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Risk and Markets for Ecosystem Services

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ABSTRACT: Market-based environmental regulations (e.g., cap and trade, "payments for ecosystem services") are increasingly common. However, few detailed studies of operating ecosystem markets have lent understanding to how such policies affect incentive structures for improving environmental quality. The largest U.S. market stems from the Clean Water Act provisions requiring ecosystem restoration to offset aquatic ecosystems damaged during development. We describe and test how variations in the rules governing this ecosystem market shift risk between regulators and entrepreneurs to promote ecological restoration. We analyze extensive national scale data to assess how two critical aspects of market structure — (a) the geographic scale of markets and (b) policies dictating the release of credits — affect the willingness of entrepreneurs to enter specific markets and produce credits. We find no discernible relationship between policies attempting to ease market entry and either the number of individual producers or total credits produced. Rather, market entry is primarily related to regional geography (the prevalence of aquatic ecosystems) and regional economic growth. Any improvements to policies governing ecosystem markets require explicit evaluation of the interplay between policy and risk elements affecting both regulators and entrepreneurial credit providers. Our findings extend to emerging, regulated ecosystem markets, including proposed carbon offset mechanisms, biodiversity banking, and water quality trading programs.

INTRODUCTION

Efforts to improve environmental protection policy have sparked widespread interest in market-based environmental policies.[1] These market structures take many forms, including publicly funded payments for ecosystem services (PES), voluntary environmental improvement programs (e.g., voluntary carbon markets), cap and trade programs, and regulated ecosystem offset markets. The United States has begun moving toward "regulated offset markets," which induce demand for ecosystem services (see Chart 1) by requiring environmental conservation, preservation, or restoration (hereafter "conservation") to offset environmental destruction elsewhere. While many have been proposed, in reality, few ecosystem markets are operational, and most lessons for proposed markets are drawn from the well-established markets for aquatic ecosystems — streams and wetlands — in the United States.[2] Because other ecosystem markets include few genuine trades,[1,3] aquatic ecosystem markets provide some of the best primary empirical data for evaluating ecological effects of markets,[4] landscape-scale market trading behavior,[5] and regulatory behavior and decision-making capacity for overseeing ecosystem service markets.[6]

Since 1988, United States water policy has sought to attain "no net-loss" of aquatic ecosystems. Regulations have gradually evolved to require offsets, usually through ecological conservation, for aquatic ecosystems impacted or destroyed during land development (for a review of policies creating this market, see ref 2). For example, if a land developer impacts 10 ha of wetlands

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Chart 1

Box 1: Lexicon for Ecosystem Service Markets

Ecosystem Services: ecosystem functions that benefit society, e.g., nutrient retention, pollination, flood retention.
Ecosystem Markets: markets in which ecosystem services are traded, usually represented as "credits" that are usually quantified using ecological assessment techniques. Markets may involve voluntary participants or participants whose purchases are compelled by regulation.

as part of a project, that developer must provide at least 10 ha of ecological conservation offsets to fulfill the no-net-loss requirement. Developers can either provide ecological conservation themselves or purchase offsets credits from a "mitigation bank". Mitigation banks are private, entrepreneurial firms (but can be public entities) that speculatively conserve large tracts of aquatic ecosystems (largely through restoration), thus creating a bank of compensation 'credits'. These credits can then be sold to multiple individuals seeking to impact aquatic ecosystems elsewhere. Compensatory mitigation, as this regulatory process is known, now comprises the largest tradable ecosystem service market in the United States.[1] Aquatic ecosystem markets trade nearly $3 billion worth of wetland and stream conservation annually[1,7] — nearly 10 times that of the Endangered Species Act habitat programs — conserving approximately 20,000 wetland ha (1999–2003 average), and over 73 km of streams annually.[7] As aquatic ecosystem markets have grown nationwide, their regulation has begun to mirror financial markets, as greater regulatory standards and outside investment have increased transparency and standardization of trades.[8]

It is important to draw a distinction between broader "pollution markets". Pollution markets trade commodities based on pollution weight, volume, or concentration (e.g., water quality trading and the U.S. SO2 market), while ecosystem service markets trade environmental services measured through ecological assessment criteria (including point to nonpoint water pollution). Ecosystem service markets also tend to trade in commodities of area of entire, bundled ecosystems (e.g., area of wetlands or endangered species habitat, length of stream or riparian buffer) rather than particular pollutants (e.g., nitrogen), although this is not a firm distinction. One major ongoing debate concerns the extent to which traded ecosystems should rigidly mimic each other's ecological functions. Trading ecosystems in this 'in-kind' manner creates trade-offs between preserving specific functions and characteristics (e.g., replacing a cold-water stream with a cold-water stream) and inadvertently 'thinning' markets for certain ecosystems,[9] since certain ecosystems (e.g., groundwater fed wetlands) become nonexchangeable due to their inherent uniqueness.

We analyze the factors affecting the prevalence of mitigation banking, which now forms the backbone of the compensatory mitigation industry.[10] We collected data from regulators, industry associations, and performed the first comprehensive survey of the national mitigation banking community. Our goal is to understand the risk considerations in this market and policies that modify risk (whether intentionally or not) and encourage mitigation banking by lowering market entry. Our results have important implications for proposed and emerging analogous ecosystem markets in the U.S. and worldwide.

PROGRAM IMPLEMENTATION: ECOLOGICAL RISK VS ENTREPRENEURIAL RISK

Risk management is an important framework for understanding the success of environmental policy.[11] Risk in aquatic ecosystem markets is derived from two primary forms: regulatory risk and entrepreneurial (or 'banker') risk. Regulatory risk is the likelihood that the goal of no net-loss of ecosystem services will not be met. Given that regulators are enforcing environmental protection regulations, regulatory risk is very much a proxy for ecological risk. The task for regulatory agencies is to minimize ecological risk. Conversely, entrepreneurial risk is the likelihood that conservation activities (production of credits) will not be profitable or worthwhile financial investments.

The primary regulator of aquatic markets is the Army Corps of Engineers (hereafter Corps), the federal agency administering Section 404 of the Clean Water Act.[6] When the Corps permits aquatic ecosystem impacts, they encounter risk that an impact will not be fully offset by the conservation provided by mitigation credits. Net ecosystem loss can result from three types of failure:

a) failure to conserve ecosystems (including the same type of ecosystems) sufficiently or altogether,[2,12]
b) failure to perform timely conservation,[13] or
c) failure to maintain long-term viability of a conserved site.[14]

Addressing these types of failures has been a goal of evolving federal policy, which recently adopted mitigation banking as a technique for reducing some of these ecological risk factors (ref 15 p 19594). Historically, compensation was provided by permittees (i.e., developers) themselves, known as 'permittee-responsible mitigation',[2] or governments, who typically run 'in-lieu fee' programs, which collect and pool fees for aquatic impacts to fund future restoration projects.[16] These approaches typically produced offset sites that imposed substantial regulatory burdens and produced little ecological success (i.e., small, fragmented, and widely dispersed offset sites[2]). Moreover, programs historically did little to ensure that the aquatic ecosystems services being lost were replaced by "equivalent" services (known as 'in-kind' mitigation, which is now an important component of mitigation programs nationwide due to substantial criticism[6,17,18]). Mitigation banks were initially proposed to solve these problems by creating ecosystem credits in advance of impacts,[19] as opposed to a contract for future conservation, thus reducing or eliminating the first two types of failure and associated ecological risk.

However, risk reduction for the regulator shifts risk to the mitigation banker — entrepreneurial risk. Mitigation bankers enter markets with heavy up-front capital investments, including substantial legal and planning work, land acquisition, design, and construction. Mitigation banks also rely on economies of scale, necessitating large, contiguous tracts of wetlands or stream reaches (typically measured in gross terms as hectares [wetlands] or linear meters [streams]), established years in advance, in order to produce credits for sale. Uncertainty around these investments and potential payoffs represent multiple sources of entrepreneurial risk. Mitigation bankers must weigh these investments against potential future demand for ecosystem credits, which are driven by urban, transportation, and land development, and are reliant on local, regional, and macroeconomic growth, i.e., other sources of uncertainty and entrepreneurial risk.

Mitigation bank investments are also weighed against regulator behavior (which institutional economists might consider as "sovereign risk"), which can significantly affect credit demand. While federal policy establishes broad rules, a large degree of autonomy in interpreting and implementing the policy is left to local-level (district) staff within the Corps, a source of variability in how mitigation banks are regulated. For example, regulators can slow the bank approval process, which has the effect of driving up the legal and planning costs. They can also alter the ecological standards required of banks, thereby forcing ad hoc adjustments to restoration investments.

Among the policies that vary by Corps districts is the credit release schedule in that regulators now typically disregard the original definition of banking as advance mitigation and, rather, allow scheduled credit releases whereby sale of a percentage of total bank credits is allowed prior to project completion. In fact, credits can be released by regulators prior to any verification that a bank has met any ecological standards set by regulators (in order to get initial advance credit releases, however, bankers must obtain conservation easements, produce financial assurances, and present detailed project designs and plans[15]). For example, policy may allow a bank to sell 30% of credits prior to achieving any ecological criteria thresholds and the rest in stages, as other criteria are achieved. This practice reduces entrepreneurial risks by increasing ecological risks.

Regulations can also influence credit demand in several ways. The first is through variations in geographic service areas, which are "...the geographic area[s] within which impacts can be mitigated at a specific mitigation bank..." [refs 10 and 15 Part 332.2]. Large geographic service areas increase potential demand for credits; small service areas reduce demand, and like the release schedule, each district has the ability to set its own service area policy. Large service areas allow conservation to be distant from impacts and thus higher ecological risk than small service areas. An interesting side note here is that recent work in Chicago has demonstrated the regulatory consequences of having few suppliers in a given service area, whereby spatial monopolies tend to form for banks.[10] Finally, and perhaps most importantly, although regulators are directed under federal rules to prefer mitigation bank credits (ref 15 Part 332.3(b)(2−6)), they can instruct or allow the use of alternative forms of compensation, which can dramatically reduce the demand for mitigation bank credits.

In sum, there is a distinct trade-off between regulatory risk and entrepreneurial risk. As originally conceived, mitigation banking practice involves substantial entrepreneurial risk. However, regulators' ability to release credits before project completion and adjust geographic service areas has potentially reduced entrepreneurial risk but at the cost of increasing regulatory (i.e., ecological) risk.

METHODS AND DATA

We developed comprehensive national statistics on supply and demand for aquatic ecosystem credits and its variation with market regulation. We collected national scale data on credit demand, including data on federal permitting behavior (FY2006−2008 permits/year; the only permit years for which data were available for each district in similar, comparable formats), and urban and transportation construction, which is measured as annual building permit (U.S. Census building permit data from 2005 to 2008) and transportation construction rates (total lane-km constructed 2000−2007). Road construction was ascertained using 2000−2007 data on road lane-km (a lane-kilometer is one lane-width for a linear km) from the Highway Performance Monitoring System,[20] which includes 12 different road types for each U.S. county, ranging in size from local rural roads to interstate highways.

On the supply side, we collected extensive data on prevalence of banking and wetlands, relative mitigation banking costs, advance credit release policies, and the geographic scale of markets ('service areas'). Estimates of banking activity levels (number of banks and credits produced by banks) in districts were established using data from the RIBITS federal banking database[21] in combination with additional data collected by Madsen et al.,[1] who assembled the first national census of the type, location, and size of stream and wetland mitigation banks. As of September, 2010, 11 districts (Albuquerque, Baltimore, Charleston, Ft. Worth, Los Angeles, Pittsburgh, San Francisco, St. Paul, Tulsa, Walla Walla, and Wilmington) had not been incorporated into the RIBITS regulatory database and therefore could not augment the Madsen et al.[1] database. As of the date of data collection, RIBITS did not reliably account for stream banking at a national level. Our analysis augmented this database with additional, available regulatory data as RIBITS continues to expand into nationwide use. To our knowledge, this is the most comprehensive and representative mitigation banking database available.

Wetland data were collected from the National Wetlands Inventory, established by the U.S. Fish and Wildlife Service.[22] This database is somewhat incomplete in the western U.S. and does not exist for the State of Wisconsin (resulting in substantial incomplete data for the St. Paul District). Data were collected for all available advance credit release policies (as of mid-2009) in the 36 districts of the contiguous United States (not including districts in Hawaii and Alaska). Districts that contained banks, but had no formal advance release policies, were asked for at least four recent mitigation bank instruments (legal documents formally describing the bank and its operation). Here, individual bank early releases were averaged to approximate a de facto formal release policy. Data on service area size were previously collected for all Corps districts by Womble and Doyle.[23]

We also sought direct input on how regulations were interpreted by ecosystem market participants. Between April and May 2009, we administered a Web-based survey to mitigation banking professionals (N = 156, 47.7% response rate[24]) to better understand banker perceptions of recent regulations and the cost framework associated with mitigation banking. Bankers were asked to disaggregate banking costs into nine separate categories, including legal and site approval, land acquisition, baseline ecological monitoring, physical restoration (hydrological/stream channel construction), biological restoration (vegetation establishment), postrestoration ecological monitoring, and site maintenance.

The Corps is divided into 36 regulatory districts in the contiguous United States, each of which operates largely autonomously through the direction of regulatory staff. It is this autonomous rule interpretation that creates nationwide variability in mitigation bank regulation and, essentially, an experiment in how different regulations affect credit production and the number of mitigation bankers entering the market. As a result, data on permitting, credit release policies, and banking prevalence were collected (and only available) at the district level, while wetland prevalence (percentage of total land area) and building and road construction data were spatially aggregated to districts. The aggregation process for wetlands and building and road construction data involved allocating counties into districts, the analysis unit for this study. Counties divided by districts were placed into the district containing the larger part. This process was completed independently by two coders and compared for

Table 1. Regression Analyses on Bank Credits and Number of Banks[a]

	total bank credits (n = 30; R^2= 0.80)			number of banks (n = 32; R^2= 0.46)		
	coef.	std. error	t	coef.	std. error	t
1) % wetland area	129791.80	34714.36	3.74[d]	294.43	73.28	4.02[d]
2) rigorous market area size (dummy)	2991.75	4870.98	0.61	7.09	10.26	0.69
3) % advance release	−77.10	192.27	−0.40	−0.92	0.42	−2.21[c]
4) road construction	0.89	0.41	2.19[c]	0.00	0.00	−0.96
5) building construction	0.23	0.11	1.97[b]	0.00	0.00	0.81
6) regulatory permitting	−0.14	2.56	−0.05	0.00	0.01	0.36
7) 8-digit HUC market area (dummy)	−4298.42	5696.71	−0.75	−0.59	11.97	−0.05
8) intercept	−8309.08	9616.23	−0.86	38.12	20.22	1.89[b]

[a] Case-wise data on total bank credits and early release were only available for 30 districts, while data on bank counts were available for 32 districts. [b] $p < 0.1$. [c] $p < 0.05$. [d] $p < 0.01$.

inter-rater reliability (97.13% match rate), whereby all inconsistencies were rectified.

To understand the relationships between the factors discussed above, we implemented two ordinary least-squares (OLS) regression models to control for intervening effects of building permitting rates, total road construction, regulatory permitting rates, wetland area as percentage of total land area, percentage of credits released before meeting ecological performance criteria, whether a district used HUC-8 boundaries (dummy variable), and whether a district had a strict policy defining bank service areas (dummy variable). The first model regressed these factors on total bank credits constructed in each district, while the second model regressed these factors on the number of individual banks constructed (see Table 1 for variable lists). No significant collinearity was found between variables (VIF < 3.5).

Aquatic ecosystem markets, which are an amalgamation of ecological, regulatory, and entrepreneurial interests, are difficult to understand, partly because data are difficult to acquire and unequivocal conclusions can rarely be drawn from the fragmented data sets. The unavailability of longitudinal data on policy, regulatory decisions, and permitting at the district level precludes the use of regression techniques that could causally link policies to bank and credit establishment (inability to establish or measure Granger causality).[25] Indeed, data for mitigation are notoriously incomplete, and severe data collection and quality issues have hindered past evaluations.[5,26,27]

However, exploratory data analysis and simple linear regression were adequate for understanding broad relationships between market geography, phased credit sale policies, and banking prevalence at the district level. Thus, we utilized available information that could be used to indicate supply and demand sites of mitigation and how these responded to regulatory variability. Although our statistical analysis is noncausal, it represents a critical analysis for understanding market dynamics, which would otherwise necessitate years of wide-scale and costly *posthoc* data collection by the Corps.

■ RESULTS

National Development Patterns. Average aquatic impact permitting rates ranged between 376 per year in the New Orleans district and 6,350 per year in the Jacksonville District (Figure 1A), both of which are wetland-dense regions (Figure 1B). New Orleans has historically had some of the highest permit counts in the nation, but development and/or permitting activities were largely curtailed following Hurricane Katrina in August 2005 (immediately preceding FY 2006). In FY 2008, the New Orleans District granted 578 permits, signaling an upward climb in post-Katrina permitting.

Between 2000 and 2007, nearly 366,000 km of roads were constructed in the United States (Figure 1C and D), primarily in the Southwest (Los Angeles and Albuquerque Districts), the upper Great Plains (Omaha, St. Paul, and Kansas City Districts), and the Southeast (Jacksonville, Wilmington, and Savannah Districts).

High growth regions, including the Jacksonville, Los Angeles, Sacramento, and Ft. Worth districts saw high rates of building construction, particularly single family housing, which accounted for the vast majority of building permitting in all measured years in these regions. Slow-growing areas in central-southern and midwestern districts, including Memphis, Little Rock, St. Louis, and Pittsburgh, had the lowest average building permit rates.

Variability in Mitigation Banking. There were approximately 201 new banks since the publication of Madsen et al.,[1] yielding a total of 994 banks containing 379,956 wetland credits within the contiguous U.S (Figure 1E; the Madsen et al.[1] data set contained information on N = 809 total banks, 793 of which contained useful location information). Banking was particularly prevalent in the Southeast, and while some Southern districts (e.g., Ft. Worth, Galveston) do not contain a large number of banks, they have accrued extensive wetland credit inventories in large banks (i.e., few large banks).

All districts with operating banks allowed early credit releases, ranging from 15 to 60% of total bank credits (*mode* = 30, *mean* = 36.7%; Figure 1F). As of August 2009 (when credit release data collection was finalized), the Albuquerque, Tulsa, Pittsburgh, and New England Districts did not contain any federally authorized mitigation banks (they still may contain state or locally authorized banks). All districts without formal policies allowed advance releases to multiple banks, often at very similar rates, thereby creating a *de facto* advance release policy.

Although wording and the specific thresholds for staged credit release varied among districts, a common series of steps allowed incremental credit releases as banks increasingly achieved ecological standards. Even so, there was significant variation between districts: the New Orleans District allowed the highest fraction of credits released prior to satisfying ecological performance criteria (to the left of the vertical dashed line), while other districts allowed only 30% (Figure 2 Left Panel). The Charleston District had a larger number of stages after which credits could be

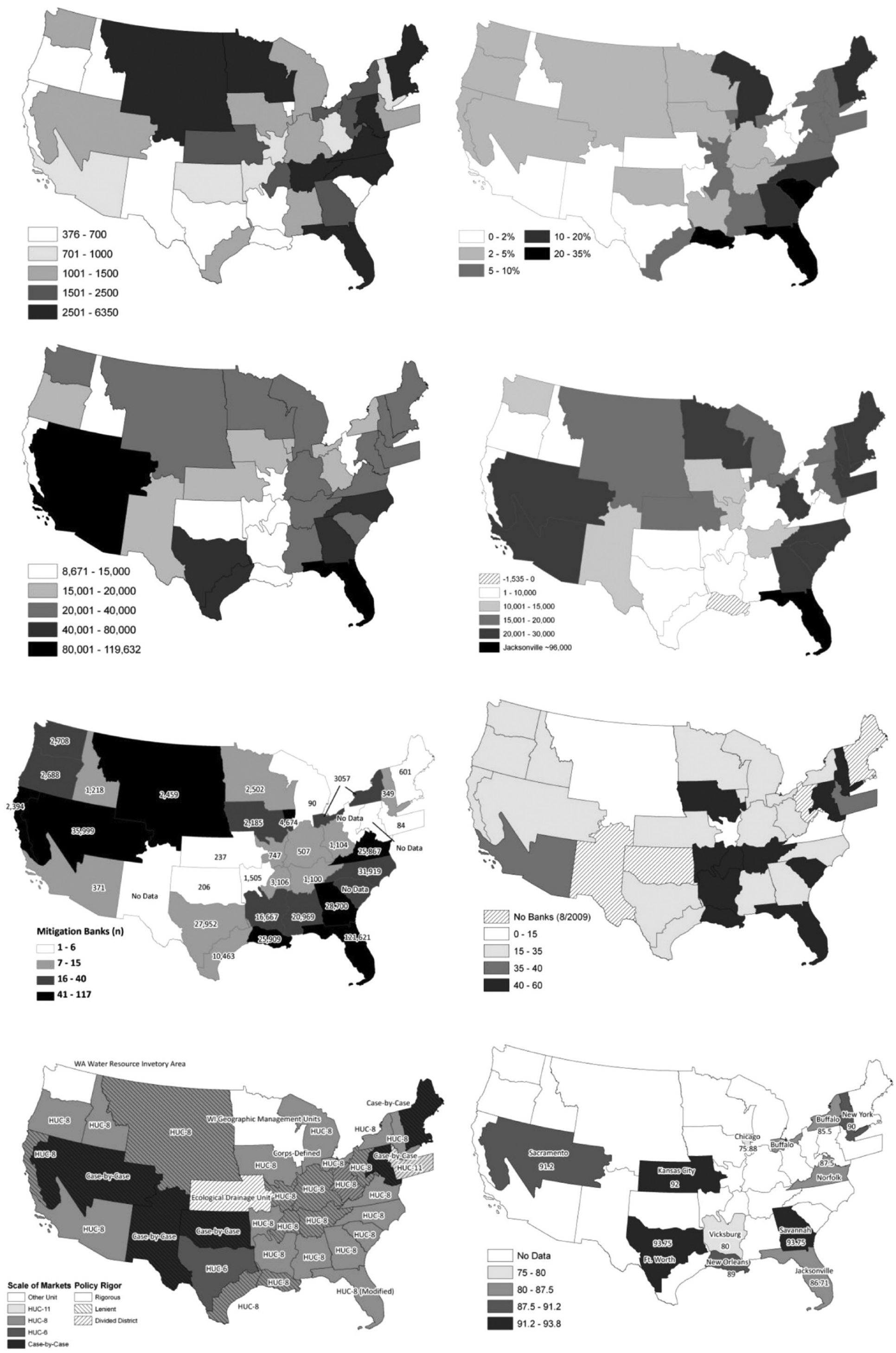

Figure 1. **Panel A:** Total impact permits granted, by Regulatory District, **Panel B**: Relative Wetland Density (% of total district land area), **Panel C:** Building permits granted (Avg. 2005−2008), **Panel D:** Total lane km construction (2000−2007), **Panel E:** Number of mitigation banks and total credits (enumerated on map), **Panel F:** Advance release rates (% of total credits in a bank), **Panel G:** Geographic scale and rigor of policies determining bank market size ('service area'), policy rigor is measured as rigorous, lenient, or a mix ('divided districts'), **Panel H:** Costs to gain access to advance release credits (% of total bank construction costs).

released (incrementally over five years of monitoring and bank closeout), although the New Orleans District required 15 years of monitoring and successful ecological establishment in order to sell the final 20% of bank credits. As shown in the Right Panel of Figure 2, there was also significant variation between districts as the required investments of each incremental step can incur very different cost structures across districts. In the Forth Worth District, for example, a much higher percentage of the costs (83.8%) are generated prior to meeting ecological performance thresholds than in the Chicago District (35.9%).

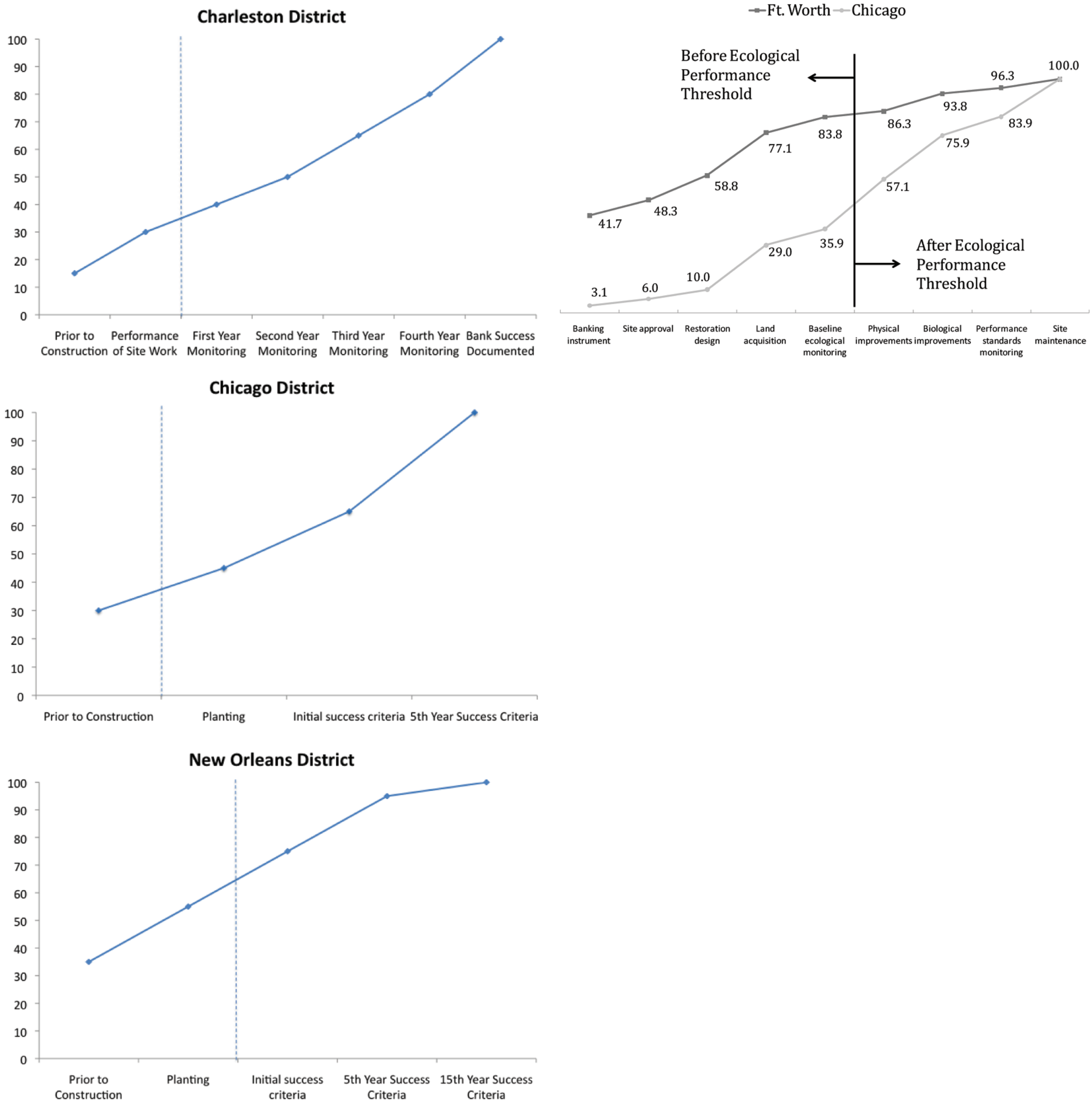

Figure 2. Left Panel: Examples of Credit Release Stages for Mitigation Banks ('Credit Release Schedules') with pre-ecological threshold marked with a dashed line (percentage of total credits on vertical axis). For example, bankers can sell 30% of the units in a Chicago wetland bank to developers before any ecological threshold has been met. **Right Panel:** Comparison of Bank Creation Cost Trajectories for Two Example Districts.

The lowest advance credit release rates occurred in the Norfolk, Omaha, and St. Louis Districts, which allowed only 15% of credits to be sold prior to meeting ecological performance standards. One quarter of the districts (n = 9) granted a 30% advance credit release, and nearly one-half (n = 16) allowed 30−35%. The highest advance releases (60%) occurred in the New York and Rock Island Districts.

Geographic service area regulation also varied from restricting transactions to a single watershed, basin, eco-region, or other government-defined boundary, or any combination thereof (Figure 1G). Most districts (~70%) relied on 8-digit watersheds (HUC[28]) to define market sizes (HUC-8 watersheds are ~1,800 km^2). While 'rigorous' districts employed strict service area policies, most districts (~64%) were more 'lenient,' allowing case-by-case variations. The Kansas City, Huntington, and Philadelphia Districts are divided regarding their enforcement of stringent service area boundaries. Many districts also use multiple geographic boundaries to determine service areas, including physiographic or EPA defined eco-regions,[29] state-defined service areas (and watershed management or resource inventory areas), counties, or cities.

Response rates for cost-related survey questions were low (18.7%), as mitigation bankers were reluctant to reveal bank construction cost information, even in confidential, aggregate forms; this reluctance is consistent with other studies of banker investment costs (e.g., refs 30 and 31). Responses yielded information for 11 districts (N = 29; Panel H of Figure 1) in which 75.9% to 93.8% of total costs were expended on activities prior to reaching performance standards, which we defined to include legal and planning costs, land acquisition, restoration design and implementation, and baseline ecological monitoring (see Right Panel of Figure 2 for examples of incremental cost structures in Forth Worth and Chicago). Although these results demonstrate substantial variation in cost structures throughout the country, due to the low response rate received, we must note that we did not use the cost-related survey data in our regression analyses.

Integrating Demand and Policy with Bank Prevalence. Regression analyses (Table 1) showed that advance credit release rates had no significant relationship to total bank credits and an inverse relationship with the prevalence of individual banks (a proxy for number of bank firms). Additionally, there was no relationship between bank prevalence or credit production and policies rigorously enforcing a geographic service area size or mandating a common and fairly large service area (the 8-digit hydrological unit[28]). Again, we note that lack of time series data precludes causally focused regression analysis. However, studying the relationships between policy and outcomes is still meaningful for drawing lessons about landscape-scale market activity and incentives.

The Environmental Paradox of Third-Party Offset Production. U.S. aquatic ecosystem markets give us some insight into how emerging markets might balance regulatory risk (a proxy for ecological risk) and entrepreneurial risk. If regulators seek to facilitate markets, they may begin by allowing advance credit sales or larger geographic market areas, thereby absorbing risk from entrepreneurs. The tension currently afflicting these ecosystem market policies lies between the goal of incentivizing credit supplier market entry versus ensuring that high quality offsets occurs well in advance of impacts and where they are needed most. However, our findings suggest that increasing ecological risk by allowing the early sale of credits, within a range of 15−60%, does not increase market activity and therefore cannot be justified for that reason alone. Early releases above or below this range may or may not have an effect. Our analysis was forced to consider the average credit release rates for each district and therefore does not allow us to determine if regulators consistently provide standardized releases that are independent of restoration project effort or quality.

Economic theory suggests that if mitigation bankers encounter significant market entry barriers (e.g., high investment costs, uncertain profit margins, and credit demand[32]), and there is no way to overcome these barriers through advance credit sales, bankers will be less likely to locate in a given market area. In the case that credit suppliers fail to enter markets, credit purchasers would be forced to seek alternative techniques for creating conservation; systemic ecological and implementation failure has often plagued these alternative techniques.[2]

Our data show that regulators, in an attempt to attract more bankers, have typically adopted policies that allow bankers to sell a large fraction of their credits prior to demonstrating establishment of ecological functions and over a wide array of geographic service areas. However, our results do not demonstrate a significant link between these policies that attempt to incentivize market entry and actual rates of market entry, as measured by number of banks and credit production. Rather, market entry is primarily related to regional geography (the prevalence of aquatic ecosystems) and regional economic growth (construction rates), i.e., demand for offsets. It appears that policies intended to increase market entry have not overcome the fundamental constraints created by the regional landscapes and economic dynamics that ultimately drive market demand.

This study goes as far as possible to understand ecosystem markets in the U.S. with available national data. In order for further ecosystem market research to be possible, regulatory records must be more complete, understandable (e.g., few districts maintain high quality geo-spatial data), and contain time-indicated information on regulatory decision-making.[5] Analyzing additional markets (e.g., carbon, endangered species habitat) in similar detail is not possible given the current scarcity of basic data. The lack of national, time-series market data (e.g., date of policy adoption, date of bank establishment) inhibits direct assertions about absolute causal linkages between individual district policies and market entry patterns.

Our findings pose several questions that need to be addressed by any type of ecosystem service market regulatory structure: What are the trade-offs of different forms of risk and failure when using markets for environmental protection? If we discover and quantify these trade-offs, what should regulators be willing to risk in order to enhance market entry?

The crux of the matter in regulating ecosystem markets that rely on private investment in ecosystem conservation involves determining whether policies that incentivize market entry are irrelevant in comparison to broader economic and ecological forces determining market behavior. In fact, policies that incentivize market entry may distort market participation, providing divergent incentives to different types of credit suppliers. This raises the more problematic issue of whether regulatory policies are actually incentivizing different qualities of conservation. The actual functional quality of ecosystem credits produced is an aspect of ecosystem markets that we have not addressed, nor has it been systematically addressed elsewhere (the closest is perhaps the 2005 U.S. Government Accountability Office[33] evaluation of seven districts, where major problems were found with permit evaluations and regulatory processes), but is of critical importance and interest to both regulators and the offset industry.[2] Restoration 'quality' can be thought of as the functional quality of ecological restoration in terms of gains to physical, chemical, or biological integrity; this is often different from the definition used by regulators which more often measures conservation actions performed (process-driven) rather than functional uplift attained (outcome-driven; see ref 14 for an empirical study of this disconnect). Moreover, the time frame during which sales occur (particularly advance credit sales) and ecological function is fully established is often very different.[31]

By allowing advance release, regulators sacrifice some precision in their ability to assess the quality of offset projects in exchange for more bankers that enter markets and (hopefully) produce higher quality credits than would be created using other mitigation methods. However, it is possible that policies incentivizing banker entry could disproportionally benefit mitigation bankers that create low quality credits. This process, known in economics as 'adverse selection',[34] occurs when buyers and sellers have asymmetric information (i.e., bankers know more about their own abilities to produce credits than regulators).

Under adverse selection, low quality credits producers will benefit under an incentive structure that lowers market entry barriers established to limit ecological risk. Assuming that market entry barriers are much higher for the creation of high quality than for low quality credits, then low quality credit producers have the most to gain from policies that lower the cost of market entry (creating high quality offsets involves greater expenditures in finding and obtaining ecologically valuable areas to conserve and elevated levels of expertise in designing and performing restoration). If regulators and credit purchases are unable to distinguish bankers based on their capability for creating high quality credits, or lack the ability to discriminate between bankers based on past conservation experience, then incentivizing market entry by decreasing entry costs may inadvertently incentivize low quality credit production.[24] Example of the consequences of low quality credit production include bank failures, such as the Northlakes Park Bank in Florida, and Virginia's Fort Lee Mitigation Bank, which sold nearly all total bank credits even though they both failed to establish proper hydrology.[35]

Given the increased use of market mechanisms for environmental management, scientists and policy makers need to increasingly view environmental conservation as a coupled ecological-economic system. Thus, the future of conservation may be affected less by species interaction and biogeochemical cycles than by local regulatory discretion, distorted incentives, market entry, and asymmetric information.

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REFERENCES

(1) Madsen, B.; Carroll, N.; Brands, K. M. *State of Biodiversity Markets: Offset and Compensation Programs Worldwide*; Ecosystem Marketplace: Washington, DC, 2010.

(2) NRC, *Compensating for Wetland Losses Under the Clean Water Act*; National Academy Press: Washington, DC, 2001.

(3) EPA, EPA Water Quality Trading Evaluation Final Report; U.S. Environmental Protection Agency: Washington, DC, 2008.

(4) Palmer, M. A.; Filoso, S. Restoration of Ecosystem Services for Environmental Markets. *Science* **2009**, *325* (5940), 575–576.

(5) BenDor, T.; Sholtes, J.; Doyle, M. W. Landscape Characteristics of a Stream and Wetland Mitigation Banking Program. *Ecol. Appl.* **2009**, *19* (8), 2078–2092.

(6) Hough, P.; Robertson, M. Mitigation under Section 404 of the Clean Water Act: where it comes from, what it means. *Wetlands Ecol. Manage.* **2009**, *17* (1), 15–33.

(7) ELI, *Mitigation of Impacts to Fish and Wildlife Habitat: Estimating Costs and Identifying Opportunities*; Environmental Law Institute: Washington, DC, 2007.

(8) Nolles, K. *Lessons on the Design and Implementation of Environmental Markets from the Financial markets (SEELab Working Paper: WP20060707)*; SIRCA Experimental Economics Laboratory: Sydney, Australia, 2006.

(9) Salzman, J.; Ruhl, J. B. Currencies and the Commodification of Environmental Law. *Stanford Law Rev.* **2000**, *53*, 607–694.

(10) Robertson, M. M.; Hayden, N. Evaluation of a Market in Wetland Credits: Entrepreneurial Wetland Banking in Chicago. *Conserv. Biol.* **2008**, *22* (3), 636–646.

(11) Yin, H.; Pfaff, A.; Kunreuther, H. Can Environmental Insurance Succeed Where Other Strategies Fail? The Case of Underground Storage Tanks. *Risk Anal.* **2011**, *31* (1), 12–24.

(12) Cole, C. A.; Shafer, D. Section 404 Wetland Mitigation and Permit Success Criteria in Pennsylvania, USA, 1986−1999. *Environ. Manage.* **2002**, *30* (4), 508–515.

(13) Gutrich, J. J.; Hitzhusen, F. J. Assessing the Substitutability of Mitigation Wetlands for Natural Sites: Estimating Restoration Lag Costs of Wetland Mitigation. *Ecol. Econ.* **2004**, *48*, 409–424.

(14) Reiss, K. C.; Hernandez, E.; Brown, M. T. Evaluation of Permit Success in Wetland Mitigation Banking: A Florida Case Study. *Wetlands* **2009**, *29* (3), 907–918.

(15) Corps, EPA Compensatory Mitigation for Losses of Aquatic Resources; Final Rule. http://www.epa.gov/owow/wetlands/pdf/wetlands_mitigation_final_rule_4_10_08.pdf (accessed 12/28/08).

(16) Wilkinson, J. In-lieu fee mitigation: coming into compliance with the new Compensatory Mitigation Rule. *Wetlands Ecol. Manage.* **2008**, *17* (1), 53–70.

(17) Bedford, B. L. The Need to Define Hydrolic Equivalence at the Landscape Scale for Freshwater Wetland Mitigation. *Ecol. Appl.* **1996**, *6* (1), 57–68.

(18) Race, M. S.; Fonseca, M. S. Fixing Compensatory Mitigation: What Will it Take? *Ecol. Appl.* **1996**, *6* (1), 94–101.

(19) Corps, EPA Federal Guidance for the Establishment, Use and Operation of Mitigation Banks. http://www.epa.gov/owow/wetlands/guidance/mitbankn.html (accessed 6/13/2005).

(20) HPMS, *Highway Performance Monitoring System (HPMS)*; U.S. Federal Highway Administration: Washington, DC, 2009.

(21) Corps, *Regional Internet Bank Information Tracking System (RIBITS)*; U.S. Army Corps of Engineers, Engineering Research and Development Center (Environmental Laboratory): Vicksburg, MS, 2008.

(22) Tiner, R. NWI Maps: Basic Information on the Nation's Wetlands. *BioScience* **1997**, *47* (5), 269.

(23) Womble, P.; Doyle, M. W. Setting Geographic Service Areas for Compensatory Mitigation Banking. *Natl. Wetlands Newsl.* In press.

(24) BenDor, T.; Riggsbee, A. A survey of entrepreneurial risk in U.S. wetland and stream compensatory mitigation markets. *Environ. Sci. Policy* **2011**, *14*, 301–314.

(25) Granger, C. W. J. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* **1969**, *37* (3), 424–438.

(26) BenDor, T.; Brozovic, N.; Pallathucheril, V. G. Assessing the Socioeconomic Impacts of Wetland Mitigation in the Chicago Region. *J. Am. Plann. Assoc.* **2007**, *73* (3), 263–282.

(27) Strand, M. Law and Policy: "Information, Please". *Natl. Wetlands Newsl.* **2010**, *32* (3), 24.

(28) Seaber, P. R.; Kapinos, F. P.; Knapp, G. L. *Hydrologic Unit Maps: U.S. Geological Survey*; U.S. Geological Survey: Washington, DC, 1987.

(29) EPA, *Ecoregions of North America*; U.S. Environmental Protection Agency: Washington, DC, 2010.

(30) EEP, *Ecosystem Enhancement Program 2004−2005 Annual Report*; N.C. Ecosystem Enhancement Program: Raleigh, NC, 2005.

(31) Robertson, M. M. Emerging Ecosystem Service Markets: Trends in a Decade of Entrepreneurial Wetland Banking. *Frontiers Ecol. Environ.* **2006**, *4* (6), 297–302.

(32) Hallwood, P. Contractual difficulties in environmental management: The case of wetland mitigation banking. *Ecol. Econ.* **2007**, *63*, 446–451.

(33) GAO, *Corps of Engineers Does Not Have an Effective Oversight Approach to Ensure That Compensatory Mitigation Is Occurring: Report to the Ranking Democratic Member, Committee on Transportation and Infrastructure, House of Representatives*; U.S. Government Accountability Office: Washington, DC, 2005.

(34) Akerlof, G. A. The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *Q. J. Econ.* **1970**, *84* (3), 488–500.
(35) McElfish, J. M.; Nicholas, S. Structure and Experience of Wetland Mitigation Banks. In *Mitigation Banking: Theory and Practice*; Marsh, L. L., Porter, D. R., Salvesen, D. A., Eds.; Island Press: Washington, DC, 1996.