

Prioritizing streams: the impacts of in-kind mitigation rules on an ecosystem offset market

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Abstract

Extensive regulations have aimed to protect streams and wetlands threatened by development activities in the United States. However, failures to offset ecosystem damage with restoration of similar ecosystems (i.e., “in-kind mitigation”) have impeded success of these policies. How do policies enforcing in-kind mitigation requirements – e.g., prioritizing stream mitigation for stream impacts – alter the structure of mitigation markets? What impacts do they have on the broader market for stream and wetland mitigation? We studied the mitigation market of Texas’s Upper Trinity River Basin (USA), where regulators implemented novel, in-kind stream mitigation requirements in 2013. Drawing on impact and mitigation data (2007-2019), we used hurdle, breakpoint, and ordinary least squares regression models to statistically examine the long-term effects of this policy on the Basin’s stream and wetland mitigation markets, including demand and supply of mitigation bank credits. We found this policy spawned an enduring stream mitigation market, while driving declines in stream impact extents and wetland mitigation credits sold and supplied. These findings have implications for other districts seeking to establish in-kind mitigation requirements while protecting the entrenched investments of existing mitigation firms.

53 **Introduction and Background**

54 While streams and wetlands provide essential ecosystem services and values (Cheng et al. 2020;
55 Lal 2008; Nahlik and Fennessy 2016; Riley 1998), rapid urban development, climate change,
56 invasive species introductions, and water pollution have impaired streams and wetlands around
57 the world (Karl et al. 2009; MEA 2005; Vorosmarty et al. 2010). Prompted by concerns about
58 wetland losses and degradation, the U.S. Army Corps of Engineers (USACE) and the U.S.
59 Environmental Protection Agency (USEPA) were charged with enforcing Section 404 of the
60 U.S. Clean Water Act (33 USC 1344), which prohibited discharges into streams and wetlands
61 without a permit. The law – as amended in 1977 – gave USACE regulatory districts the authority
62 to issue impact permits, with which they eventually encouraged avoidance and minimization of
63 wetland impacts (Hough and Robertson 2008). In the wake of unavoidable impacts, the USACE
64 began requiring ecological restoration as offsets to avoid “net loss” of wetland resources
65 (National Research Council 2001).

66
67 The 1990s and early-2000s saw the development of a decentralized, regulated market primarily
68 consisting of for-profit “mitigation banks,” private firms that sell credits as compensation for
69 stream and wetland damage (BenDor and Doyle 2010; Hough and Harrington 2019; Wilkinson
70 and Thompson 2006), which generated \$2.95 billion in transactions in 2003 (ELI 2007).
71 Mitigation bankers purchase land, permanently protect the property with conservation easements
72 and restore or enhance any streams or wetlands present, compensating losses before impacts
73 have occurred and tying ecological success with the generation of credits (Lave et al. 2008;
74 Robertson 2006; Strand 2009). An example of this process can be seen when the Texas
75 Department of Transportation (TXDOT) determined that planned construction of a new road in

Fort Worth would impact local streams. In order to gain a permit to impact these streams, TXDOT purchased 87.13 stream credits from Mill Branch Mitigation Bank (MBMB 2019), which the bank had generated through prior in-stream restoration work on land that the bank owned. Upon agreeing to sell the credits to TXDOT, Mill Branch Mitigation Bank reported the sale and credit deduction to the local USACE office and recorded the transaction within its ledger (a publicly accessible, federal database; USACE 2021b).

In 2008, the USACE and the USEPA created formal regulations (“the 2008 Rule”; 40 CFR Part 230; 73 Fed. Reg. 19594, April 10, 2008) aimed at improving mitigation outcomes and success. Among other goals, the regulations established a series of preferences, including the preference for in-kind restoration for “difficult-to-replace resources” (§332.3 (e)(3)), a category that explicitly includes “streams.”

Wetland and stream impact metrics – acres of wetlands and linear feet of streams, respectively – are a crude currency, selected to represent both the fungible (land area) and non-fungible (social values, ecosystem services) aspects of these ecosystems within the mitigation market (Salzman and Ruhl 2000). As a result, the "in-kind" offset requirement is one of several market constraints (along with clearly defined geographic service areas [Doyle and Womble 2012] and credit release schedules [BenDor and Riggsbee 2011b]) imposed by the USACE that can minimize potential harm to the environment at the cost of potentially "thinning" the market of already risk-prone mitigation banks, thereby reducing the availability/marketability of mitigation credits.

However, despite explicit preferences by state governments and USACE regulatory districts (Doyle and Shields 2012) for in-kind mitigation, and articulated in a variety of federal (e.g., USEPA and USACE 1990; 2008) policies, failure to assure in-kind compensation for losses has led to the net gain of some resources at the expense of others. The 2008 Rule reaffirmed the goal of in-kind mitigation, but a survey of mitigation bankers found that 46.0% believed it did not lead to any increased levels of in-kind mitigation (BenDor and Riggsbee 2011a). Even though a survey of USEPA staff indicated that more than 50% of permits are issued for stream impacts in many regions (Lave et al. 2008), many states still lack stream mitigation mechanisms (USACE IWR 2015).

While there has been substantial growth in stream mitigation markets around the United States (USACE IWR 2015), many questions still remain about the impacts of in-kind mitigation requirements. In particular, how do in-kind mitigation requirements – specifically, those that prioritize stream mitigation for stream impacts – change the structure and operation of mitigation markets, including the prevalence of stream and wetland impacts and the supply and demand of mitigation credits?

To answer this question, in this paper, we present an assessment of the effects of the USACE Fort Worth District’s (SWF; the “District”) 2013 Stream Mitigation Method (SMM), one of the first formal, published policies to require in-kind mitigation for stream impacts in the United States. Using several statistical regression models (hurdle, ordinary least-squares, and breakpoint regressions), we assess wetland and stream impact and mitigation data (2007-2019; summarized

at a monthly timescale) in the Upper Trinity River Basin, an active area of aquatic ecosystem impacts and mitigation that stretches across much of the State of Texas (Figure 1).

After SMM implementation, we predict that total or average impacts on wetlands and streams per month were not altered by the SMM, as the policy only prioritizes stream mitigation, changing the market for mitigation bankers without limiting the market for developers. We hypothesize that this policy led to a sudden growth in stream mitigation banking and therefore, an increase in stream restoration, while retaining a market for wetland banking. However, it is likely that after SMM implementation, less *new* wetland mitigation occurred as new stream bankers began to participate in the market, limiting opportunities for wetland bankers. We hypothesize that the supply of stream credits likely increased under the SMM, but the supply of wetland credits likely declined.

Our results indicate that the SMM prompted the formation of a lasting stream mitigation market, a reduction in credits sold within the wetland mitigation market, a reduction in the extents and average sizes of stream impacts, and a shift in mitigation investments by bankers from wetland to stream credits. While the SMM still facilitates a net loss of streams, the policy has greatly expanded the local mitigation market to provide in-kind mitigation for both stream and wetland impacts. The SMM, designed specifically for the SWF District and the firms operating there, appeared to create a larger, more competitive, and more sustainable market after implementation, despite some concerns over lagged market response and protections for preexisting bankers, which we will describe in our Discussion and Conclusion sections. The SMM could function as a model for other USACE districts seeking to balance the need for new sources of in-kind stream

mitigation with USACE approved, pre-existing investments of established mitigators, many of which are protected by the 2008 Rule's grandfathering provision (§332.8(v)).

Methods and Data

Study area

[Insert Figure 1 about here]

The Trinity River provides drinking water for more than half of the State of Texas's 29 million residents, and its basin extends across 46,387 square kilometers and includes 1,424 square kilometers of surface water (Trinity River Authority 2016; US Census 2019; USDA et al. 2020). While the *lower* part of this basin falls within the boundaries of the neighboring USACE Galveston District (subject to different policies and not studied as part of this analysis), the *Upper* Trinity River Basin contains ~80% (18,690 km²) of the land area of the rapidly-growing Dallas-Fort Worth-Arlington Metropolitan Area (USDA et al. 2020; US Census 2020a). Among the 27 counties intersecting or contained within the Upper Trinity River Basin, seven are among the top 100 fastest-growing counties in the United States (US Census 2020b).

Spatially, this study area is reminiscent of the Chicago, Illinois region, where wetland mitigation patterns have been extensively studied (BenDor and Brozović 2007; BenDor et al. 2007; Robertson 2006; Robertson and Hayden 2008). Moreover, this study area is representative of many other growing metropolitan areas in the United States, such as Atlanta, Georgia and San Antonio, Texas (US Census 2020b), where development has taken an appreciable toll on local water resources (Fitzhugh and Richter 2004).

Within the Basin, all mitigation¹ is provided by eight mitigation banks, which are individual wetland or stream mitigation sites that have been restored or enhanced and allowed to generate credits to offset development-related impacts that have been granted USACE regulatory approval. While these banks directly compete to offset impacts within the basin, the banks provide different credit types:

- Three banks are wetland banks (i.e., offering wetland credits): *South Forks Trinity River Mitigation Bank* (est. 2006), *South Forks Trinity River Mitigation Bank Ten Mile Creek Tract* (est. 2010), and *Bunker Sands Mitigation Bank* (est. 2008);
- Two banks are stream banks (i.e., offering stream credits): *Mill Branch Mitigation Bank* (est. 2012) and *Bill Moore Mitigation Bank* (est. 2017);
- Three banks provide both wetland and stream credits: *Red Oak Umbrella Mitigation Bank - Palmer Tract* (est. 2013), *Rockin' K on Chambers Creek Mitigation Bank* (est. 2015), and *Trinity River Mitigation Bank* (est. 2001). It should be noted that while *Trinity River Mitigation Bank* offers “stream credits”, these credits are derived by way of mathematical conversion of wetland acres to linear feet, not any direct restoration or enhancement of streams specifically. Thus, these are “out-of-kind” credits per federal regulatory definition.

¹ Mitigation banking is currently the primary and preferred method for mitigation in our study area, but in many USACE districts, other common mitigation methods include in-lieu fee (ILF) programs, which charge impactors fees that accrue and are spent on specific mitigation projects (USACE IWR 2015), and permittee-responsible mitigation (PRM), whereby developers themselves remain responsible for providing on-site or off-site mitigation (National Research Council 2001). As of May 2021, there were no ILF programs in the SWF District (USACE 2021a), and PRM is rarely permitted (Walker 2021, personal communication).

Policy history

In 2013, the Fort Worth District (SWF), the USACE district that encompasses our study area (Figure 1), implemented its Stream Mitigation Method (SMM), a policy that was part of an effort to address recommendations and requirements of the 2008 Rule (USACE SWF 2013) while simultaneously grandfathering “legacy” wetland banks approved before 2008 with mitigation banking instruments that allow their credits to offset stream impacts. While the District had a collection of documents defining mitigation procedures (ELI et al. 2016), it had not previously set any goals to limit the net loss of resources other than wetlands (J. Walker 2021, USACE SWF, personal communication). Upon the determination that in-channel ecological stream functions were being lost and not replaced, the District became motivated to implement the SMM; the District then implemented a public notice process, which included a public comment period and a public meeting, before finalizing and publishing the SMM.

While other Districts had implemented informal policies/practices that represent de facto requirements for in-kind mitigation, few of these Districts had been in SWF’s position, with several large wetland mitigation banks that were approved before the 2008 Rule and were still operating. These older mitigation banks had mitigation banking instruments (signed by the USACE and bank sponsors) that allowed for the use of wetland credits as stream mitigation. The scale of SWF’s predicament, with respect to the sheer size of these grandfathered wetland banks, was unique; for example, the Trinity River Mitigation Bank contains ~1,400 acres [567 ha] of wetlands and Pineywoods contains ~19,000 acres [7690 ha] of wetlands (Pineywoods 2021; TRMB 2021). Studying SWF’s issuance of the SMM in October 2013, therefore, provides a

208 unique opportunity to see how policy can affect mitigation bank inventories and the use of those
209 credits over time.

210

211 Under the SMM, the District established that stream impacts would require at least 50% of
212 compensatory mitigation to come from approved stream mitigation banks. In the absence of
213 available stream credits, developers would still be allowed to purchase wetland credits from
214 grandfathered wetland mitigation banks in lieu of stream credits (USACE SWF 2013). While
215 standards for stream credits were established independently of – and prior to – the SMM, prior to
216 2013, developers could choose not to purchase more expensive stream credits if wetland credits
217 provided the same degree of compliance.

218

219 Along with allowing wetland banks a period of grandfathering, the SMM’s requirement for only
220 partial (50%) in-kind stream mitigation (stream credits for stream impacts) represented efforts to
221 protect existing wetland mitigation firms. The SMM was the SWF District’s attempt to strike a
222 balance between the 2008 Rule’s in-kind mitigation mandate (and its goal of avoiding net-losses
223 of impacted ecosystems) and practical realities of working within an existing market that had
224 well-established and highly-invested interests.

225

226 As of September 2021, there were eight states and one territory without approved stream
227 mitigation credits (USACE 2021d). While the national stream mitigation market has grown
228 rapidly, many stream mitigation banks are located within a limited number of states, such as
229 North Carolina, Virginia, Kentucky, and Texas. Several states, including Minnesota and

Wisconsin, were home to numerous wetland banks in 2021 (289 and 78 banks², respectively; USACE 2021e), but not a single stream mitigation bank. In these states, if mitigation banking were to remain the sole compensatory practice, stream impacts would continue to be mitigated by wetland mitigation banks (or via other mitigation methods, which include their own problems; Wilkinson 2009; BenDor et al. 2014). While the reasons may vary among the many districts without stream banks, it is vital to understand whether a new policy attempting to cultivate a stream mitigation market could be successful, especially in regions with established wetland banks. No comprehensive assessments of the effects of the SMM – or any other policy like it – have been attempted. This paper endeavors to understand if (and how) the SMM has changed the stream and wetland mitigation markets within the Upper Trinity River Basin.

Data

Two primary databases track wetland and stream impact and mitigation activity in the United States; the first is the OMBIL Regulatory Module v.2 (“ORM2”) database, which the USACE has used nationally to manage records of aquatic impact permit applications and approvals since 2007 (USACE 2018). ORM2 tracks various facets of impact data, including permit numbers, the type of resource impacted, the project location (geographic coordinates), the authorized linear feet of impact (later replaced by the authorized fill length; this refers to authorized linear impact to a body of water through development activity and used primarily to measure in-stream impact [USACE 2018]), the authorized acres of impact (e.g., authorized fill of acres of wetlands), and permit approval dates.

² This includes all mitigation banks that have not been terminated or withdrawn as of September 2021.

From the USACE, we obtained all ORM2 approved permit data between October 2007 (the first year with reliable data within ORM2) and September 2019 (the end of the 2019 fiscal year). While 3,189 total permits were approved during this time period in the entirety of the Fort Worth District, only 2,405 (75.42%) impacted stream or wetland resources³ and, among those, only 954 (39.67%) contained geographic coordinates within the Upper Trinity River Basin (USACE 2020a).

The USACE also maintains the Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS; USACE 2021b), which tracks in-lieu fee program (non-existent in our study area) and mitigation banking activity, including site approvals, credit releases⁴ and transaction data (i.e., credit sales). Transaction data (i.e., “credit sales ledgers”) include details on credit types (i.e., stream or wetlands, and sub-classes of each), transaction dates, impact permit numbers, and amounts of credit transactions (including the geographic area or linear feet that wetland or stream credits represent, respectively).⁵ Using RIBITS, we collected transaction data for the eight mitigation banks in the Upper Trinity River Basin from the first credit withdrawal in March 2002 until October 2020.

Several prior studies have used RIBITS and ORM2 to study mitigation activity, including Hough and Harrington’s (2019) Environmental Law Institute study of mitigation banking activity, and

³ Of the remaining 784 permits, 322 (41.07%) impacted lake resources, while 418 (53.32%) impacted unclassified resources; the remaining permits impacted riparian areas.

⁴ USACE regulators allow “credit releases” -- making available some portion of credits for sale -- gradually over time as mitigation banks meet pre-determined administrative and ecological standards (BenDor et al. 2011).

⁵ In order to determine the SMM’s effects on no net loss of streams (a major goal of the 2008 Rule), we converted stream credits to linear feet of restoration (see Supp. Material 3 for more details).

Julian and Weaver's (2019) analysis of stream mitigation demand in Colorado. However, there were two important barriers to using the entire extent of ORM2 permit data for this analysis.

First, the USACE may issue permits for development projects that are never implemented (e.g., due to financial difficulties, such as the 2008 Great Recession; S. Martin 2020, USACE Institute for Water Resources, personal communication) and therefore never incur environmental impacts. Therefore, it was important to only rely on permits that had corresponding, documented mitigation purchases from banks (again, in-lieu fee programs are not active in SWF). Moreover, it would not have been feasible to track down any permittee-responsible mitigation project data independently for each permit (e.g., see laborious process documented in BenDor et al. 2007).

Second, given that banking has long been the dominant mitigation method used in our study area, any non-bank mitigation records in the ORM2 data may be erroneous or not fully documented. For example, prior to June 2007, USACE districts stored their own permitting data separately, leading to divergent levels of quality when these data were aggregated into the ORM2 database (USACE 2018). Therefore, we decided to limit stream and wetland impact permits included in this analysis to only those during or after October 2007 (start of the 2008 fiscal year) that had documented, corresponding permit purchases from one of the eight mitigation banks in RIBITS⁶. See Supp. Material 1 and Table S1 for a comparison of the universe of wetland and stream impacts in the Basin (n=954) and the subset included in this analysis.

⁶ Accounting for 27.67% (n = 264 permits) of permits approved within the Basin. Again, many permits did not have corresponding permit purchases, potentially due to aforementioned financial difficulties of impacting firms.

We partitioned ORM2 impact data by month ($n = 144$ months; Oct. 2007 - Sept. 2019), aggregating permits into monthly totals of 1) linear feet [meters] of stream impacts and 2) acres [hectares] of wetland impacts.⁷ We similarly aggregated RIBITS data into monthly summaries ($n = 144$ months; Oct. 2007 - Sept. 2019), organized into monthly 1) stream mitigation credit sales, 2) wetland mitigation credit sales, 3) new wetland credits released (i.e., authorized by USACE to be sold by the banks; representing credit supply), and 4) new stream credits released.

Finally, we endeavored to understand if economic growth was associated with changes within the mitigation market in the Upper Trinity River Basin and whether it explained alterations in the market better than the implementation of the SMM. To assess the role of economic growth, we considered including a variety of variables, including employment rates, wages, and time itself (i.e., month). Texas's Coincident Economic Index, developed by Crone and Clayton-Matthews (2005), represents a well-developed index that allows assessment of the economic conditions of an individual state based on an aggregation of state employment, unemployment rates, average hours worked, and real wage and salary disbursements (Federal Reserve Bank of Philadelphia 2021). Our initial analysis, presented in Supp. Material 2, found that this index and time are so highly correlated ($r = 0.99$) as to render the inclusion of both variables impossible. Moreover, time is more easily interpretable as a covariate in our regression analyses.

⁷ Linear feet of stream impacts are equivalent to stream length; before June 2017, the USACE only recorded stream length measurements within ORM2 without (or only sporadically with) corresponding width measurements (USACE 2020a) that would facilitate precise area estimates of stream impacts. After June 2017, the USACE required local offices to submit areal measurements of both length and width of streams (USACE 2018). For this analysis, we only analyze linear feet measurements for streams to maximize data to draw from for this analysis.

Analysis methods

Our goal was to understand the relationship, over time, between the SMM policy and amounts of wetland and stream impacts (demand for all mitigation, not necessarily in-kind), stream and wetland mitigation credit sales (representing in-kind mitigation demand post-SMM), and credit releases (in-kind mitigation supply). Alongside each of the monthly time series datasets discussed above, we represented the presence or absence of the SMM policy across our study period using a binary variable (1 = SMM present, implemented in October 2013; 0 = SMM absent). To understand the impact of the SMM on trends in mitigation and impact demand over time (i.e., changes in slopes/trends of mitigation or impact demand before and after SMM implementation), we also evaluated the interaction between time and this binary policy variable.

Modeling impact and credit demand: hurdle models

As part of our exploratory data analysis prior to regression modeling, we implemented unpaired two-sample t-tests (Welch procedure used because the assumption of equal variance cannot be assured with our data; Dalgaard 2008; Welch 1947) to understand shifts in average impacts and mitigation per month before and after the SMM. Exploratory data analysis revealed that monthly-aggregated impact and mitigation data were not normally distributed and contained a disproportionately large number of zeros, with many months containing very few or zero impacts or mitigation.

To manage the nuances in the monthly impact and mitigation sales dependent variables and their over-dispersion (i.e., many zero entries), we employed a statistical regression technique known as a hurdle model (Martin et al. 2018; Mullahy 1986), which contains two parts: a “zero hurdle

model,” which determines whether the dependent variable is equal to zero or is positive (i.e., a logistic regression; Berkson 1944), and a count model, which estimates the size of the non-zero dependent variable (i.e., a gamma-distributed generalized linear model (GLM), which models positively skewed data with no negative entries [i.e., count data; Ng and Cribbie 2017] while employing a log link to connect the dependent variable to the independent variables and log transform the independent variables; Agresti 2015).

Modeling credit supply analysis

Robertson’s (2006) analysis of the Chicago mitigation market offers a framework for analyzing shifts in the availability of mitigation credits for sale by mapping the credits that were released over time as different mitigation banks moved through several stages of the bank approval process over nine years. For this analysis, we extended this idea by creating a dynamic measure of the number of available mitigation credits, which we call “credit supply.” This allowed us to expand on Robertson’s (2006) work to understand how credit sales impact the number of unsold credits over time as banks enter and exit the market.⁸ We defined the credit supply (c_t) of a given month (t) as the sum of mitigation credits available for purchase at the start of a given month (a_t) and new credits released by the USACE to mitigation banks throughout the month (r_t), subtracting the credits sold (s_t) during the same month: $c_t = a_t + r_t - s_t$.

We calculated wetland and stream credit supply for each month of our study period and used an ordinary least-squares (OLS) model to regress credit supply on the same independent variables

⁸ This is an alternative measure to RIBITS’ “potential credits” metric, which is a more static count of the sum of all the credits that *could* be sold if a bank fulfills its ecological and performance standards (USACE 2021c).

as previous regressions: the binary indicator of the SMM, time (month), and the interaction between the SMM and time (Table 1).

Modeling the timing of market changes: breakpoint regressions

Finally, after developing, running, visualizing, and analyzing our hurdle and linear regression models, we also implemented a “breakpoint regression” for each of the models. Breakpoint regression attempts to determine the true “breakpoint” of the model based on the data alone; i.e., it does not consider the actual implementation date of the SMM and instead uses patterns in the data to estimate inflection points (Muggeo 2003). This can help to understand whether the SMM is most likely the reason for hypothesized shifts in impact or mitigation behavior, or if additional, unobserved factors may have played a role.

All regression models are summarized in Table 1 and all statistical analyses and data visualizations were implemented using the R statistical software platform (v4.0.3, R Core Team 2020).⁹

[Insert Table 1 about here]

Results

Summary statistics

Figure 2 shows patterns of monthly stream and wetland impacts, mitigation, and credit supply over the course of the study period, while Table 2 shows differences in the distributions of each of these factors. The average, pre-SMM monthly rates of wetland impacts (1.56 acres [0.63 ha]),

⁹ Visualization and statistical packages for R included *dplyr* (v1.0.4, Wickham et al. 2021), *ggplot2* (v3.3.3, Wickham 2016), *ggthemes* (v4.2.4, Arnold 2021), *lmtree* (v0.9-39, Zeileis and Hothorn 2002), *lubridate* (v1.7.9.2, Grolemund and Wickham 2011), and *segmented* (v1.3-2, Muggeo 2008).

stream impacts (1436.72 linear ft [437.91 m]), wetland credit sales (14.08 credits), and wetland credit supplies (675.83 credits available) declined after the SMM (to 1.05 acres [0.42 ha], 1158.72 linear ft [353.18 m], 6.60 credits sold, and 654.74 credits available, respectively). Concurrently, the average monthly stream credit supply on hand of 431.26 credits during the pre-SMM period increased to 10,128.59 credits after SMM implementation (Table 2). Furthermore, the average impact size per permit per month before the SMM declined from 2.14 acres [0.87 ha] to 0.85 acres [0.34 ha] of wetlands and 1366.75 linear feet [416.59 m] to 866.75 linear feet [264.19 m] of streams (Table 2). The difference between pre-SMM and post-SMM means was significant for average monthly stream impacts per permit, stream mitigation sales per month, wetland mitigation sales per month, and stream credit supplies per month (Table 2).

[Insert Table 2 about here]

Much of our impact and mitigation data were over-dispersed; monthly total wetland impacts ranged from 0 to 31.79 acres per month, but across 34.03% (n = 49 months) of the 144-month study period, no impacts occurred, and more than half of the study period contained less than 2 acres of impacts per month (52.08%; n = 75 months). Likewise, wetland mitigation credit sales ranged from 0 to 90.60 credits per month, but over the study period, 15.28% (n = 22 months) of months saw zero credit sales, and 27.78% (n = 40 months) saw sales of less than 2 credits.

As described in Supp. Material 3, we attempted to convert stream credits to linear feet of restoration. From July 2014, when the first stream credits were sold, through September 2019, developers impacted 69,341.00 linear feet of streams, and stream mitigation banks sold credits generated from restoring approximately 34,782.52 linear feet of streams. This means that for

every impacted linear foot of streams, almost exactly six inches of streams were restored¹⁰ (i.e., the in-kind component of the SMM), with the rest of the mitigation purchased in the form of wetland credits.

[Insert Figure 2 about here]

Regression modeling

Stream and wetland impacts

We regressed stream and wetland impacts and mitigation using a series of hurdle models to control for time, implementation of the SMM, and interaction effects between the SMM and time (Table 3). Our interpretations of these models focus on the count components (i.e., the incident rate ratios [IRR]), which seek to predict the rates of non-zero impacts or mitigation per month.

The first model, evaluating the relationship between stream impacts and the SMM, reveals that, while the SMM appears to be associated with a stepwise increase in stream impacts, the interaction effect of the SMM and time suggests a gradual decrease in stream impact volumes after SMM implementation ($IRR = 0.98$; $P < 0.1$). This same trend does not significantly hold for wetlands; the hurdle model of wetland impacts did not determine a clear relationship between the implementation of the SMM and wetland impact volumes.

[Insert Table 3 about here]

¹⁰ This calculation accounts for impacts within stream channels, not their riparian areas (i.e., the side of the channel), which may or may not be affected by a given impact. The USACE's jurisdiction is limited to the dredging and filling of "waters of the US". In terms of streams, this means USACE jurisdiction includes only the bed and banks of a stream and does not include associated riparian areas. Riparian impacts are sometimes considered along with authorized fill in determining a developer's mitigation requirements; however, if a developer only impacts a riparian area, and not a stream's bed or banks, the USACE would not have jurisdiction, and a permit would not be required (meaning no mitigation is necessary).

420 *Stream and wetland mitigation credit sales*

421 While stream mitigation credit sales clearly increased after SMM implementation, the lack of
422 pre-SMM sales made it impossible to model the effects of the SMM on stream credit sales.
423 Figures 2E and 2G show the post-SMM emergence of this new market for stream credits.
424 Per Figure 2F and Table S4 (see Supp. Material 4), prior to the SMM, the wetland credit market
425 was growing at an average rate of 1% per month.¹¹ However, after implementation of the SMM,
426 we found a significant declining trend in wetland mitigation credit sales (time*SMM interaction
427 effect; Table 3), where a one month increase in time resulted in a ~5% decrease in wetland
428 credits sold (IRR = 0.95; $p < 0.01$).

429
430 *Credit supply*

431 We found diverging relationships between wetland and stream credit supplies and
432 implementation of the SMM (Table 3). While wetland credit supplies grew at an average rate of
433 ~1 additional credit added to the market per month before SMM implementation (Figure 2H;
434 Table S4), the SMM was associated with a reversal of this pattern. Our OLS model of wetland
435 credit supply reveals a decline of 2.05 credits per month ($p < 0.01$; again, the time*SMM
436 interaction effect) after SMM implementation (which must be weighed against the 1.01
437 credit/month increasing trend the regression found across the entire 144-month study period;
438 $p < 0.05$).

439

¹¹ Models of wetland mitigation sales and stream and wetland mitigation supply were conducted independently for the pre- and post-SMM periods using time (month) as a single independent variable. The results of these models can be found in Table S4.

Stream credit supply remained zero until June 2012, when 1940.66 credits were released by the USACE to Mill Branch Mitigation Bank (USACE 2020b). These credits remained unsold (with no additional releases made) until July 2014, nine months after SMM implementation in October 2013. After SMM implementation, Figure 2G and Table S4 show that stream credit supply grew at an average rate of ~217 credits per month. Our OLS model (Table 3) likewise shows that post-SMM credit supply increased by ~189 credits per month ($p < 0.01$), in addition to the ~28 credit increase per month over the entire 144-month study period ($p < 0.01$).

Breakpoint regressions

For each of the aforementioned models, we aimed to determine a “true” breakpoint that indicates the inflection points in each impact, mitigation sale, and mitigation supply time series, discarding our knowledge of the actual implementation date of the SMM. In three of the five models – wetland impacts, stream credit supply, and wetland credit supply – we found a breakpoint occurring prior to implementation of the SMM (Table 3). In the other two models – stream impacts and wetland credit sales – we found breakpoints occurring after SMM implementation. All of the breakpoint regressions relating to mitigation – wetland mitigation and stream and wetland credit supplies – had confidence intervals that stretched over less than two years.

The wetland credit sales model determined a breakpoint approximately two and a half years after the SMM was implemented, while the wetland credit supply model determined a breakpoint approximately three and a half years before the SMM was released. Stream credit supply was closest to the actual implementation date of the SMM, with an estimated breakpoint seven months prior. Breakpoints for wetland and stream impacts were less clear, with wetland impacts

estimating a breakpoint between 2007 and 2014 and stream impacts estimating a breakpoint between 2015 and 2019.

Discussion

Our analysis reveals that, on average, there has been a significant, declining trend in stream impacts after SMM implementation, as indicated visually in Figures 2A and 2C and analytically in Table 3. Why did this occur?

While total impacts fell after implementation after the SMM (Figure 2A), average impacts per permit had already begun to decline before implementation (Figure 2C). This could potentially be a response to the District's increased attention to avoidance and minimization. We also hypothesize that the decline may have resulted from a shift in the way that mitigation credits were priced before and after the SMM. We can take two permits as an anecdotal example; in 2011, two years prior to the SMM, Bunker Sands Mitigation Bank charged TXDOT (permit SWF-2011-00616) approximately \$4,800 for 0.2 wetland credits to offset 909 linear feet [277.06 m] of stream impacts and 0.17 acres [0.07 ha] of wetland impacts (A. McDaniel 2021, RiverBank Ecosystems, Inc., personal communication; Wetlands 2014; USACE 2020b). Contrasting this, in 2019 (11 years later and 6 years after the SMM), Mill Branch Mitigation Bank, charged the same permittee, TXDOT (permit SWF-2018-00449), \$121,982 for 87.13 stream credits to offset 250 linear feet [76.2 m] of stream impacts (McDaniel 2021, personal communication; MBMB 2019; USACE 2020a; USACE 2020b).. This latter case represents a much higher cost for a smaller area of impact of streams relative to wetlands.

We theorize that, as demand for ecosystem-specific (in-kind) stream credits replaced demand for what had been more generalized wetland credits, the supplies of wetland credits dropped as suppliers (i.e., bankers) pivoted towards stream credits. Additionally, more stringent – and potentially more expensive – ecological standards for mitigation banks were encouraged by the USACE within the District after SMM implementation (USACE SWF 2015). Therefore, we would expect that prices would rise for both stream (increased demand) and wetland (reduced supply) mitigation credits in the wake of the SMM.

If this pricing trend were systematic, increased mitigation costs would likely discourage many impacts, thus prompting the decrease in stream impact volumes (Figure 2A) and average impact sizes (Figure 2C) as permittees adjusted their willingness to incur additional expenses due to higher stream impact prices. However, there are still cases of large, linear infrastructure projects capable of generating extensive quantities of impacts, even with much higher mitigation expenses; for example, Atmos Energy Corporation’s permit in 2016 (SWF-2016-00049; USACE 2020a) impacted 8,635 linear feet of streams, while another TXDOT project impacted 5,892 linear feet of streams in 2016 (SWF-2015-00506; USACE 2020a). However, these permits appear to be outliers (see Table S1 with impact summary statistics).

We would expect that among the likely implications of the SMM’s 50% in-kind mandate would be a sharp decline in the average number of wetland credits purchased from banks, along with a strong increase in stream mitigation credit purchases. Both of these are confirmed by our analysis. It is clear from Figure 2E that the SMM played a major role in opening the market for stream mitigation banking. Before the SMM, there were no credits sold for streams; afterward,

bankers began selling an average of ~252 credits a month (2013-2019). Additionally, stream credit supply increased rapidly under the SMM as more banks entered the market and generated credits. Concurrently, although wetland credit supply rose consistently before the SMM, we now observe wetland credit supplies slowly declining (Figure 2H) as the demand for wetland credits drops in the wake of in-kind mitigation requirements.

Our breakpoint analysis determined a wetland mitigation breakpoint approximately two and a half years after the SMM was released. Under the SMM, if stream credits were unavailable, developers were allowed to purchase wetland credits (USACE SWF 2013). In the first nine months after implementation of the SMM, there were no stream bank sales (even though credits were available), and from July 2014 until February 2015, only one stream bank sold credits (USACE 2020a). Therefore, our wetland credit demand breakpoint seems to indicate that while the SMM opened the market for stream banking, wetland banking continued to direct the market until potentially late 2015.

As the first stream credits were sold in July 2014, nine months after the SMM was released, even though they were approved in 2012, we hypothesize that wetland banks were still selling credits to entirely offset stream impacts approved before the passage of the SMM (i.e., “grandfathered permits”; Galik and Olander 2018). This limbo period may explain why wetland credit sales do not immediately drop upon SMM implementation in Figure 2F, and why the breakpoint for wetland credit sales is not estimated until 1.5 - 3.5 years after SMM implementation (Table 3). Eventually, however, permits began to be approved under the SMM, and, upon projecting the higher cost for credits, permittees either paid increased mitigation costs, avoided impacts entirely

(and therefore, were not included in this study), reapplied for a permit impacting fewer wetland acres or stream linear feet, or abandoned the permit. Additional anecdotal evidence from transactional data between the TXDOT and banks indicates that some banks eventually began to increase prices for wetland credits as well, representing essentially a “re-appraisal” of wetland credit values. For example, for approximately 0.38 acres [0.15 ha] of wetland impacts, the TXDOT was charged \$18,962.67 per wetland credit before SMM implementation; 3 credits were purchased from the South Forks Trinity Mitigation Bank for \$56,888 (SWF-2007-00573). On the other hand, for approximately 500 linear feet [152.4 m] of stream and 0.015 acres [0.006 ha] of wetland impacts, the TXDOT was charged \$101,648.75 per credit after SMM implementation, with 0.8 credits purchased from the Trinity River Mitigation Bank for \$81,319 and with 87 stream credits purchased from Mill Branch Mitigation Bank. This represents a substantial increase in market value for wetland credits (MBMB 2019; McDaniel 2021, personal communication; TRMB 2019; USACE 2020b). However, despite the marked increase in wetland credit pricing, our models did not clearly confirm whether the policy led to a significant reduction of wetland impacts alongside a reduction in wetland credit sales.

Breakpoints for stream and wetland credit supplies were both estimated to be well before the SMM was released. Stream credit supply’s breakpoint was placed before the SMM but only by 7 months. In contrast, the earlier, March 2010 breakpoint for wetland credit supplies was 26 months before the USACE approved the first stream credits for release by stream banks (June 2012).

We hypothesize that discussions of the SMM proposal – which first began in the fall of 2012– may have both *affected* the mitigation market and *been affected* by ongoing market shifts. First, any proposed regulatory intervention regarding stream credits may have signaled future decreasing demand to wetland bankers, thus prompting decreased efforts to create more credit supplies before the SMM was formally implemented. Second, the first release of stream credits in June 2012 – which was obviously the true breakpoint in establishing the SWF stream mitigation market – may have influenced the regulatory landscape. With stream credits becoming available, the USACE in the Fort Worth District may have felt pressure to fulfill in-kind requirements present in the 2008 Rule, regardless of the particularly extensive supply of wetland credits. This pressure may have prompted the SMM itself.

Conclusions

Despite national in-kind mitigation requirements dating back to 2008, the following years have seen limited stream mitigation banking development. There has been a historical focus on wetland mitigation despite the USACE mandate to protect the waters of the United States (Lave and Doyle 2020), perhaps the result of prioritizing no net loss of all wetlands, generally, over streams, specifically (USEPA and USACE 1990). While, presently, there is pressure on the USACE to require stream mitigation and meet in-kind requirements of the 2008 Rule, USACE districts do not desire to alienate wetland mitigation firms, negatively impact their business, or potentially risk legal action taken by individual bankers opposed to the prioritization of stream mitigation. Indeed, representatives of another USACE district were surprised that the SMM successfully passed in Texas (Walker 2021, personal communication), as the passage of a specific policy prioritizing streams seemed untenable to them.

577

578 What then made the SMM tenable? The SMM attempted to avoid these consequences through
579 compromise. The SMM may act as a model for other districts – an example of a policy that both
580 prioritizes streams and protects existing wetland banker interests. Prior to the SMM, four
581 existing banks controlled all mitigation credits in the USACE Fort Worth District, and all Basin
582 impacts – streams and wetlands – were offset using wetland credits (USACE 2020b). In 2013,
583 the SMM rapidly opened the Upper Trinity River Basin’s market for stream mitigation, with the
584 first stream mitigation bank transaction occurring the following year (2014).

585

586 The SMM represents a novel effort to balance the promotion of new, in-kind mitigation priorities
587 with protections for a long-established mitigation industry. Our analysis suggests that this
588 balancing act has had a variety of effects, direct and induced. First, our analysis suggests that,
589 while the SMM appears to have accomplished its 50/50 in-kind stream mitigation goal, it is clear
590 that this requirement can only achieve 50% of the "no net loss" goal of the 2008 Rule.

591

592 Second, the SMM appears to have reduced the total volume and average size of stream impacts.
593 Our analysis suggests that, by requiring more stringent, in-kind mitigation, the SMM induced
594 higher mitigation costs, thereby making stream impacts more expensive and increasing the
595 economic incentives for developers to minimize stream impacts.

596

597 The USACE considers rivers and streams fragile and difficult to replace (USEPA and USACE
598 2008), and mitigation is not always successful, depending on whether “success” refers to
599 improved hydrologic processes, biogeochemical processes, ecological processes, or other

processes (Louhi et al. 2011; Palmer et al. 2014). Therefore, stream impact avoidance is still important (Clare et al. 2011), regardless of the improvements in the science of restoration and enhancement that mitigation bankers and scientists have proposed and begun to implement, like designer streams or uncontrolled restoration projects (Lave and Doyle 2021).

In weighing the implications of the SMM for the future of mitigation, it is important to consider that the SMM represents a complex compromise between established wetland banking firms, regulators, land developers, and newly emerging stream banking firms. The SMM prioritizes stream mitigation where it previously had not existed, while recognizing the complicated political nature and diverse interests operating in the District's established mitigation market. By requiring partial, in-kind mitigation for stream impacts, the District attempted to avoid the perception of a regulatory "taking" and any potential litigation from established wetland mitigation banking firms within the District (Walker 2021, personal communication) and may have tried to avoid cooling effects on the willingness of banking firms to enter the market.

This compromise opened the market to new stream mitigation firms and protected the interests of established wetland banks. While it appears that wetland bankers were negatively affected by the policy, with sales volumes declining, anecdotal evidence suggests that the SMM allowed these bankers to raise their prices, thereby increasing their margins to an extent that appears to more than offset their loss of pre-SMM sales volumes.

Implications for policy

While plenty of USACE districts and states have expanded their policies regarding stream mitigation in response to the 2008 Rule, beyond the SMM, there are no formally published policies with clear, in-kind stream mitigation requirements. Generally, it appears that the market growth for stream mitigation has outpaced the development of USACE district-level requirements and assessment methodologies. Therefore, as in-kind mitigation options have not historically been mandated (or even available), districts have historically defaulted to allowing out-of-kind mitigation for stream impacts.

This Fort Worth case study implies that – rather than harming the mitigation industry – localized, in-kind mitigation requirements can usher in an expanded, more competitive, and ultimately, more sustainable mitigation market. This should be encouraging to other USACE districts, especially those experiencing increasing pressure on water resources. Indeed, conversations with regulators indicate that other districts have noted the SMM, intending to learn from it and potentially apply it within their own regulatory boundaries (Walker 2021, personal communication).

However, our analysis also suggests that policymakers should not expect the market to change immediately. SMM implementation did not lead to a sudden shift in mitigation banking behavior. Instead, we observed gradual market shifts, especially as stream banks began selling credits in 2014. Moreover, the wetland credit breakpoint suggests that there was a two-year period between the SMM's release and a decline in wetland credit sales.

The literature includes several solutions to shift the market at an even faster rate, such as speeding up reviews of mitigation projects to allow for rapid approval for mitigation banks (Kihlslinger et al. 2020). Other potential solutions include allowing higher rates of “advance credit sales” – i.e., credits sold before all performance standards are met – to early in-kind market entrants (Galik and Olander 2018) while balancing the enforcement date for in-kind requirements with the dates of approvals for stream-focused mitigation projects.

However, there was one bank that had approved stream credits before the SMM but did not sell immediately upon the SMM’s release (USACE 2020b). Grandfathered permits may have limited stream bank participation. The SMM does uniquely reduce the ability for banks to sell wetland credits for stream impacts, but for permits that were accepted by the USACE before the SMM, they were grandfathered into the new market. While grandfathering is a common environmental market practice (Galik and Olander 2018), it can stifle new actors, prioritize older ones (Nash 2009), and reduce the probability of a policy accomplishing its goals (Damon et al. 2019). Reducing the ability of banks to grandfather pre-policy permits may be the most useful step in growing a stream market quickly. If grandfathering is inevitable, care should be taken to reduce negative outcomes for the policy. Any grandfathering that may occur should be made temporary, like granting exceptions to developers purchasing credits for a strict, limited period of time and prohibiting grandfathering if the policy is later updated (Damon et al. 2019).

As regulators seek to add in-kind mitigation requirements to mitigation markets, additional investigations are needed to determine how robust the reaction of other mitigation markets are to in-kind requirements and whether protections are needed for existing mitigation banks. In our

669 analysis, several banks (Trinity River Mitigation Bank, South Forks Trinity River Mitigation
670 Bank, and South Forks Trinity River Mitigation Bank Ten Mile Creek Tract) recorded fewer
671 transactions post-SMM, indicating that the SMM may have differentially harmed or benefited
672 specific banks. If banks remain the preferred mitigation mechanism - as explicitly spelled out in
673 the 2008 Rule as a way of elevating mitigation quality across the board – then it behooves
674 regulators to seek policies that protect bankers in the wake of changing regulatory structures.
675

676 How can USACE districts avoid undermining banks in the wake of these types of regulatory
677 changes? How can districts avoid damaging the established mitigation industry, while promoting
678 in-kind mitigation and achieving full no net loss of specific ecosystems? Stated in another way:
679 how can other districts avoid the tradeoffs that the Fort Worth District faced in creating the
680 SMM? Addressing these issues will enhance the ability of USACE Districts to achieve the aims
681 of the 2008 Rule, and ultimately achieve no net loss of all impacted aquatic ecosystems.

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Table 1. Hurdle and linear regression models employed. ORM2 (USACE 2020a) and RIBITS (USACE 2020b) refer to impact and mitigation databases, respectively. Odds ratio (OR) and incident rate ratios (IRR) refer to the exponentiated outputs of hurdle models' logistic and count models, respectively. All models rely on three independent variables: time (month; Oct. 2007 to Sept. 2019), SMM (binary; 1 = Oct. 2013 and later), Time*SMM (interaction). Breakpoint regressions were additionally performed for each of these dependent variables, using only time (month) as an independent variable.

	Model and Dependent Variable	Source	Outputs	Estimated Breakpoints
Hurdle models	Stream impacts (linear ft)	ORM2	Exponentiated coefficients (OR, IRR)	Time (month)
	Wetland impacts (ac)	ORM2	Exponentiated coefficients (OR, IRR)	Time (month)
	Stream mitigation credit sales (credits)	RIBITS	Exponentiated coefficients (OR, IRR)	Time (month)
	Wetland mitigation credits sales (credits)	RIBITS	Exponentiated coefficients (OR, IRR)	Time (month)
OLS (linear) models	Stream credit supply (credits)	RIBITS	Coefficients	Time (month)
	Wetland credit supply (credits)	RIBITS	Coefficients	Time (month)

Table 2. Average monthly stream and wetland impacts, mitigation credit sales, and mitigation credit supplies before and after SMM implementation (October 2013). Difference in means assessed with Welch's (1947) two-sample t-test procedure (95% confidence intervals given in parentheses).

*p < 0.1. **p < 0.05. ***p < 0.01.

Variable	Pre-SMM mean (95% CI)	Post-SMM mean (95% CI)	t-value and significance
Stream impacts (ft)	1436.72 (1055.1; 1818.35)	1158.72 (746.13; 1571.31)	0.99
Wetland impacts (ac)	1.56 (0.35; 2.77)	1.05 (0.61; 1.5)	0.78
Avg. stream impact per permit (ft)	1366.75 (1007.54; 1725.97)	866.75 (622.97; 1110.52)	2.31**
Avg. wetland impact per permit (ac)	2.14 (0.42; 3.86)	0.85 (0.40; 1.31)	1.47
Stream mitigation sales (credits)	0 (NA; NA)	251.57 (170.87; 332.27)	-6.22***
Wetland mitigation sales (credits)	14.08 (10.57; 17.58)	6.60 (3.14; 10.06)	3.03***
Wetland credit supply (credits)	675.83 (652.29; 699.37)	654.74 (643.3; 666.17)	1.61
Stream credit supply (credits)	431.26 (240.34; 622.18)	10128.59 (8911.71; 11345.46)	-15.70***

975 **Table 3.** Hurdle and OLS model predictions of the effects of the Stream Mitigation Method (SMM) on impacts, mitigation, and credit
976 supply. Hurdle models show effects on odds ratios (OR) for logistic (binary) components and incident rate ratios (IRR) for gamma
977 (count) components. OLS models show coefficients (95% confidence intervals shown in parentheses).
978 * p < 0.1; ** p < 0.05; *** p < 0.01.
979

	Hurdle Models								OLS Models	
	OR (95% Interval)				IRR (95% Interval)					
	Stream impacts (ft)	Wetland impacts (ac)	Stream mitigation sales (credits)	Wetland mitigation sales (credits)	Stream impacts (ft)	Wetland impacts (ac)	Stream mitigation sales (credits)	Wetland mitigation sales (credits)	Stream mitigation supply (credits)	Wetland mitigation supply (credits)
Time (month)	1.04*** (1.02; 1.08)	1.03** (1.01; 1.06)	-	1.03 (0.99; 1.07)	1 (0.99; 1.02)	1.02 (0.98; 1.05)	-	1.01 (0.99; 1.03)	27.96*** (7.70; 48.21)	1.01** (0.15; 1.86)
SMM (Binary; 1 = after Oct. 2013)	9603.3*** (15.76; 9.39E6)	3351.2** (6.14; 2.8E6)	-	3582.47** (1.73; 14.53E6)	32.9* (0.87; 1220.86)	1.46 (0; 1659.40)	-	12006.82*** (54.05; 2.98E6)	-30485.31*** (-35373.13; -25597.49)	319.52*** (113.07; 525.97)
Time (Month) *SMM Interaction	0.94*** (0.9; 0.98)	0.95** (0.92; 0.99)	-	0.95** (0.9; 0.99)	0.98* (0.96; 1)	0.99 (0.95; 1.03)	-	0.95*** (0.92; 0.98)	189.43*** (160.78; 218.07)	-2.05*** (-3.26; -0.84)
Intercept	0.01** (0; 0.34)	0.02** (0; 0.39)	-	0.31 (0; 33.27)	1306.86*** (197.5; 10345.54)	0.28 (0; 38.24)	-	4.18 (0.39; 52.94)	-3189.21** (-5845.71; -532.71)	545.25*** (433.05; 657.46)
AIC	163.87	175.15	-	123.9	1778.9	300.61	-	809.04	2574.37	1663.01
Log Likelihood	-77.94	-83.57	-	-57.95	-884.46	-145.31	-	-399.52	-1282.19	-826.51
Estimated Breakpoints (date [month])	-	-	-	-	Oct. 2017 [213.84] (Nov. 2015 [190.87]; Sep. 2019 [236.82])	May 2011 [137] (Dec. 2007 [96.12]; Oct. 2014 [177.89])	-	Apr. 2016 [196.98] (Jun. 2015 [186.1]; Apr. 2017 [207.86])	Mar. 2013 [159.27] (Sep. 2012 [153.1]; Sep. 2013 [165.45])	Mar. 2010 [122.79] (Sep. 2009 [117.04]; Sep. 2010 [128.54])

Figure 1. Map of Upper Trinity River Basin study area, as well as wetland and stream impacts ($n = 311$) and mitigation banks ($n = 8$). Inset map shows Basin and USACE Fort Worth District (SWF) situated within the U.S. State of Texas.

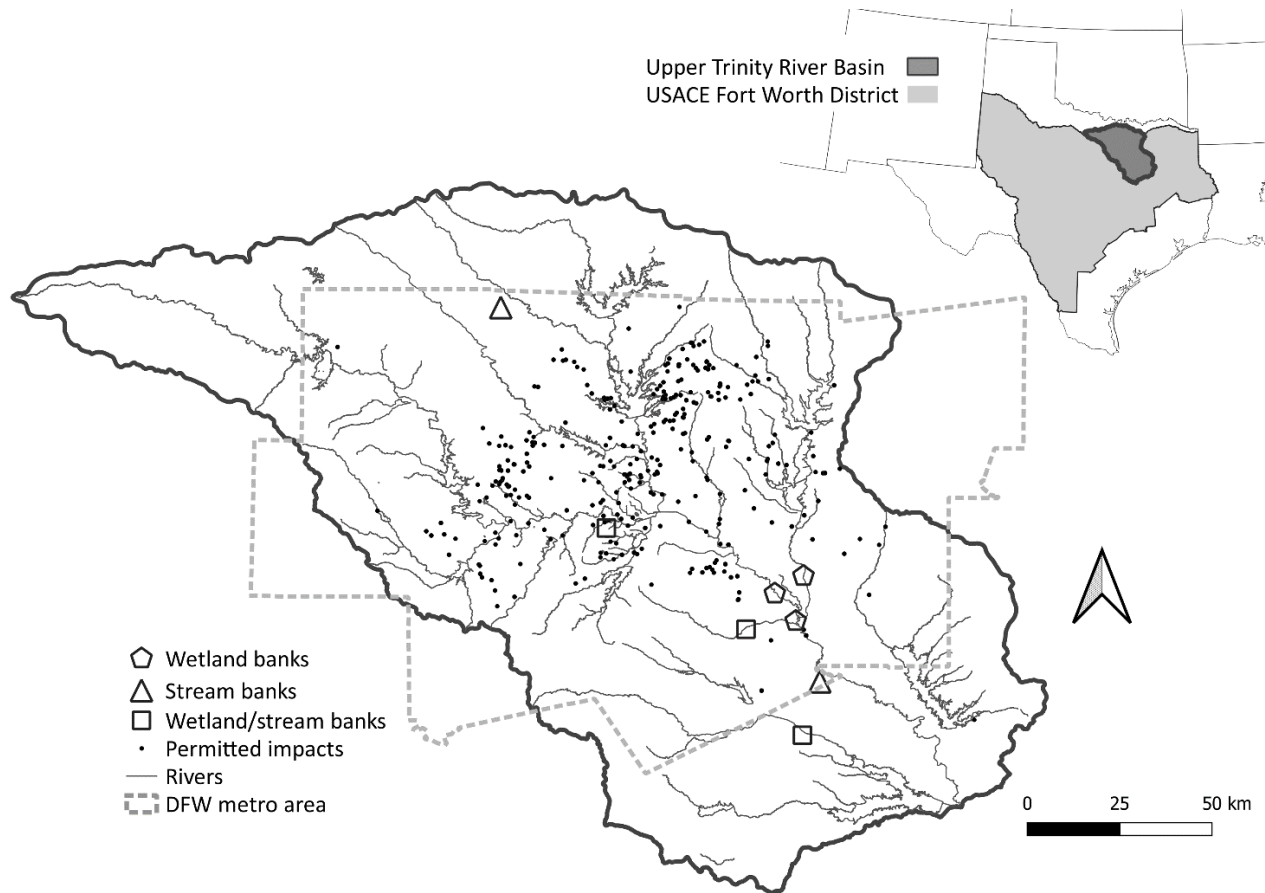
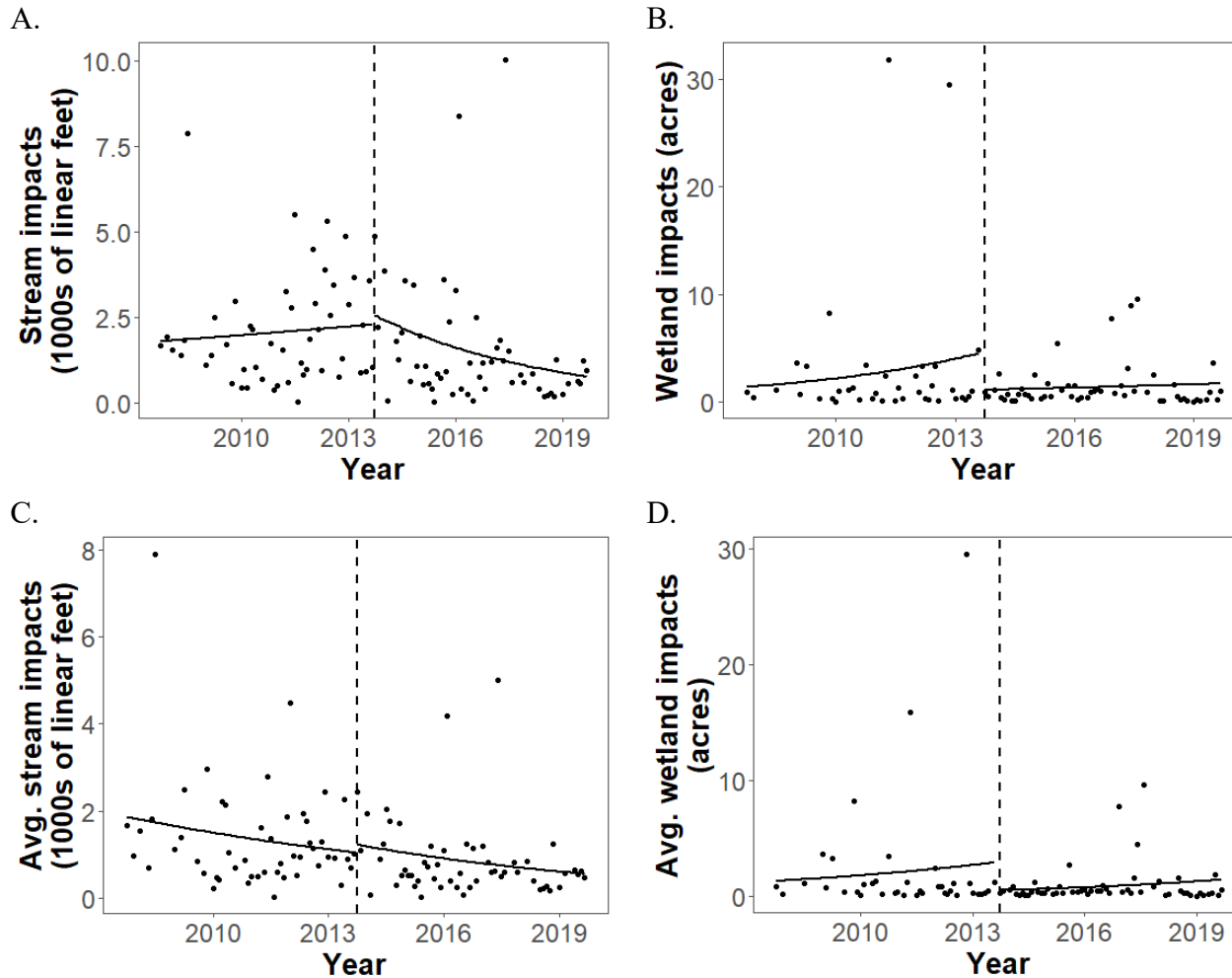
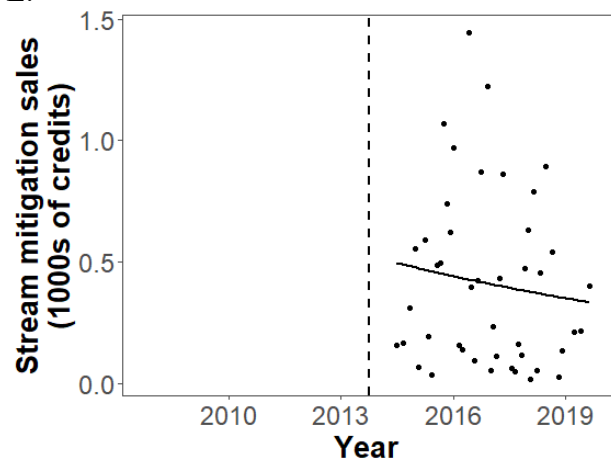


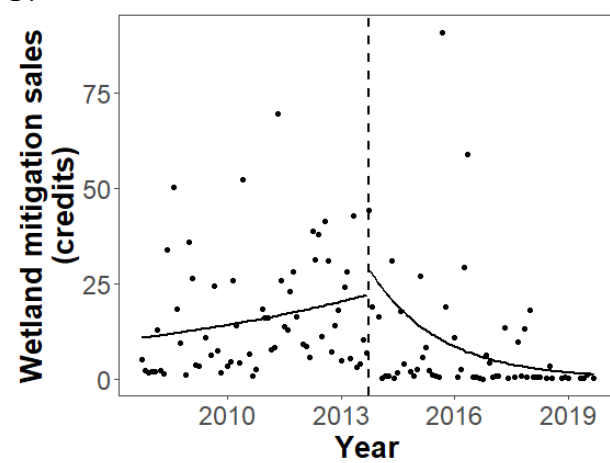
Figure 2. Monthly (A) total stream impacts, (B) total wetland impacts, (C) average stream impacts per permit, (D) average wetland impacts per permit, (E) stream mitigation credit sales, (F) wetland mitigation credit sales, (G) stream mitigation credit supply, and (H) wetland mitigation credit supply, before and after implementation of the SMM (indicated by dotted vertical lines; Oct. 2013). Trend lines over time for impacts and credit sales (panels A-F) are split before and after SMM implementation and employ count models (GLM with gamma distribution and with a log link).



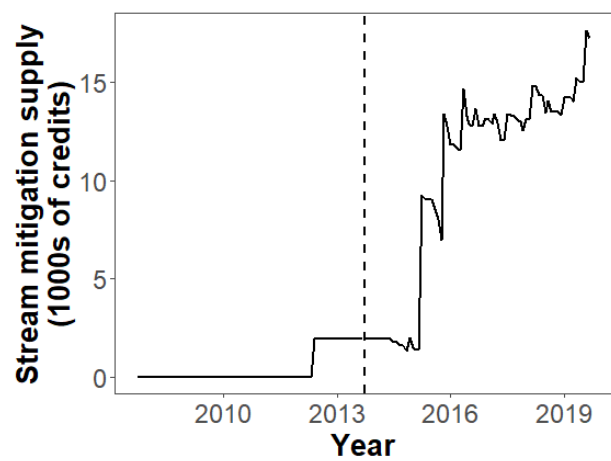
E.



F.



G.



H.

