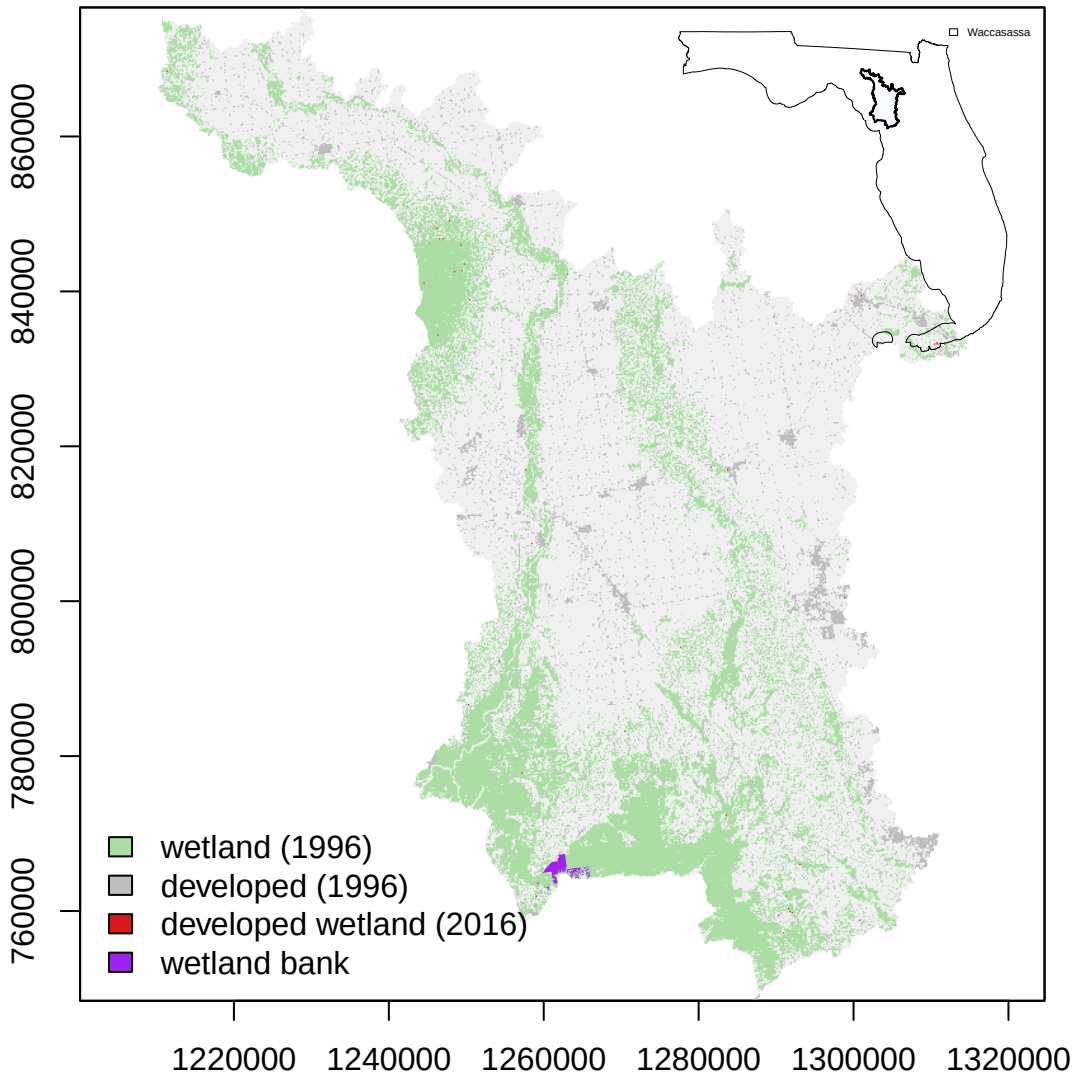


FIGURE A9.27. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

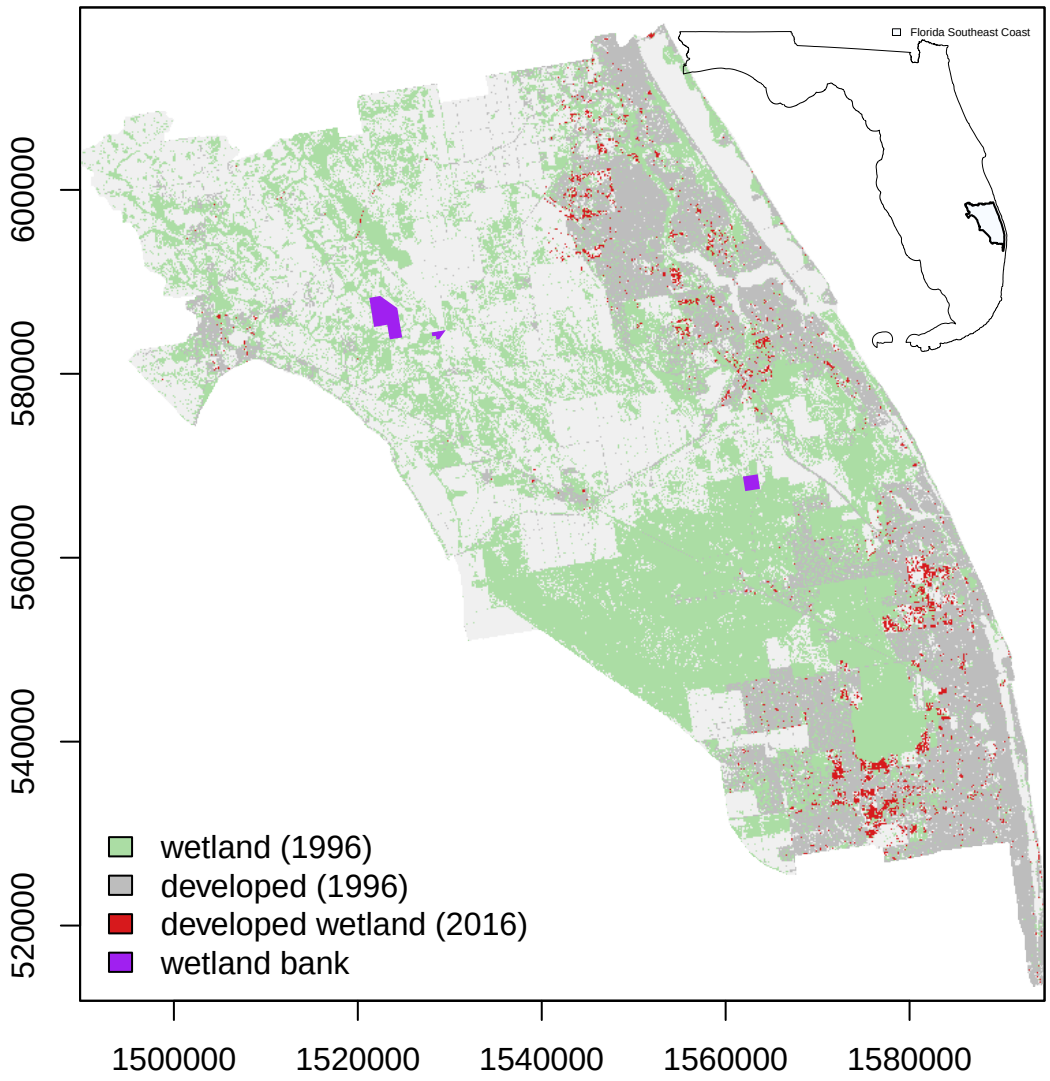


FIGURE A9.28. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

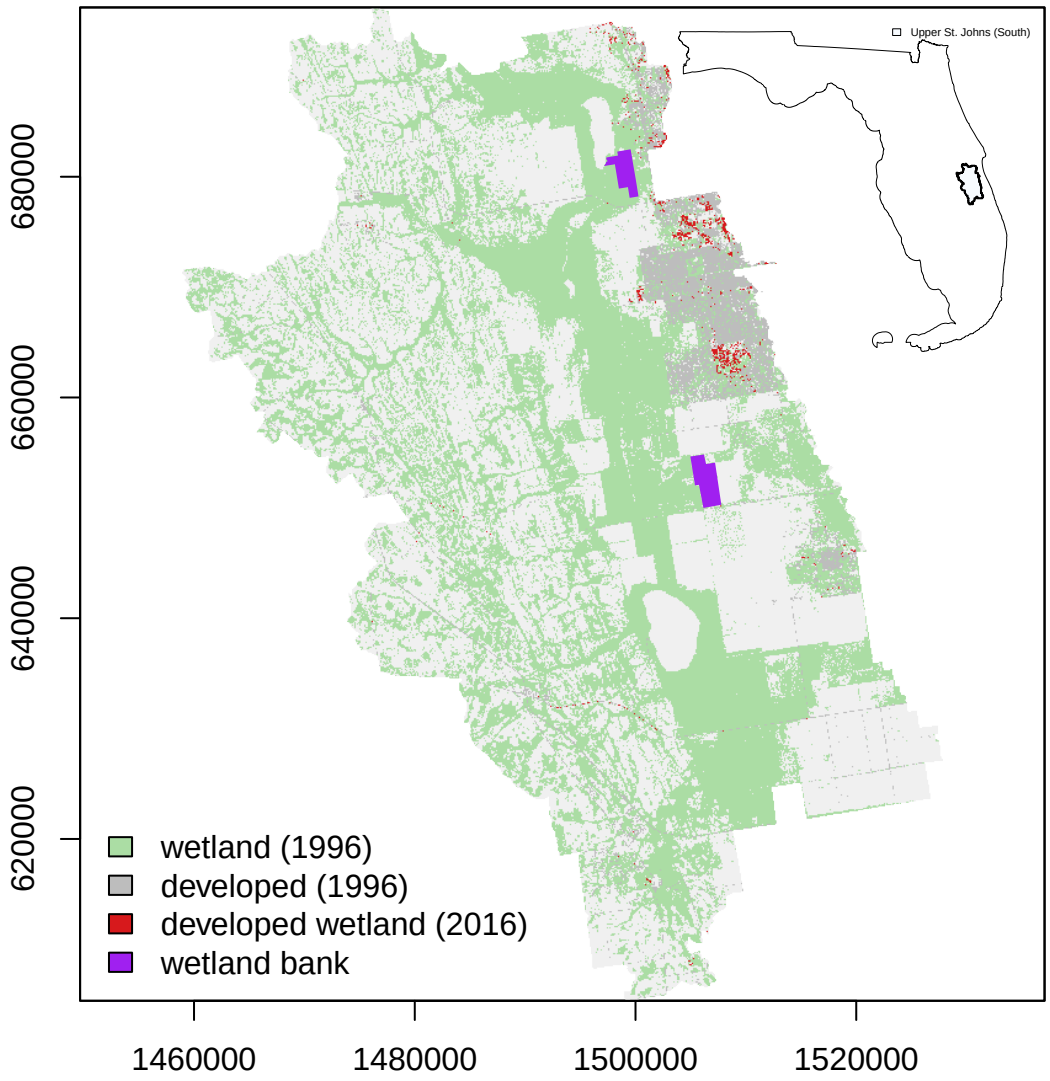


FIGURE A9.29. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

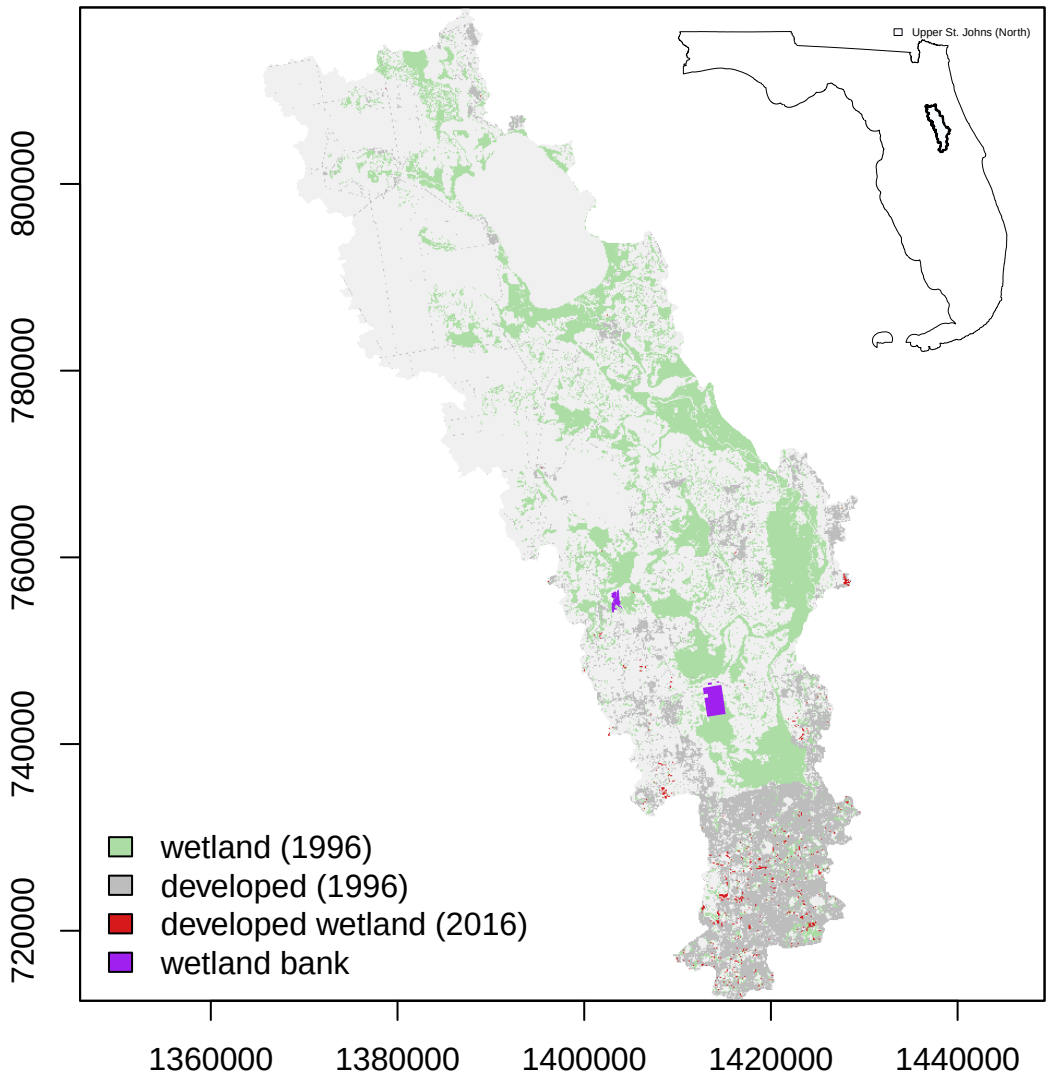


FIGURE A9.30. MARKET-LEVEL WETLAND DEVELOPMENT AND BANKS

Pixel-level land use for initial wetlands (**green**) and initial developed land in 1996 (**grey**), new development on wetlands from 1996–2016 (**red**), and wetland banks (**blue**) established by 2018.

Source. Author's calculations using NOAA C-CAP data, USGS (2013) hydrological regions, and Florida wetland mitigation bank contracts described in Appendix A.

obtained in B.1.1. For example, the conditional choice probability of developing a private wetland from 1996–2001 in watershed h is the share of 1996 wetland pixels in watershed h that are converted to development in 2001.

B.1.3 Watershed offset prices

We use the transaction-level offset prices (Appendix A.2) to construct average prices for each watershed-period.

Each transaction is matched to a wetland bank.

We construct a one-to-many match of watersheds to banks by constructing for each watershed the set of banks whose service area polygons overlap with that watershed. We also construct one-to-one matches of watersheds to markets and banks to markets.

For each watershed-period, we calculate the average price per offset observed for banks whose service area contain that watershed during that period.

For remaining watershed-periods without prices, we look for the average offset price for transactions observed in that watershed's market during the five-year period, using the algorithm that matches watersheds to markets discussed below in B.2.1.

B.1.4 Watershed price instruments

We follow the same approach used to construct watershed-period-level offset prices in B.1.3 to build watershed-period-level price instruments from bank-level data.

Sunk capacity instruments

For the own historical capacity instrument, we calculate the average licensed capacity over banks that entered prior to that start of the period whose service area contain that watershed during that period.

Hausman instruments

For the Hausman historical capacity instrument, we calculate the average licensed capacity over banks that entered prior to that start of the period who operate in the same water management district as the watershed but whose service areas do not contain the watershed.

For the Hausman price instrument, we calculate the average price over the period observed for banks who operate in the same water management district as the watershed but are matched to different markets and whose service areas do not contain the watershed.

Conservation land instruments

For the public conservation land instrument, we add public wetland acres in 1996 to the acres in each HUC12 bought under Florida Forever and/or Preservation 2000 between 1995–2000 as described in Appendix A.8 during the period, i.e., from 1995–2000 for the first period, 2001–2005 for the second period, et cetera. We construct the leave-out instrument for each h by summing this measure of public conservation land over all other HUC12s $h' \neq h$ in the same market as h.

B.1.5 Watershed demographics

For each watershed-period, we construct demographic values from the annual demographic and home price data introduced in Sections A.9.1–A.9.2. This requires matching zip codes to watersheds.

Spatial interpolation

For quantities (population and number of housing units), we allocate to watersheds in proportion to the zip code's overlap with that watershed. This ensures that population and housing unit aggregates will sum to the Florida total.

For prices (median income, median home price, average home price), we obtain values for watersheds by calculating the weighted average value over all zip codes with observed data that intersect with the watershed, weighted by area intersected.

Temporal aggregation

We calculate values for each watershed-period by averaging the annual watershed time series over each period. Baseline values are constructed from 1995 and lagged values from the five-year period prior to the observed period (and from 1995 for the first period, 1996–2001).

B.1.6 Water management district

We match watershed to water management districts using the first four digits of the watershed's HUC12 code and the matching of HUC4s to water management districts from Appendix A.6.

B.1.7 Flood risk controls

We intersect block-level flood risk maps (Appendix A.12) with watershed polygons to calculate the percentage of the watershed's area contained in storm surge and 100-year flood zones, respectively.

B.2 Market-by-year panel (used to estimate supply)

We use the market-by-year (30×26) panel to estimate entry policy functions and build aggregate market-level demand curves for the forward-simulation.

B.2.1 Market definition algorithm

We observe the service area for each bank, which we use to construct a partition of Florida watersheds into markets. Service areas largely coincide with USGS (2013) 8-digit hydrologic unit or subbasin (HUC8) regions:

1. Every bank is matched to the HUC8 that contains the most of its service area.
    - 23 bank service areas (22.3%) have at least 90% of their area in a single HUC8 and also cover at least 90% of that HUC8's area.
    - 83 bank service areas (80.6%) have at least two-thirds of their area in a single HUC8.
    - coincide perfectly with a single HUC8.
2. Some bank service areas do not cover their entire principal HUC8 area.
    - 51 bank service areas (49.5%) cover less than half of their principal HUC8 area.

    Typically, service areas do not cover the entire HUC8 because some parts of that HUC8 are not served by any bank (e.g., Oklawaha, Kissimmee).

    In two HUC8s, different banks in the same principal HUC8 operate primarily in different parts of the HUC8 with limited overlap. We split

    - Lower St. John's into Lower St. John's (North) and Lower St. John's (South)
    - Upper St. John's into Upper St. John's (North), Upper St. John's (Middle), and Upper St. John's (South)
3. Some bank service areas extend beyond one HUC8.
    - 20 bank service areas (19.4%) have more than one-third of their area in another HUC8.

There are three cases:

A. Banks that cover all of more than one HUC8 already defined as a market. We merge St. Mary's and Nassau into one market.

B. Banks that cover some, but not all, of another HUC8, already defined as a market:

- Cape Canaveral, Lower St. John's (North), Lower St. John's (South), St. Andrew – St. Joseph Bays, and Upper St. John's (South).

We assign these banks to their principal HUC8.

C. Bank service areas that cover some, but not all, of another HUC8, not defined as markets (i.e., without any native banks). We add the relevant HUC12s not in the principal HUC8, but who are included in bank service area(s) assigned to that HUC8, to the market. This extends

- Crystal-Pithlachascotee, Kissimmee, Big Cypress Swamp, St. Andrew – St. Joseph Bays, Pensacola Bay, Charlotte Harbor, Econfina-Steinhatchee, and Sarasota Bay

beyond their limit. The most common situation here is an inland bank service area extended to cover a subset of a coastal HUC8s (smaller than the principal [inland] HUC8s) that is not otherwise covered by existing mitigation banks.

B.2.2 Market states

We build public and private wetland stocks, as well as developed and highly-developed land extent, for 1996, 2001, 2006, 2011, and 2016 following the procedure used for the watershed-level panel (Appendix B.1.1), summing over all HUC12s contained within each market.

We calculate the within-pixel total area of other land converted into development as in Appendix B.1.1, converting the five-year values to annual values by dividing by five.

We extend these states to 1995–2020 by linearly interpolating across missing years.

We obtain average market-level flood risk by averaging the flood risk variables over all HUC12s contained within the market.

We obtain other states (number of firms, number of entrants, number of incumbents, annual offsets produced, annual offsets sold, cumulative offsets produced, cumulative offsets sold, offset balances) from the firm-by-year panel discussed in Appendix B.3.

B.3 Firm-by-year panel (used to estimate supply)

We build a bank-by-year balanced panel from 1995–2020.

We obtain the entry year and total production potential from the bank contracts discussed in A.1.1.

For each bank-year, we calculate cumulative annual production, cumulative annual sales, and offset balances or reserves (the difference between cumulative production and cumulative sales) from the ledger assembled in A.1.2.

For a small number of banks, we fix some apparent measurement error in production, where some early observed balances exceed historically observed production; in these cases, we add surplus balances to the banks' initial production year

A small number of banks also have negative production recorded on the ledger (six banks, 1-2 times per bank); we reduce the prior year's production by that amount.

B.4 Watershed long difference (used to estimate flood protection)

B.4.1 Initial land use and CCPs

We follow the same procedure as in Sections B.1.1 and B.1.2 to build initial land cover and total development on wetlands, constructing long transition probabilities from 1996–2016.

To obtain total development on wetlands for each watershed attributed to offset markets, we sum development on wetlands occurring in periods where the watershed's market had at least one wetland bank at the start of the period.

B.4.2 Wetland banking activity

We include the total area of land committed to wetland banks from 1995–2018 in our flood protection regressions.

Most bank sites (60 of 107) are contained within a single watershed and nearly all banks (102 of 107) have more than half of their area within a single watershed.

For wetland bank sites that cover more than one watershed, we attribute the area of the bank site that intersects that watershed to that watershed.

B.4.3 Flood insurance claims

Spatial interpolation

For each flood claim introduced in Appendix A.10, we observe its latitude and longitude (to one decimal place), census tract (2010), and zip code tabulation area (ZCTA5).

We identify each flood claim with a "claim area," i.e., a polygon corresponding to its approximate location, by intersecting a one-decimal-place latitude-longitude grid with census tracts and zip codes to build a partition of Florida of about 22,000 separate polygons.

We then assign each flood claim to watersheds in proportion to the claim area's overlap with that watershed.

For robustness, we consider results that use only the latitude-longitude-by-census-tract grid, as well as a binary match that assigns flood claims that overlap with more than one HUC12 to the HUC12 that contains the largest share of that claim's area.

Temporal aggregation

For each watershed, we sum annual flood claims for each year, first for structures built up to 1995, then for structures built after 1995, then for all structures.

We deflate each to current (2020 USD) prices using the price index defined in A.13.

We then construct annual average watershed-level claims for the periods used in the analysis: 1991–1995 (benchmark pre-period), 2016–2020 (benchmark post-period), 1985–1994 (robustness pre-period), 2011–2020 (robustness post-period).

B.4.4 Flood insurance policies

Spatial interpolation

For each flood insurance policy introduced in Appendix A.11, we observe latitude and longitude (to one decimal place) and zip code (ZCTA5) but—unlike claims—not census tract. We repeat the interpolation algorithm in B.4.3.

B.4.5 Flood risk

We use the watershed-level measures of flood risk from B.1.7.

B.4.6 Hydrological network extension

In Table A13, we run some specifications with neighboring watershed values, where neighbors are defined with respect to the hydrological network topology (A.5).

We use the flow matrices from Appendix A.5. Upstream values correspond to the inflow matrix multiplied by the vector of watershed values. Downstream values correspond to the outflow matrix multiplied by the vector of watershed values.

For each watershed, we calculate total wetlands developed 1996–2016, area committed to wetland banks 1996–2016, and total area of watersheds upstream and downstream.

B.5 Overlapping federal jurisdiction

Our analysis abstracts from trade in federal offsets under §404 of the Clean Water Act; here, we describe in more detail how state and federal wetland regulation interacts in Florida.

The 1993 Environmental Reorganization Act (FS §373.4135) directed the Florida Department of Environmental Protection (FDEP) and regional water management districts to adopt rules governing wetland banks by February 1994. There are two primary differences between Florida's §373 and the CWA §404: (i) a broader definition of wetlands (Florida requires evidence of two of the following: wetland vegetation, wetland hydrology, and hydric soils; the federal government requires evidence of all three) and (ii) broader jurisdiction (Florida has authority over all wetlands in the state; §404 only covers waters of the U.S.).

Given that we abstract from trade in federal offsets, the primary concerns are that, on the supply side, wetland banks have additional payoffs due to federal credit sales, and on the demand side, some developers face additional federal regulation in some periods and not others. Most, but perhaps not all, of these shocks will be absorbed by our time period and water management district fixed and our controls for local watershed characteristics.

Several facts indicate this approximation will not create problems for our analysis.

First, legally, courts have been clear that state governments retain authority to regulate all wetlands in their state, whether or not the federal government also has additional regulatory authority under Section 404 of the Clean Water Act (**?**). The resulting predictability and durability of the state offset program has made it significantly more influential than shifting federal guidelines.

Second, while most Florida wetland banks also receive some federal offset credits, Florida wetland banks must first satisfy the state offset program requirements before applying for federal credits, and our conversations with experts indicate that federal credits are awarded by EPA/Corps regardless of the jurisdictional status of the bank's new wetlands (**?**). ("[T]he changes in federal jurisdiction with the various Supreme Court decisions (Rapanos and now Sackett) and the way various administrations have implemented EPA regulations (NWPR) ... has not affected mitigation banks in Florida to my knowledge," **?**).

Third, empirically, overlapping federal requirements, where they apply, appear to be minimal relative to Florida state requirements. Banks sell fewer federal offsets at much lower prices than state offsets, reflecting the fact that federal credits are easily obtained by existing state banks (as federal credits are awarded regardless of federal jurisdictional status) but are demanded by fewer wetland developers (those with federal wetlands).

Table A15 compiles federal offset prices from our data, and the ledger of all federal offsets traded in Florida. It shows that federal wetland offsets comprise 18% of all Florida wetland offsets traded (by estimated market value) from 2006–2018.

These facts lead us to consider changes in federal regulation in Florida as not central to the incentives to restore or develop Florida wetlands. Indeed, recognizing this redundancy, the EPA transferred authority to manage the §404 program to Florida in 2020 to streamline permitting (**?**).

We emphasize this conclusion is specific to Florida. Outside of Florida, we view the investigation of shifting federal jurisdiction over wetlands on wetland bank industry dynamics as an interesting area for future research. In such places, the changing probability of regulatory scrutiny over time could affect wetland bank payoffs and the economics of wetland offsets (see, e.g., the recent economic analysis of the regulatory uncertainty created by air pollution standards in **?**).

C Estimation details

C.1 Details of wetland acre-to-offset ratios

Both demand and flood risks are estimated using land cover data, but entry costs and market outcomes are denominated in offsets.

We combine land cover changes from 1996–2016 with observed offset production and sales from 1995–2016 to approximate ratios of wetland development acreage to offsets for each water management district. This gives us $\tilde{v}_h$ that is common to all h in a water management district.

Table A4 reports this data and resulting ratio estimates.

Some development on wetlands involves on-site mitigation, and when offsets are purchased, the number of offsets per acre will vary based on the wetland value of the converted land. Fortunately, we can use our ledger data to restrict the developed wetland pixel data to watershed-periods with active offset markets, in order to construct average acre-to-offset ratios for each water management district. Table A4 shows that, for markets with offset sales, wetland acres convert to offsets at a ratio of between 4.8 to 12.6 acres per offset. For a subset of transactions in the South Florida Water Management District, we observe parcels that purchased wetland offsets, which we link to our ledger of trades and intersect with our within-pixel calculations. Developers of these parcels purchase offsets at a ratio of 1 offset to 5.36 developed wetland acres on average, corroborating our water management district calculations. We also intersect pixel-level initial conditions and within-pixel transitions with bank sites and find that wetland mitigation banks obtain offsets primarily in proportion to their initial wetland cover, averaging 4.49 initial wetland acres per offset received, reflecting the fact that much of these parcels' area is initially classified as wetlands.

C.2 Details of demand curve estimation

Here, we describe some details of some calculations in Table 2.

Regression details

Functional forms for covariates in the regressions are natural logs for median income, population, and other development (with the inverse hyperbolic cosine used for population and other development to allow for zeros), percent area for development, high development as a fraction of overall development, flood zone A, and flood zone V. Instruments are quadratic polynomials.

Consumer surplus calculation

See C.5.1.

C.3 Details of dynamic estimation algorithm

Here, we specify the details of the dynamic estimator underlying the results in Table 3.

Step I

The model is simulated at a quinquennial resolution from 1995–2095.

The simulation runs over $m \in \{1, 2, \ldots, M\}$ with $M = 30$ markets (hydrological regions with observed entry) and all local watersheds h contained in these regions.

The initial conditions for each m and h are the extent of wetland, the extent of developed land, and the initial population and median income, observed at baseline (1996).

We fix the annual discount factor to $\beta = 0.95$.

Production

Each entrant's lifetime offset production or wetland value, $\tilde{v}_f$, is drawn from the conditional empirical distribution of capacities of wetland mitigation banks in our data, conditioned on water management district and the number of incumbents. The production function $\mathcal{B}$ issues offsets over the first ten years of production, i.e., $\mathcal{B}(\tau, x_{ft}) = \tilde{v}_f/10$ for $\tau \leq 10$ and $\mathcal{B}(\tau, x_{ft}) = 0$ for all $\tau > 10$.

Entry and trade

Entry policy functions, reported in column (3) of Table A6, are estimated using a probit model with period fixed effects (indicators for $t < 2001$, $t < 2006$, and $t < 2011$), water management district fixed effects, the number of incumbents, and indicator for markets without incumbents, and the natural logarithms of private wetlands, public wetlands, median income, population, and total incumbents' offset reserves in the market (with asinh() for balances).

Endogenous market state transitions are the set of incumbents and their ages and offset balances; the wetlands, developed land, and home prices for each local watershed; and the total stock of wetlands, total area of developed land, and average home price in each market.

Our data requires that we estimate local demand over five-year intervals. We assume banks commit to trades over a five-year period.

Trading functions are built from the estimating equation in the main text using estimates from column (3), Table A7 and using the bounds implied by offset balances and the myopic Cournot IR constraints.

Myopic Cournot IR constraints constructed jointly for each market-period for all incumbents using the market-level inverse demand elasticity and a fixed point in bank trading strategies. contains estimates.

Figure A5 reports observed trades, predicted trades, and myopic Cournot IR constraints.

Figure A8 illustrates geometrically how these constraints operate.

Exogenous demand states

The exogenous local demand shifters are (a) median income, (b) population, and (c) other contemporaneous development on non-wetlands.

For each local watershed, the evolution of other development is estimated as a function of the share of developed land, water sub-basin (HUC8) fixed effects, and period fixed effects (indicators for $t < 2001$, $t < 2006$, and $t < 2011$). The evolution of the natural logarithm of the demographic variables are specified as an AR(1) process with a common intercept.

To forward-simulate local demand shifters, we calculate the expected component of the next period's state from the current state and the estimated persistence coefficients, then draw a shock from the empirical distribution of residuals of these regressions to obtain the next period's state.

Step II

To estimate costs using the value function (18), we invert $\phi_t(s_t, x_{ft}) = G_t\left(z|x_{ft}\right)$ at $z = V(0, 1, s_t|x_{ft})$ to obtain the conditional entry cost distribution $G_t(\cdot|x_{ft})$. Specifically, we assume that $G_t(\cdot|x_{ft})$ is lognormal, so that we can obtain the entry costs via

$$\Phi^{-1}(\phi_t(s_t, x_{ft})) = \frac{1}{\sigma(x_{ft})}\left[\ln V(0, 1, s_t|x_{ft}) - \mu(x_{ft})\right].$$

Specifically, we regress $\ln V = \ln V(0, 1, s_t|x_{ft})$ on $x = x_{ft}$, $\Phi^{-1}(\phi_t(s_t, x_{ft}))$, and their interaction. In practice, we take as (s_t, x_{ft}) water management district fixed effects and indicators for a market with zero incumbents, one incumbents, and more than one incumbent. This regression gives us coefficients $(\beta_x, \beta_{\phi x}, \beta_\phi)$, which allows us to use the identity

$$\hat{\ln V} = \beta_x' x + \left(\sum \beta_{\phi x}' x + \beta_\phi\right)\Phi^{-1}(\phi_t(s_t, x_{ft})) = \mu(x) + \sigma(x)\Phi^{-1}(\phi_t(s_t, x_{ft}))$$

to approximate $\mu(x)$ with $\beta_x' x$ and $\sigma(x)$ with $\sum \beta_{\phi x}' x + \beta_\phi$.

To obtain realized entry costs $\hat{\kappa}_{ft}$ for each bank f that entered at t with value function $\hat{V}_{ft}$, i.e., expected costs conditional on entry, we integrate $G(\cdot|x_{ft})$ over $(0, \hat{V}_{ft})$. We do this by evaluating the

closed-form (up to the Gaussian CDF, Φ) expression for the conditional expectation of a lognormal random variable bounded by a positive constant V,

$$\mathbb{E}[\kappa|\kappa < \ln V] = \exp\left(\mu + \frac{\sigma^2}{2}\right) \cdot \frac{\Phi\left(\frac{\ln V - \mu - \sigma^2}{\sigma}\right)}{\Phi\left(\frac{\ln V - \mu}{\sigma}\right)}$$

at the bank's $\hat{V}_{ft}$ and estimated $\mu(x_{ft})$ and $\sigma(x_{ft})$.

To construct the annual rates of return on capital reported in Table 3, we take markups and solve for the average annual return that would realize the full value in 10 years.

C.4 Details of marginal flood damage calculations

Here, we describe some of the derived values reported in Table 4 and Tables A11–A16.

For marginal damages per acre reported in Table 4 and Table A16, we calculate the derivative of predicted annual damages from the coefficient estimates in Table 4, $D_h(Q_h; \hat{\zeta}, \hat{\gamma}, \hat{\rho})$, numerically around $[Q_h - \frac{1}{2}\Delta, Q_h + \frac{1}{2}\Delta]$ for $\Delta = 1$ acre as $\hat{D}'_h(Q_h; \hat{\zeta}, \hat{\gamma}, \hat{\rho}) = D_h(Q_h + \frac{1}{2}\Delta; \hat{\zeta}, \hat{\gamma}, \hat{\rho}) - D_h(Q_h - \frac{1}{2}\Delta; \hat{\zeta}, \hat{\gamma}, \hat{\rho})$. We then multiply this value by $\sum_{t=0}^{\infty}(1+r)^{-t}$ to obtain the NPDV permanent damages for $r = 0.05$ (baseline) as well as $r = 0.03$ and $r = 0.07$ (Table 5, rows 13–14).

For marginal damages per offset (Table A16, column 2), we multiply each $D'_h(Q_h; \hat{\zeta}, \hat{\gamma}, \hat{\rho})$ by $\tilde{v}_h$.

For marginal damages per acre with hydrological network spillovers (Table A13), we calculate the derivative of predicted annual damages from the coefficient estimates numerically around $[Q_h - \frac{1}{2}\Delta, Q_h + \frac{1}{2}\Delta]$ for $\Delta = 1$ acre as $\hat{D}'_h(Q_h; \hat{\zeta}, \hat{\gamma}, \hat{\rho}) = \sum_{h'} D_{h'}(Q_h + \frac{1}{2}\Delta; \hat{\zeta}, \hat{\gamma}, \hat{\rho}) - \sum_{h'} D_{h'}(Q_h - \frac{1}{2}\Delta; \hat{\zeta}, \hat{\gamma}, \hat{\rho})$, because Q_h can now affect damages in HUC12s $h' \neq h$ through the hydrological network.

C.5 Details of welfare calculations

Here, we describe some of the details of the calculations that underly the results presented in Table 5.

C.5.1 Aggregate consumer surplus

To calculate watershed-level consumer surplus using the estimates $(\hat{\theta}, \hat{\xi}_h)$, we use the closed-form expected consumer surplus from Small and Rosen (1981), which in our model is

$$\sum_t \sum_h \tilde{v}_h W_{ht} \frac{1}{\tilde{v}_h \hat{\theta}_P} \ln\left(1 + \exp\{\hat{\theta}' X_{ht} - \tilde{v}_h \hat{\theta}_P P_t + \hat{\xi}_{ht}\}\right) \tag{A1}$$

dividing by $\tilde{v}_h \hat{\theta}_P$ to express values in 2020 USD.

Average expected parcel utility reports $\frac{1}{\hat{\theta}_P} \ln\left(1 + \exp\{\hat{\theta}' X_{ht} - \tilde{v}_h \hat{\theta}_P P_t + \xi_{ht}\}\right)$ and measures the expected utility of an acre of private wetland under the distribution of observed offset market prices relative to the outside option.

Evaluating (A1) over all watersheds requires prices, but some local watersheds do not have observed prices in our estimation. To evaluate (A1), we infer these unobserved prices by calculating the predicted price for each watershed that fits observed choice probabilities in each period to construct an average offset price for each period, which we use for watersheds missing prices. An alternative is to use the simulated prices from our dynamic estimator; we do not find significant differences between these two approaches' consequences for consumer welfare.

C.5.2 Aggregate costs and producer surplus

To construct the aggregate marginal producer prices function in Figure 4B, we order bank sales by descending simulated value per offset sold, i.e., $\hat{v}_{f_1} \equiv \hat{V}_{f_1}/\hat{q}_{f_1} > \hat{V}_{f_2}/\hat{q}_{f_2} > \ldots$, then define $V'(Q) = \max_{f_k}\{\hat{v}_{f_k} : Q \leq \sum_{f \leq f_k} \hat{q}_f\}$.

To construct the aggregate marginal entry cost function in Figure 4B, we use the same order over banks and define $C'(Q) = \sum_f \hat{\kappa}_{ft} \mathbf{1}(f_k \in \arg\max\{\hat{v}_{f_k} : Q \leq \sum_{f \leq f_k} \hat{q}_f\})$.

Aggregate costs used for total private gains from trade and counterfactuals involving Q offsets sold overall are then calculated as

$$C(Q) = \int_0^Q C'(q)dq \tag{A2}$$

and aggregate producer surplus as

$$\Pi(Q) = \int_0^Q \left[V'(q) - C'(q)\right] dq, \tag{A3}$$

using numerical integration.

C.5.3 Aggregate flood damages

For total flood damages, we integrate $D'_h(\cdot; \hat{\zeta}, \hat{\gamma}, \hat{\rho})$ over $[1, Q_h]$, where Q_h are observed wetlands developed from 1996–2016. For watersheds with some wetland development that occurs prior to trade, $Q_h^{\text{pre}} \leq Q_h$, we scale total damages by $y_h = (Q_h - Q_h^{\text{pre}})/Q_h$. Total damages then equal

$$\sum_h y_h \int_1^{Q_h} D'_h(q; \hat{\zeta}, \hat{\gamma}, \hat{\rho})dq \tag{A4}$$

For total damages under the counterfactual tax designs, we calculate (A4) for $\{Q_h^{\text{cf}}\}_h$.

C.6 Details of counterfactuals

Here, we describe some of the details of the counterfactuals presented in Table 5 and Table 6.

C.6.1 Value of offset markets

Wetlands developed under the market correspond to all wetlands developed in watershed-periods with trade. Wetland offsets are a weighted average of acres of wetlands developed with weights $\tilde{v}_h$ from the water management district trading ratios discussed in C.1.

Total developer value equals total consumer surplus calculated from (A1) plus producer surplus plus total producer costs. The alternative definition, total consumer surplus plus the market value of all offsets purchased, gives a similar, though not identical, number because the observed market value of all offsets purchased relies on the price interpolation discussed in C.5.1 while the producer surplus uses the price simulations from the dynamic estimator.

Producer surplus and supply costs and producer surplus or observed trade are obtained from (A3) and (A2) at the total volume of trade under the market.

Private gains from trade equal the sum of consumer surplus and producer surplus.

Welfare defined as private gains from trade net total flood damages.

C.6.2 Benchmark Pigouvian counterfactual

Pigouvian taxes constructed with C.4 and a 5% discount rate to value future flood protection.

Counterfactual producer prices calculated for each successive market state with χ^{IR} under the new aggregate demand curves, which append local Pigouvian taxes to the transaction (producer) price for each local watershed, evaluating the original χ at the market state, and obtaining $\mathcal{Q}$ from these two objects and the forward-simulated bank reserves, B_{ft}, with equation (16).

Counterfactual consumer surplus obtained by evaluating (A1) at the counterfactual vector of counterfactual producer prices plus Pigouvian taxes.

Total bank costs calculated by integrating the cost function under the total counterfactual volume traded, i.e., with (A2).

Producer surplus defined as the market value of trades under the counterfactual net of the total costs.

Tax revenue calculated as the sum of wetland development that occurs under the counterfactual weighted by the vector of per-offset Pigouvian taxes.

Private gains from trade equal the sum of consumer surplus, producer surplus, and tax revenue.

C.6.3 Uniform tax counterfactual

Counterfactual consumer surplus, producer surplus, and costs obtained for each candidate tax identically as in C.6.2 and a 5% discount rate to value future flood protection.

We run a grid search over \$500/offset intervals to find the tax that maximizes welfare (consumer surplus added to producer surplus and tax revenue net of damages).

The objective function appears globally concave, with an interior solution at $\tau^* = \$29{,}000$/offset.

C.6.4 Full passthrough counterfactual

Pigouvian taxes constructed with C.4 and a 5% discount rate to value future flood protection.

Counterfactual consumer surplus obtained by evaluating (A1) at the counterfactual vector of prices (observed prices plus Pigouvian taxes).

Total bank costs calculated by integrating the cost function under the total counterfactual volume traded, i.e., with (A2).

Producer surplus defined as the market value of trades under the counterfactual net of the total costs.

Tax revenue calculated as the sum of wetland development that occurs under the counterfactual weighted by the vector of per-offset Pigouvian taxes.

Private gains from trade equal the sum of consumer surplus, producer surplus, and tax revenue.

C.6.5 Myopic Cournot counterfactual

Pigouvian taxes constructed with C.4 and a 5% discount rate to value future flood protection.

Counterfactual producer prices calculated by forward-simulating χ^{IR} under the new aggregate demand curves, which append local Pigouvian taxes to the transaction (producer) price for each local watershed.

Counterfactual consumer surplus obtained by evaluating (A1) at the counterfactual vector of counterfactual producer prices plus Pigouvian taxes.

Total bank costs calculated by integrating the cost function under the total counterfactual volume

traded, i.e., with (A2).

Producer surplus defined as the market value of trades under the counterfactual net of the total costs.

Tax revenue calculated as the sum of wetland development that occurs under the counterfactual weighted by the vector of per-offset Pigouvian taxes.

Private gains from trade equal the sum of consumer surplus, producer surplus, and tax revenue.

C.6.6 Myopic collusion counterfactual

Same as myopic Cournot (C.6.5), except that for each market-period, we aggregate all bank balances into a single bank for which we calculate a single χ^{IR}.

We then apportion the aggregate trade volume to banks in the cartel in proportion to their balances.

D Supplement—C-CAP Regional Land Cover Classification Scheme

No pixels were unclassified for our study area. The definitions from NOAA are below:

D.1 Developed land

- Developed, High Intensity (2) – contains significant land area and is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.
- Developed, Medium Intensity (3) – contains areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.
- Developed, Low Intensity (4) – contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
- Developed, Open Space (5) – contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.

D.2 Agricultural land

- Cultivated Crops (6) – contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
- Pasture/Hay (7) – contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
- Grassland/Herbaceous (8) – contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

D.3 Forest land

- Deciduous Forest (9) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
- Evergreen Forest (10) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
- Mixed Forest (11) – contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.

- Scrub/Shrub (12) – contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

D.4 Barren land

- Unconsolidated Shore (19) – includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
- Barren Land (20) – contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.
- Tundra (24) – is categorized as a treeless region beyond the latitudinal limit of the boreal forest in pole-ward regions and above the elevation range of the boreal forest in high mountains. In the United States, tundra occurs primarily in Alaska.
- Perennial Ice/Snow (25) – includes areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.

D.5 Freshwater (palustrine) wetlands

- Palustrine Forested Wetland (13) – includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Palustrine Scrub/Shrub Wetland (14) – includes tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.
- Palustrine Emergent Wetland (Persistent) (15) – includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. Plants generally remain standing until the next growing season.

D.6 Saltwater (estuarine) wetlands

- Estuarine Forested Wetland (16) – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Scrub/Shrub Wetland (17) – includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Emergent Wetland (18) – Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). These wetlands occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. Perennial plants usually dominate these wetlands.

D.7 Water and submerged lands

- Open Water (21) – includes areas of open water, generally with less than 25 percent cover of vegetation or soil.
- Palustrine Aquatic Bed (22) – includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.
- Estuarine Aquatic Bed (23) – includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.