Journal of Business and Management Studies
ISSN: 2709-0876
DOI: 10.32996/jbms
Journal Homepage: www.al-kindipublisher.com/index.php/jbms

JBMS

AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Synthesizing the Green Value Chain: A Systematic Review of Vetiver Bioengineering, Coastal Entrepreneurship, and Consumer Valuation in the U.S. Green Economy

Md Raihanul Islam[1]✉, Bart Weathington[2], and Morgan Bryant[3]
[1]Graduate Student, Raj Soin College of Business, Department of Marketing Analytics & Insights, Wright State University, Ohio, USA
[2]Graduate Student, College of Business and Economic Development, Department of Entrepreneurship, University of Southern Mississippi, Mississippi, USA
[3]Graduate Student, College of Media Strategic Brand Communication, Department of Business Analytics, University of Illinois Urbana-Champaign, Illinois, USA
Corresponding Author: Md Raihanul Islam, **E-mail**: islam.215@wright.edu

| ABSTRACT
The accelerating trajectory of climate change, characterized by rising sea levels, intensifying precipitation events, and coastal erosion, has exposed the critical vulnerabilities of traditional "gray" infrastructure in the United States. While the paradigm shift toward Nature-Based Solutions (NbS) offers a promising pathway for resilience, the commercial and operational integration of these technologies remains fragmented. This research paper presents an exhaustive systematic review of the "Green Value Chain" a conceptual framework linking the biotechnical engineering performance of the Vetiver System (VS), the emerging business models of coastal entrepreneurship, and the socio-economic dynamics of consumer valuation. Focusing specifically on the sterile, non-invasive 'Sunshine' genotype of Chrysopogon zizanioides, the analysis synthesizes geotechnical data confirming Vetiver's capacity to increase soil shear strength by 30–40% and stabilize slopes in high-plasticity clays. Economically, the review establishes that while green infrastructure often entails higher initial stewardship costs compared to the "build-and-forget" model of gray infrastructure, it delivers superior benefit-cost ratios over decadal lifecycles through avoided capital replacement and ecosystem service generation. However, the market penetration of Vetiver bioengineering is severely constrained by "aesthetic friction"—a deep-seated consumer preference for manicured landscapes and hardened shorelines, driven by social norms and risk misperceptions. By integrating findings from U.S. Army Corps of Engineers studies, coastal homeowner surveys, and bioengineering field trials, this paper proposes a "Nurse Crop Succession" framework. This model positions Vetiver not as a climax monoculture but as a temporary biological scaffold that facilitates the establishment of native dune and riparian ecosystems, thereby reconciling immediate engineering requirements with long-term ecological restoration goals. The findings suggest that unlocking the U.S. green economy requires a tripartite evolution: the standardization of bio-technical certification to unlock FEMA Community Rating System (CRS) incentives, the maturation of "Resilience-as-a-Service" business models, and a targeted cultural shift in how coastal protection is visualized and valued.

| KEYWORDS

Vetiver System, Green Value Chain, Bioengineering, Coastal Entrepreneurship, Nature-Based Solutions, Soil Stabilization, Consumer Valuation, Resilience Economics, Aesthetic Friction, Nurse Crop Succession.

| ARTICLE INFORMATION

ACCEPTED: 01 January 2026 **PUBLISHED:** 13 January 2026 **DOI:** 10.32996/jbms.2026.8.2.1

1. Introduction

The United States is at a pivotal moment in its approach to managing soil stability, flood risk, and coastal erosion (Daro Justine & Seenath, 2025). For decades, the dominant approach has been gray infrastructure, such as concrete, steel, and riprap, that forces a rigid boundary between development and natural systems. These structures can work under stable conditions, but they are increasingly fragile under climate-driven extremes, often reflecting wave energy, disrupting ecosystems, and accumulating massive long-term maintenance and replacement costs (Adkisson, 2021; Lovseth, 2018). As failures and accelerating land loss become more common, agencies and engineers are shifting toward Nature-Based Solutions and a broader, resilience-focused green economy (Dunlop et al., 2024). However, scaling these solutions is challenging because living systems are variable and context-dependent, unlike standardized materials and mature supply chains (Martin et al., 2025a).

A promising tool within this shift is the Vetiver System, built around Chrysopogon zizanioides and, in the United States, the sterile "Sunshine" genotype to avoid invasiveness (Darajeh et al., 2019; Luu, 2010). Vetiver functions like a living soil nail: stiff shoots slow surface flows, while a dense vertical root system can reach roughly 3 to 4 meters, mechanically reinforcing soil and resisting shear (Huang et al., 2024; Jandyal & Shah, 2024; G. Wang et al., 2020a). Reported root tensile strength averages about 75 MPa, making it comparable in function to reinforcement used in civil works, and it has shown potential for highway slope stabilization and coastal dune protection in parts of the Southeast, the Gulf Coast, and Hawaii (Mohammad et al., 2022; Noorasyikin & Zainab, 2016). Even with this technical promise, Vetiver remains underused relative to hard armoring or more familiar native plant options (Barcellos-Silva et al., 2025).

This paper argues that the main barrier is fragmentation across the green value chain: engineering validation, contractor entrepreneurship, and end-user acceptance are not aligned. Engineers need reliable, codified design guidance; contractors struggle to sell benefits that are often realized as avoided future losses; and property owners can resist taller, denser buffers due to aesthetic preferences. To address this, the study synthesizes U.S.-relevant evidence on Vetiver performance and design needs, evaluates lifecycle economics and ecosystem-service value against hardening alternatives, and analyzes adoption barriers across regulation, business models, and consumer psychology. The scope is limited to the United States, focusing on viable climates in USDA Hardiness Zones 8 to 11 and the constraints of the sterile Sunshine genotype, and it concludes by proposing a nurse crop succession strategy to connect near-term bioengineering stability with longer-term native restoration.

2. Literature Review

2.1 Bioengineering Mechanics: The Science of Soil-Root Interaction

The foundational literature of bioengineering posits that vegetation influences slope stability through two primary mechanisms: mechanical reinforcement and hydrological modification (Kumar et al., 2025; Lann et al., 2024).

Mechanical Reinforcement:

Classical soil mechanics relies on the Mohr-Coulomb failure criterion, where shear strength is a function of cohesion and friction angle (Shen et al., 2018; Xie et al., 2024). The literature indicates that plant roots contribute to effective cohesion (c') (Chok et al., 2015). Chrysopogon zizanioides is exceptional in this regard due to its high root biomass density and tensile strength (Chok et al., 2015; Rajamanthri et al., 2021). Direct shear tests reported in recent studies indicate that Vetiver roots can increase the internal friction angle of soils significantly, from ~31º to ~40º in specific unsaturated conditions (Mahannopkul & Jotisankasa, 2019b). The roots intersect potential failure planes, acting as anchors that transfer shear stress from the soil to the root fibers. This "root cohesion" has been quantified in various studies to add between 1.0 and 18 kPa to soil shear strength, depending on root density and diameter (Mahannopkul & Jotisankasa, 2019b; Veylon et al., 2015). The tensile strength of Vetiver roots (75 MPa) is frequently cited as a benchmark, superior to many temperate woody species and comparable to synthetic geotextiles (G.-Y. Wang et al., 2020).

Hydrological Modification:

Beyond mechanics, the literature emphasizes the role of Vetiver in matric suction. Soil saturation is a primary trigger for slope failure, as positive pore water pressure reduces effective stress (Cueva et al., 2025; Lan et al., 2025; Zheng et al., 2020). Vetiver acts as a biological pump, extracting moisture through transpiration (Na Nagara et al., 2024). Research on the Yazoo clays of Mississippi, a highly expansive and problematic soil formation, demonstrates that Vetiver hedges significantly reduce soil moisture fluctuation at depth, thereby mitigating the shrink-swell cycles that destabilize highway embankments (Brister, 2022; Khan et al., 2023; Rahman et al., 2024). This hydro-mechanical coupling is a critical advantage over inert structures like riprap, which provide weight but do not actively manage soil moisture regimes (P. Chen et al., 2022; Zhang et al., 2023).

2.2 The Restoration Economy and Coastal Entrepreneurship

The emerging field of "Restoration Economics" frames ecological restoration not as a cost center but as a productive industry (Iftekhar & Polyakov, 2021).

Economic Scale and Impact: Recent reports indicate that the U.S. restoration economy generates substantial direct and indirect economic output estimated at over $76 billion annually, supporting more jobs than the coal mining, steel, or logging industries combined (Morgan, 2025). This sector includes planning, engineering, earthmoving, and nursery production. For coastal entrepreneurs, the business case is increasingly driven by "avoided cost" logic (Kelmenson et al., 2016). NOAA and other agencies have published extensive data showing that for every $1 invested in disaster mitigation and wetland restoration, the U.S. saves approximately $6 to $7 in future disaster recovery costs (Noaa, 2025).

Supply Chain Dynamics: The literature identifies a unique constraint in the Vetiver supply chain: the requirement for clonal propagation (Krol et al., 2025). Because the 'Sunshine' genotype is sterile (non-invasive), it cannot be grown from seed. This necessitates a network of vegetative nurseries (Rahman et al., 2024). In Hawaii and Puerto Rico, this infrastructure is relatively mature, with suppliers like Agriflora Tropicals and Vetiver Farms Hawaii providing verified sterile stock (Jindapunnapat et al., 2018; Joy & Evans, 2012; Panja et al., 2021). However, on the U.S. mainland, the supply chain is thinner, creating logistical bottlenecks for large-scale infrastructure projects that require hundreds of thousands of slips (Meki et al., 2020). This biological constraint is a key barrier to scaling, distinguishing bioengineering from the infinite scalability of manufactured concrete blocks (Barnard et al., 2013a; Clark et al., 2023; Gittman et al., 2016).

2.3 Consumer Valuation and the Aesthetics of Resilience

The final node of the value chain, the consumer, is the subject of extensive socio-economic research (Shah & Asghar, 2023).

The "Neighbor Effect" and Hardening Bias: Studies in North Carolina and the Chesapeake Bay region have documented a strong "neighbor effect" in shoreline hardening (Stafford, 2020). If adjacent properties have bulkheads, a homeowner is significantly more likely to install a bulkhead, regardless of the site's erosion risk (Gittman et al., 2021). This is driven by a perception of "permanence" and "neatness." The literature describes a widespread "hardening bias," where consumers equate concrete with safety and vegetation with vulnerability (Li et al., 2025).

Aesthetic Friction: "Aesthetic friction" refers to the conflict between the ecological necessity of complex, structured vegetation and the cultural preference for simplified, manicured landscapes (Wetli, 2024; Zhu, 2023). Survey data suggest that while coastal residents value "nature," their definition of nature often centers on a scenic view of the water, unobstructed by tall vegetation (Shi et al., 2025; Van Berkel et al., 2018). Vetiver, which grows as a tall (1-2m) hedge, can obstruct views if not managed, potentially clashing with the aesthetic values of coastal property markets (Hasan et al., 2017). However, the literature also suggests that when functional benefits (e.g., erosion control, insurance savings) are clearly articulated, Willingness to Pay (WTP) for green infrastructure increases (Imamura et al., 2023; T.-G. Kim & Petrolia, 2013; Netusil et al., 2022; Zalejska-Jonsson et al., 2020).

3. Methodology

3.1 Systematic Review Design

This research employs a systematic review methodology adapted for a multi-disciplinary synthesis. The approach integrates quantitative geotechnical data, qualitative socio-economic surveys, and market analysis reports to construct a holistic view of the Vetiver value chain.

Data Sources: The review draws upon a curated dataset comprising:

1. **Peer-Reviewed Journals:** *International Journal of Geomechanics*, *Ecological Engineering*, *Coastal Management*, *Journal of Sustainable Development*.
2. **Government Reports:** Technical Notes from the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC); Technical Guides from the USDA Natural Resources Conservation Service (NRCS); Reports from NOAA's Office for Coastal Management and FEMA.
3. **Industry Literature:** Case studies from The Vetiver Network International (TVNI), nursery propagation guides, and restoration contractor portfolios.

Inclusion Criteria:

- **Subject:** *Chrysopogon zizanioides* (sterile 'Sunshine' genotype); living shorelines; coastal bioengineering; consumer valuation of green infrastructure.
- **Geography:** United States (Continental, specifically Gulf Coast and Florida), Hawaii, Puerto Rico. International data (e.g., Vietnam, Australia) is included only for comparative technical validation where U.S. data is sparse.
- **Timeframe:** 1990–2025, capturing the modern era of bioengineering and recent climate adaptation policies.

3.2 Analytical Framework: The Value Chain Integration Model

The collected data is synthesized using a "Value Chain Integration Model," which dissects the technology's journey through three phases:

1. **Phase I: Technical Validation (Does it work?)**
   - Analysis of root tensile strength, shear strength improvement, and hydrological performance.
   - Review of failure modes and climatic limitations (cold tolerance).
2. **Phase II: Economic Viability (Is it profitable?)**
   - Comparative analysis of installation and lifecycle costs (Green vs. Gray).
   - Evaluation of ecosystem service valuation (carbon, nutrient cycling).
   - Assessment of supply chain logistics and entrepreneurial barriers.
3. **Phase III: Social Acceptance (Is it wanted?)**
   - Synthesis of consumer preference surveys regarding shoreline management.
   - Analysis of aesthetic perceptions and risk communication.
   - Review of policy incentives (FEMA CRS, grants).

3.3 Limitations of the Review

A primary limitation is the fragmented nature of long-term longitudinal data for Vetiver in the continental U.S. While short-term studies (2-5 years) are available, decadal performance data are less prevalent than in tropical regions. Furthermore, economic data is highly site-specific; costs for "living shorelines" vary wildly based on local labor rates, material availability, and site accessibility. The review addresses this by focusing on relative cost ratios and trends rather than absolute pricing.

4. Findings:

Technical Efficacy of Vetiver Bioengineering

The technical review indicates that vetiver-based soil bioengineering is a mature, high-performance option for targeted U.S. use cases, with documented success on expansive clay highway and levee slopes and demonstrated potential for sand-dune stabilization in suitable warm-climate settings when properly designed and managed (Mickovski & van Beek, 2009; Rahman et al., 2024; G.-Y. Wang et al., 2020).

4.1 Geotechnical Performance in Cohesive Soils

The most robust U.S. data emerges from the stabilization of highway embankments on expansive clays, particularly the Yazoo Clay formations in Mississippi (Khan et al., 2019; Rahman et al., 2024).

Mechanism of Stabilization: Research conducted by Jackson State University and the USACE highlights the dual-action stabilization of Vetiver. In highly plastic clays, which are prone to shallow slope failures due to shrink-swell cycles, Vetiver roots act as vertical reinforcement (Rahman et al., 2024; Zalejska-Jonsson et al., 2020).

- *Shear Strength:* Direct shear tests on Vetiver-reinforced soil samples demonstrate a significant increase in the internal friction angle (ϕ) and apparent cohesion (c). One key study reported an increase in the internal friction angle from ~31.7° in bare soil to ~40.6° in Vetiver-rooted soil (Garzón et al., 2020).
- *Factor of Safety (FoS):* Numerical modeling of slope stability indicates that the inclusion of Vetiver roots can increase the FoS by 20% to over 50%, depending on the root density and depth. The roots effectively "suture" the active zone of the slope (typically the top 1.5–2 meters) to the more stable subsoil (Rahman et al., 2024).

Hydrological Regulation: Field monitoring, utilizing moisture sensors and LiDAR in Mississippi, confirmed that Vetiver hedges maintain a more consistent soil moisture regime compared to bare slopes (Rahman et al., 2024). During intense rainfall, Vetiver-covered slopes can reduce effective rainwater infiltration into the soil mass and help maintain matric suction, leading to smaller or delayed pore-water pressure increases compared with bare slopes, which lowers the likelihood of rainfall-triggered shallow failures (Rahardjo et al., 2014; G. Wang & Sassa, 2003). Overall, vetiver supports slope stability through two coupled pathways: root reinforcement and rainfall regulation via plant water uptake, as well as changes to soil hydraulic behavior, which helps preserve suction and reduce destabilizing pore-pressure responses during storms (Prasetyaningtiyas et al., 2024).

4.2 Coastal and Dune Stabilization Capabilities

In coastal environments, the stress factors shift from shear failure to wave erosion and scour (Leshchinsky et al., 2019; Muller et al., 2026; Salauddin & Pearson, 2019).

Hydraulic Resistance: Vetiver's stiff stems can withstand flow depths of up to 0.6–0.8 meters and reduce flow velocity, promoting the deposition of sediment. This "sediment trapping" capability is crucial for dune building (Meyer et al., 1995; Truong & Hengchaovanich, 1997; White et al., 2024). In Hawaii and the Gulf Coast, Vetiver has been used to stabilize sand dunes against wind and wave erosion. The roots, which can penetrate deep into sandy substrates where native grasses may be shallower, provide a "deep anchor" for the dune core (K. Kim et al., 2022; Mahannopkul & Jotisankasa, 2019a).

Salinity Tolerance: A critical finding for coastal applications is the salinity threshold. The 'Sunshine' genotype is highly salt-tolerant. Studies indicate it can survive soil salinity levels up to roughly 19 dS/m (decisiemens per meter), though growth is optimal below 8 dS/m (Liu et al., 2016; Su et al., 2021). This allows it to thrive in the "back dune" and "interdune" zones where salt spray is prevalent, though it is not a seagrass and cannot withstand permanent inundation in high-salinity seawater (Tresballes, 2003).

4.3 Phytoremediation and Water Quality

Beyond slope and shoreline stabilization, vetiver (*Chrysopogon zizanioides*) can measurably improve water quality by reducing sediment and nutrient export in runoff and by removing nutrients and other pollutants in treatment-wetland systems (Aregu et al., 2021; Oshunsanya et al., 2019; Panja et al., 2021).

- *Nutrient and Heavy Metal Uptake:* The dense root system is highly efficient at absorbing Nitrogen and Phosphorus (mitigating eutrophication) and sequestering heavy metals like Lead, Zinc, and Chromium from landfill leachate and mine tailings (R. Banerjee et al., 2016; S. Banerjee et al., 2025; Hassan et al., 2020; Panja et al., 2021; Wu et al., 2011).

- *Emerging Contaminants:* Recent U.S.-based research has demonstrated Vetiver's capacity to remove antibiotics such as tetracycline and ciprofloxacin from wastewater effluent, achieving removal rates of >90% in hydroponic and constructed wetland systems (Panja et al., 2021). This capability positions Vetiver as a functional component in "green" wastewater treatment infrastructure (Almeida et al., 2019).

4.4 The Sterile Genotype: A Non-Negotiable Standard

The U.S. technical landscape is defined by the strict adherence to the 'Sunshine' genotype (Meki et al., 2020). The USDA NRCS Plant Guide explicitly lists 'Sunshine' as non-invasive, citing decades of observation in Hawaii and the Pacific Islands with no evidence of volunteer seedlings or invasive spread. This sterility is the "license to operate" for the entire industry; any deviation from fertile genotypes would likely result in immediate regulatory prohibition, given the U.S. history with invasive species like Kudzu (Barnard et al., 2013a).

Economic and Market Analysis

The economic synthesis reveals that Vetiver bioengineering offers a compelling "Value-for-Money" proposition over the lifecycle of a project, despite facing structural barriers in the current market economy.

4.5 Comparative Cost Analysis: Green vs. Gray

The cost differential between Vetiver bioengineering and traditional hard engineering is stark.

Table 1: Comparative Costs of Shoreline and Slope Stabilization Methods (USD)

Stabilization Method	**Estimated Unit Cost**	**Primary Cost Drivers**	**Maintenance Profile**
Vetiver Bioengineering	**\$3 - \$15 per m^2**	Labor (planting), Plant Material	High Initial (Watering/Weeding) -> Low Long-term
Native Grass Hydroseeding	\$5 - \$8 per m^2	Machinery, Seed	Low -> Medium (Erosion Risk)
Riprap / Rock Armor	\$50 - \$150 per linear ft	Material Transport, Heavy Equipment	Low -> Medium (Settling/Displacement)
Bulkhead / Seawall	**\$100 - \$1,200+ per linear ft**	Materials (Concrete/Vinyl), Specialized Labor	Low -> Catastrophic (Replacement every 20-30 yrs)

Lifecycle Value: Cost-benefit evidence suggests vetiver-based bioengineering can deliver strong lifecycle value (for example, over multi-decade project horizons), but its diffusion is often constrained by institutional and economic barriers such as grey infrastructure path dependency and evaluation systems that prioritize upfront costs over long-term benefits (Boonyanuphap, 2013; K. Kim et al., 2022; Martin et al., 2025b). A seawall is a depreciating asset; its value and performance peak at installation and degrade daily until failure (H.-P. Chen & Alani, 2012; H.-P. Chen & Mehrabani, 2019; Nolan et al., 2021). A living shoreline or Vetiver hedge is an *appreciating* asset; its root system grows stronger, deeper, and more effective over time. Economic studies indicate that over 60 years, living shorelines are more economically efficient than bulkheads due to the avoided capital costs of replacement and the self-healing nature of vegetation after storm events (Barry et al., 2024; Gittman et al., 2014a; Palinkas et al., 2023; Smith et al., 2018; G. Wang et al., 2020b).

4.6 The Supply Chain Ecosystem

The U.S. Vetiver supply chain is a niche, vertically integrated market (Barnard et al., 2013a).

- **Production:** Production is concentrated in tropical/subtropical hubs (Hawaii, Puerto Rico, South Florida). Key suppliers like *Agriflora Tropicals* and *Vetiver Farms Hawaii* operate as both nurseries and technical consultancies (Rojas-Sandoval, 2020).
- **Distribution:** Because the plant must be propagated vegetatively (via slip splitting), scaling production is linear rather than exponential (unlike seeds). This creates a "lead time" constraint (Barnard et al., 2013b; Pandey et al., 2025; Whittet et al., 2016). Large infrastructure projects requiring 100,000+ plants often face supply shortages, necessitating forward contracting and contract-growing arrangements (Tangren et al., 2022).
- **Service Delivery:** Specialized firms like *Vetiver Systems International* and ecological contractors like *Davey Resource Group* act as intermediaries, bridging the gap between raw plant material and engineered installation (B. Allen et al., 2024).

4.7 Institutional Incentives and the Insurance Market

A critical finding is the role of insurance as a market driver. The Federal Emergency Management Agency (FEMA) manages the Community Rating System (CRS), which offers discounts on flood insurance premiums to communities that implement floodplain management activities exceeding minimum standards (Brent et al., 2024a; Highfield & Brody, 2017; Zahran et al., 2010).

- **Open Space Preservation (Activity 420):** Protecting open land functions as flood storage.
- **Natural Shoreline Protection:** Communities can earn points for regulations that incentivize living shorelines over bulkheads. This institutional validation monetizes the "resilience" value of Vetiver, converting it from an abstract environmental good into a direct financial saving for homeowners (up to 45% premium reduction in top-tier communities).

Consumer Valuation and Social Perception

Despite the technical and economic case, the consumer interface remains the primary point of friction.

4.8 The Psychology of Hardening

Surveys of coastal residents, particularly in North Carolina and the Gulf Coast, reveal a tenacious preference for hard infrastructure (S. B. Scyphers et al., 2019).

- **Perceived Efficacy:** Homeowners consistently rate bulkheads as "more effective" at preventing erosion than living shorelines, despite scientific evidence often proving the contrary (bulkheads cause scouring and flanking erosion) (Barry et al., 2024; Gittman et al., 2014b; Sun et al., 2022).
- **The Neighbor Effect:** The strongest predictor of a homeowner's shoreline choice is the condition of their neighbor's shoreline. If the neighbor has a wall, the social norm and perceived risk dictate a wall. Breaking this cycle requires "early adopters" and highly visible demonstration projects to shift the neighborhood norm (Kochnower et al., 2015; Scyphers et al., 2015).

4.9 Aesthetic Friction and the "Messy" Ecology

"Aesthetic friction" defines the conflict between ecological function and visual preference (H. Gobster et al., 2007).

- **Neatness Bias:** There is a cultural association between "manicured" landscapes (short turf, defined edges) and "care/value." Tall, tussocky grasses like Vetiver or native marsh plants are often perceived as "weedy," "neglected," or harborers of pests (snakes, rodents) (Cooper et al., 2024; Filibeck et al., 2016; Li & Nassauer, 2020; Nassauer, 1995).
- **View Obstruction:** On coastal properties, the view is a primary component of property value. Vetiver hedges, which can reach 6 feet in height, can obstruct sightlines if not actively managed (trimmed). This trade-off between *protection* (hedge) and *amenity* (view) significantly depresses WTP for Vetiver in residential contexts unless the risk of erosion is acute and visible (Benson et al., 1998; Guthrie et al., 2023; Nordstrom et al., 2007; S. B. Scyphers et al., 2014).

4.10 Willingness to Pay (WTP) Nuances

However, valuation is not static. Studies show that when consumers are educated about the co-benefits, specifically *habitat creation* (better fishing) and *resilience* (protection from storms), their WTP for green infrastructure increases (Imamura et al., 2023; Petrolia et al., 2014; Wieczerak et al., 2022). There is a specific premium for "accessible" green space (e.g., walkability) versus purely functional green space. This suggests that Vetiver installations that are integrated into a broader landscape design (e.g., with pathways, terracing) are more valued than simple utility plantings (Łaszkiewicz et al., 2022; Mazzotta et al., 2014; Tanaka et al., 2022; R. Wang et al., 2022).

5. Discussion: Synthesizing the Green Value Chain

5.1 Bridging the Gap: The "Nurse Crop" Succession Model

One of the most significant insights from this review is the potential for Vetiver to serve not as a permanent monoculture, but as a "Nurse Crop" for native restoration (Wen Chen et al., 2020).

- **The Challenge:** Native dune grasses like Sea Oats (*Uniola paniculata*) and Bitter Panicum (*Panicum amarum*) are ecologically preferred but slow to establish and vulnerable to initial erosion stress (Joyce et al., 2022; Miller et al., 2001).

- **The Solution:** Vetiver, with its rapid growth (establishing in 12 weeks) and deep roots, can be planted as the primary stabilizer. Once the soil is anchored, native species are interplanted. The Vetiver provides a windbreak and moisture trap (nurse effect), facilitating the establishment of the natives (Holanda et al., 2022; Oshunsanya et al., 2019).
- **The Transition:** Over time (3-5 years), as the native ecosystem matures, the Vetiver can be managed (shaded out or trimmed), leaving a restored native dune system that retains the deep-root legacy of the initial Vetiver application. This approach satisfies the *engineering* need for speed and stability while satisfying the *ecological* mandate for nativity, potentially unlocking funding sources restricted to "native restoration" (Castanho & Prado, 2014; Tessema et al., 2022).

5.2 Resilience-as-a-Service (RaaS)

The economic friction of "high maintenance" can be flipped into a business opportunity (Knapik et al., 2024). The traditional construction model is transactional (build and leave) (Sánchez-Garrido et al., 2023). The bioengineering model is relational (plant and steward). Entrepreneurs can adopt a "Resilience-as-a-Service" model. Instead of selling a "Vetiver Wall," they sell a "10-Year Stabilization Contract" (Andersson et al., 2014; Davies & Santo-Tomás Muro, 2024; Smith et al., 2020). This bundles the installation with the necessary annual maintenance (trimming, monitoring). This aligns the incentives: the contractor ensures the plants survive to minimize their own rework costs, and the homeowner gets a guaranteed outcome without the burden of horticultural management (Baker & Gittman, 2024; Knapik et al., 2024; Mitchell & Bilkovic, 2019). This model mirrors the software industry's shift to SaaS (Software as a Service), providing recurring revenue streams for the "Restoration Economy" (T. BenDor et al., 2015; T. K. BenDor et al., 2015; Benlian & Hess, 2011; Cusumano, 2008).

5.3 Unlocking the Insurance Lever

The connection to FEMA's CRS is the most potent lever for mass adoption (Davlasheridze & Fan, 2025; Sadiq et al., 2020). If a Vetiver stabilized shoreline can be certified to provide a specific flood reduction credit, the ROI calculation for the homeowner shifts immediately. The cost of the system is offset by the annual insurance savings (Brent et al., 2024b; Guthrie et al., 2023; Hudson et al., 2016). To achieve this, the industry must move toward standardized "performance certificates" for Vetiver installations, verified by licensed engineers, to provide the documentation required by insurers (Eab et al., 2015; Marchal et al., 2019; Rödl & Arlati, 2022; G. Wang et al., 2020b).

6. Conclusion

The synthesis of the Green Value Chain shows that Vetiver bioengineering is an underused but highly capable option within the U.S. coastal resilience toolkit. From a technical standpoint, the sterile 'Sunshine' genotype can deliver strong geotechnical stabilization at a much lower lifecycle cost than many gray alternatives, especially in Gulf Coast soils and Atlantic dune systems where erosion pressure is persistent and damages compound quickly (Adams et al., 1998).

Its long-term promise depends on more than performance data. Widespread adoption requires blending entrepreneurship with homeowner psychology and institutional incentives, so the solution feels credible, insurable, and easy to maintain. The most scalable direction is to treat Vetiver as a temporary bio-technical bridge to native communities through a "Nurse Crop Succession" approach, and to professionalize upkeep through a "Resilience-as-a-Service" model that turns stewardship into a managed outcome rather than a homeowner burden (Islam et al., 2015).

At the same time, deployment in the U.S. has clear constraints that shape where and how the system can be responsibly used. Vetiver is tropical and reliably perennial mainly in USDA Zones 8 to 11, while in Zone 7 and colder it tends to die back, reducing the deep-root stabilization benefits that drive its engineering value. It is also shade-intolerant, limiting its applicability on forested streambanks or heavily canopied riparian corridors. Finally, there is a real establishment risk window of roughly 3 to 4 months after planting when extreme storm events can overwhelm young root systems, which often makes temporary measures like biodegradable coir mats necessary to bridge early vulnerability.

Future research should move from isolated demonstrations toward integrated, verifiable pathways that reduce risk for regulators, insurers, and buyers. Priority work includes a practical genetic chain-of-custody system, ideally, rapid low-cost field verification of the sterile 'Sunshine' material to prevent accidental introduction of fertile types (Celestino et al., 2015; Ocenar et al., 2019; Papadakis et al., 2022). In colder regions, research should test annual use as a short-term nurse crop in Zones 6 to 7 to see whether one growing season can provide enough stabilization to establish natives before winter dieback (David et al., 2023; Dorafshan et al., 2023). Additional value could come from rigorous measurement of belowground carbon storage in U.S. soil conditions to assess eligibility for voluntary carbon markets, and from multi-year property valuation studies that track how communities shifting from bulkheads to living shorelines affect home prices over time (Good & Pindilli, 2022; Landry & Hindsley, 2011; Pompe & Rinehart, 1994).

Appendix:

Table 2: Technical Specifications of Vetiver Bioengineering in U.S. Context

Parameter	Performance Metric	Engineering Implication
Root Tensile Strength	~75 MPa (Mean)	Approx. 1/6th strength of mild steel; high tensile reinforcement.
Shear Strength Increase	+30% to +40%	Increases soil internal friction angle (e.g., 31° $\rightarrow$ 40°).
Root Depth	3.0 – 4.0 meters	Penetrates typically shallow slip circles; anchors surface soil to subsoil.
Hydraulic Tolerance	Flow velocity reduction	Withstands flow depths up to 0.8m; promotes sediment trapping.
Salinity Tolerance	Threshold ~19 dS/m	Viable for back-dune and interdune stabilization; not for direct sub-tidal use.
Contaminant Removal	>90% (Antibiotics/Metals)	High utility for leachate management and wastewater polishing.

Table 3: Economic Comparison of Coastal Stabilization Options

Cost Category	Vetiver / Living Shoreline	Hard Armor (Bulkhead/Seawall)	Economic Insight
Capital Cost (Install)	**Low** ($30-$150/linear ft)	**High** ($100-$1,200+/linear ft)	Green solutions offer immediate CAPEX savings.
Maintenance Cost	**High Initial** (Watering/Weeding)	**Low Initial** (none)	Green requires stewardship; Gray appears "maintenance-free" initially.
Long-Term Cost	**Decreasing** (Self-sustaining)	**Increasing** (Structural degradation)	Green systems appreciate; Gray systems depreciate.
Lifecycle ROI (60yr)	**Positive** (Benefit:Cost > 1)	**Lower/Negative** (Replacement costs)	Avoided replacement drives green ROI.
Externalities	Positive (Habitat, Filtration)	Negative (Scouring, Habitat Loss)	Green creates public value; Gray creates public cost.

References

[1]. Adams, R. P., Turuspekov, M. Z. Y., Dafforn, M. R., & Veldkamp, J. F. (1998). DNA fingerprinting reveals clonal nature of Vetiveria zizanioides (L.) Nash, Gramineae and sources of potential new germplasm. *Molecular Ecology*, *7*(7), 813–818. https://doi.org/10.1046/j.1365-294x.1998.00394.x

[2]. Adkisson, K. (2021, October 14). *Greening the Gray: Fighting Floods with Restoration Versus Riprap*. Pacific Northwest National Laboratory; Pacific Northwest National Laboratory. https://www.pnnl.gov/news-media/greening-gray-fighting-floods-restoration-versus-riprap

[3]. Almeida, A., Ribeiro, C., Carvalho, F., Durao, A., Bugajski, P., Kurek, K., Pochwatka, P., & Jóźwiakowski, K. (2019). Phytoremediation potential of *Vetiveria zizanioides* and *Oryza sativa* to nitrate and organic substance removal in vertical flow constructed wetland systems. *Ecological Engineering*, *138*, 19–27. https://doi.org/10.1016/j.ecoleng.2019.06.020

[4]. Andersson, E., Barthel, S., Borgström, S., Colding, J., Elmqvist, T., Folke, C., & Gren, Å. (2014). Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services. *Ambio*, *43*(4), 445–453. https://doi.org/10.1007/s13280-014-0506-y

[5]. Aregu, M. B., Soboksa, N. E., & Kanno, G. G. (2021). High Strength Wastewater Reclamation Capacity of Vetiver Grass in Tropics: The Case of Ethiopia. *Environmental Health Insights*, *15*, 11786302211060162. https://doi.org/10.1177/11786302211060162

[6]. B. Allen, E., T. Cross, A., M. Berger, A., & Aronson, J. (2024, September 6). *Restoration seed and plant material supply chains are complex social networks—Allen—2024—Restoration Ecology—Wiley Online Library*. https://onlinelibrary.wiley.com/doi/10.1111/rec.14279

[7]. Baker, R., & Gittman, R. K. (2024). Co-Funding Robust Monitoring with Living Shoreline Construction is Critical for Maximizing Beneficial Outcomes. *Estuaries and Coasts*, *48*(1), 5. https://doi.org/10.1007/s12237-024-01433-9

[8]. Banerjee, R., Goswami, P., Pathak, K., & Mukherjee, A. (2016). Vetiver grass: An environment clean-up tool for heavy metal contaminated iron ore mine-soil. *Ecological Engineering*, *90*, 25–34. https://doi.org/10.1016/j.ecoleng.2016.01.027

[9]. Banerjee, S., Jha, S., Chakraborty, S., Ghosh, S., Sarkar, D., Datta, R., Bhattacharya, S. S., & Bhattacharyya, P. (2025). Mycorrhiza-assisted phytoremediation of spiked chromium-contaminated soil: Assessing AMF-vetiver symbiosis for Cr accumulation and soil quality enhancement. *Environmental Research*, *283*, 122143. https://doi.org/10.1016/j.envres.2025.122143

[10]. Barcellos-Silva, I. G. C., dos Santos, F. K. F., Kharkwal, H., Chander, S., Kharkwal, A. C., Awasthi, R., Dhiman, N., Sharma, B., Kulkarni, G. T., Larssen, H., Silva, J. M. L., de Souza, M. A., Setzer, W. N., & Veiga-Junior, V. F. (2025). Vetiver, Vetiveria zizanioides (L.) Nash: Biotechnology, Biorefineries, and the Production of Volatile Phytochemicals. *Plants*, *14*(10), 1435. https://doi.org/10.3390/plants14101435

[11]. Barnard, S., Diedericks, V., & Conradie, K. R. (2013a). Genetic diversity of vetiver isolates (*Chrysopogon zizanioides*/*nigritanus*) available in South Africa based on *ITS*, *ndh*F and *rbc*L sequencing analyses. *South African Journal of Botany*, *86*, 63–67. https://doi.org/10.1016/j.sajb.2013.02.005

[12]. Barnard, S., Diedericks, V., & Conradie, K. R. (2013b). Genetic diversity of vetiver isolates (*Chrysopogon zizanioides*/*nigritanus*) available in South Africa based on *ITS*, *ndh*F and *rbc*L sequencing analyses. *South African Journal of Botany*, *86*, 63–67. https://doi.org/10.1016/j.sajb.2013.02.005

[13]. Barry, S. C., Reynolds, L. K., Braswell, A. E., Gittman, R. K., Scyphers, S. B., & Smyth, A. R. (2024). Perceived effectiveness drives shoreline decision-making for Florida's waterfront property owners. *Ocean & Coastal Management*, *258*, 107353. https://doi.org/10.1016/j.ocecoaman.2024.107353

[14]. BenDor, T. K., Livengood, A., Lester, T. W., Davis, A., & Yonavjak, L. (2015). Defining and evaluating the ecological restoration economy. *Restoration Ecology*, *23*(3), 209–219. https://doi.org/10.1111/rec.12206

[15]. BenDor, T., Lester, T. W., Livengood, A., Davis, A., & Yonavjak, L. (2015). Estimating the Size and Impact of the Ecological Restoration Economy. *PLOS ONE*, *10*(6), e0128339. https://doi.org/10.1371/journal.pone.0128339

[16]. Benlian, A., & Hess, T. (2011). Opportunities and risks of software-as-a-service: Findings from a survey of IT executives. *Decision Support Systems*, *52*(1), 232–246. https://doi.org/10.1016/j.dss.2011.07.007

[17]. Benson, E., Hansen, J., Schwartz, A., & Smersh, G. T. (1998). Pricing Residential Amenities: The Value of a View. *The Journal of Real Estate Finance and Economics*, *16*(1), 55–73.

[18]. Boonyanuphap, J. (2013). Cost-benefit analysis of vetiver system-based rehabilitation measures for landslide-damaged mountainous agricultural lands in the lower Northern Thailand. *Natural Hazards*, *69*(1), 599–629. https://doi.org/10.1007/s11069-013-0730-y

[19]. Brent, D. A., Ren, Y., & Wrenn, D. H. (2024a). The distributional impact of FEMA's community rating system. *Agricultural and Resource Economics Review*, *53*(1), 87–118. https://doi.org/10.1017/age.2023.37

[20]. Brent, D. A., Ren, Y., & Wrenn, D. H. (2024b). The distributional impact of FEMA's community rating system. *Agricultural and Resource Economics Review*, *53*(1), 87–118. https://doi.org/10.1017/age.2023.37

[21]. Brister, A. A. (2022). Mitigating the shrink-swell capacities of the Yazoo Clay through application of lime and biochar. *Mississippi State University*.

[22]. Castanho, C. de T., & Prado, P. I. (2014). Benefit of Shading by Nurse Plant Does Not Change along a Stress Gradient in a Coastal Dune. *PLOS ONE*, *9*(8), e105082. https://doi.org/10.1371/journal.pone.0105082

[23]. Celestino, R. S., Zucchi, M. I., Pinheiro, J. B., Campos, J. B., Pereira, A. A., Bianchini, F. G., Lima, R. N., Arrigoni-Blank, M. F., Alves, P. B., & Blank, A. F. (2015). Molecular and chemical characterization of vetiver, Chrysopogon zizanioides (L.) Roberty, germplasm. *Genetics and Molecular Research: GMR*, *14*(3), 9452–9468. https://doi.org/10.4238/2015.August.14.9

[24]. Chen, H.-P., & Alani, A. M. (2012). Reliability and optimised maintenance for sea defences. *Maritime Engineering*, *165*(2), 51–64. https://doi.org/10.1680/maen.2010.37

[25]. Chen, H.-P., & Mehrabani, M. B. (2019). Lifetime wave overtopping risk analysis of sea defences subjected to changing operational conditions. *Engineering Failure Analysis*, *97*, 464–479. https://doi.org/10.1016/j.engfailanal.2019.01.037

[26]. Chen, P., Zhang, H., Yang, G., Guo, Z., & Yang, G. (2022). Thermo-Hydro-Mechanical Coupling Model of Unsaturated Soil Based on Modified VG Model and Numerical Analysis. *Frontiers in Earth Science*, *10*. https://doi.org/10.3389/feart.2022.947335

[27]. Chok, Y. H., Jaksa, M. B., Kaggwa, W. S., & Griffiths, D. V. (2015). Assessing the influence of root reinforcement on slope stability by finite elements. *International Journal of Geo-Engineering*, *6*(1), 12. https://doi.org/10.1186/s40703-015-0012-5

[28]. Clark, P. W., D'Amato, A. W., Palik, B. J., Woodall, C. W., Dubuque, P. A., Edge, G. J., Hartman, J. P., Fitts, L. A., Janowiak, M. K., Harris, L. B., Montgomery, R. A., Reinikainen, M. R., & Zimmerman, C. L. (2023). A lack of ecological diversity in forest nurseries limits the achievement of tree-planting objectives in response to global change. *BioScience*, *73*(8), 575–586. https://doi.org/10.1093/biosci/biad049

[29]. Cooper, C., Collier, M. J., Pineda-Pinto, M., Castañeda, N. R., O'Donnell, M., & Nulty, F. (2024). Urban novel ecosystems as affective landscapes. *Sustainability Science*, *19*(6), 1921–1933. https://doi.org/10.1007/s11625-024-01539-w

[30]. Cueva, M., Kang, X., Wang, S., Soranzo, E., & Wu, W. (2025). Unveiling the role of saturation and displacement rate in the transition from slow movement to catastrophic failure in landslides. *Engineering Geology*, *352*, 108042. https://doi.org/10.1016/j.enggeo.2025.108042

[31]. Cusumano, M. A. (2008). The Changing Software Business: Moving from Products to Services. *Computer*, *41*(1), 20–27. https://doi.org/10.1109/MC.2008.29

[32]. Darajeh, N., Truong, P., Rezania, S., Alizadeh, H., & Leung, D. W. M. (2019). Effectiveness of vetiver grass versus other plants for phytoremediation of contaminated water. *Journal of Environmental Treatment Techniques*, *7*(3), 485–500.

[33]. Daro Justine, Y. E., & Seenath, A. (2025). Vegetative nature-based solutions for coastal flood risk management: Benefits, challenges, and uncertainties. *Ocean & Coastal Management*, *261*, 107520. https://doi.org/10.1016/j.ocecoaman.2024.107520

[34]. David, A., Fărcaș, A., & Socaci, S. A. (2023). An overview of the chemical composition and bioactivities of *Vetiveria zizanioides* (L.) Nash essential oil. *Trends in Food Science & Technology*, *140*, 104153. https://doi.org/10.1016/j.tifs.2023.104153
[35]. Davies, C., & Santo-Tomás Muro, R. (2024). Stewardship and green infrastructure in England. Planning perspectives informed through an investigation of urban green infrastructure. *Journal of Environmental Planning and Management*, *67*(12), 2748–2773. https://doi.org/10.1080/09640568.2023.2197557
[36]. Davlasheridze, M., & Fan, Q. (2025). Flood risk, insurance, and community-level mitigation efforts: Evidence from the National Flood Insurance Program's (NFIP) Community Rating System. *International Journal of Disaster Risk Reduction*, *118*, 105255. https://doi.org/10.1016/j.ijdrr.2025.105255
[37]. Dorafshan, M. M., Abedi-Koupai, J., Eslamian, S., & Amiri, M. J. (2023). Vetiver Grass (Chrysopogon zizanoides L.): A Hyper-Accumulator Crop for Bioremediation of Unconventional Water. *Sustainability*, *15*(4), 3529. https://doi.org/10.3390/su15043529
[38]. Dunlop, T., Khojasteh, D., Cohen-Shacham, E., Glamore, W., Haghani, M., van den Bosch, M., Rizzi, D., Greve, P., & Felder, S. (2024). The evolution and future of research on Nature-based Solutions to address societal challenges. *Communications Earth & Environment*, *5*(1), 132. https://doi.org/10.1038/s43247-024-01308-8
[39]. Eab, K. H., Likitlersuang, S., & Takahashi, A. (2015). Laboratory and modelling investigation of root-reinforced system for slope stabilisation. *Soils and Foundations*, *55*(5), 1270–1281. https://doi.org/10.1016/j.sandf.2015.09.025
[40]. Filibeck, G., Petrella, P., & Cornelini, P. (2016). All ecosystems look messy, but some more so than others: A case-study on the management and acceptance of Mediterranean urban grasslands. *Urban Forestry & Urban Greening*, *15*, 32–39. https://doi.org/10.1016/j.ufug.2015.11.005
[41]. Garzón, E., González-Miranda, F. M., Reca, J., & Sánchez-Soto, P. J. (2020). Stabilization to prevent soil erosion using vetiver (Chrysopogon zizanioides L.) in slopes: A field case study of selected grounds at Guatemala. *E3S Web of Conferences*, *195*, 01014. https://doi.org/10.1051/e3sconf/202019501014
[42]. Gittman, R. K., Peterson, C. H., Currin, C. A., Fodrie, F. J., Piehler, M. F., & Bruno, J. F. (2016). Living shorelines can enhance the nursery role of threatened estuarine habitats. *Ecological Applications: A Publication of the Ecological Society of America*, *26*(1), 249–263. https://doi.org/10.1890/14-0716
[43]. Gittman, R. K., Popowich, A. M., Bruno, J. F., & Peterson, C. H. (2014a). Marshes with and without sills protect estuarine shorelines from erosion better than bulkheads during a Category 1 hurricane. *Ocean & Coastal Management*, *102*, 94–102. https://doi.org/10.1016/j.ocecoaman.2014.09.016
[44]. Gittman, R. K., Popowich, A. M., Bruno, J. F., & Peterson, C. H. (2014b). Marshes with and without sills protect estuarine shorelines from erosion better than bulkheads during a Category 1 hurricane. *Ocean & Coastal Management*, *102*, 94–102. https://doi.org/10.1016/j.ocecoaman.2014.09.016
[45]. Gittman, R. K., Scyphers, S. B., Baillie, C. J., Brodmerkel, A., Grabowski, J. H., Livernois, M., Poray, A. K., Smith, C. S., & Fodrie, F. J. (2021). Reversing a tyranny of cascading shoreline-protection decisions driving coastal habitat loss. *Conservation Science and Practice*, *3*(9), e490. https://doi.org/10.1111/csp2.490
[46]. Good, A., & Pindilli, E. (2022). Estimating the Effect of Tidal Marsh Restoration on Housing Prices: A Hedonic Analysis in the Nisqually National Wildlife Refuge, Washington, USA. *Land*, *11*(9), 1432. https://doi.org/10.3390/land11091432
[47]. Guthrie, A. G., Stafford, S., Scheld, A. M., Nunez, K., & Bilkovic, D. M. (2023). Property owner shoreline modification decisions vary based on their perceptions of shoreline change and interests in ecological benefits. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1031012
[48]. H. Gobster, P., I. Nassauer, J., C. Daniel, T., & Fry, G. (2007, May 24). *The shared landscape: What does aesthetics have to do with ecology? | Landscape Ecology*. https://link.springer.com/article/10.1007/s10980-007-9110-x
[49]. Hasan, S. N. M. S., Kusin, F. M., Lee, A. L. S., Ukang, T. A., Yusuff, F. M., & Ibrahim, Z. Z. (2017). Performance of Vetiver Grass (Vetiveria zizanioides) for Phytoremediation of Contaminated Water. *MATEC Web of Conferences*, *103*, 06003. https://doi.org/10.1051/matecconf/201710306003
[50]. Hassan, M. M., Haleem, N., Baig, M. A., & Jamal, Y. (2020). Phytoaccumulation of heavy metals from municipal solid waste leachate using different grasses under hydroponic condition. *Scientific Reports*, *10*(1), 15802. https://doi.org/10.1038/s41598-020-72800-2
[51]. Highfield, W. E., & Brody, S. D. (2017). Determining the effects of the FEMA Community Rating System program on flood losses in the United States. *International Journal of Disaster Risk Reduction*, *21*, 396–404. https://doi.org/10.1016/j.ijdrr.2017.01.013
[52]. Holanda, F. S. R., Santos, L. D. V., Pedrotti, A., de Araújo Filho, R. N., Sartor, L. R., Santos-Sobrinho, V. R. A., de Jesus, R. J. S., de Oliveira Silva, P. A., & Andrade, K. M. A. (2022). Evaluation of the root system of Vetiver grass (Chrysopogon zizanioides L. Roberty) using different sampling methods. *Environmental Systems Research*, *11*(1), 16. https://doi.org/10.1186/s40068-022-00262-8
[53]. Huang, Y., Deng, P., Wang, G., & Zhang, H. (2024). Effects of vetiver root on cracking of expansive soils and its mechanistic analysis. *Scientific Reports*, *14*, 19737. https://doi.org/10.1038/s41598-024-70934-1
[54]. Hudson, P., Botzen, W. J. W., Feyen, L., & Aerts, J. C. J. H. (2016). Incentivising flood risk adaptation through risk based insurance premiums: Trade-offs between affordability and risk reduction. *Ecological Economics*, *125*, 1–13. https://doi.org/10.1016/j.ecolecon.2016.01.015
[55]. Iftekhar, M. S., & Polyakov, M. (2021). Economics of Ecological Restoration. In *Oxford Research Encyclopedia of Environmental Science*. https://oxfordre.com/environmentalscience/display/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-751
[56]. Imamura, K., Takano, K. T., Yoshida, Y., Nakashizuka, T., & Managi, S. (2023). Effects of information provision on willingness to pay for conservation of alpine plants in Japan. *Journal of Environmental Management*, *342*, 118175. https://doi.org/10.1016/j.jenvman.2023.118175
[57]. Islam, M. R., Rita, A., Ng, C. C., McKeown, R., Entwistle, E., & Shutian, X. (2015). *Green Entrepreneurship for Island Resilience: A Vetiver-Based Business Model for Tanna, Vanuatu*. https://doi.org/10.13140/RG.2.2.36795.53288
[58]. Jandyal, T., & Shah, M. Y. (2024). An experimental investigation on the effect of vetiver grass root system on the engineering properties of soil. *Life Cycle Reliability and Safety Engineering*, *13*(3), 335–350. https://doi.org/10.1007/s41872-024-00257-7
[59]. Jindapunnapat, K., Reetz, N. D., MacDonald, M. H., Bhagavathy, G., Chinnasri, B., Soonthornchareonnon, N., Sasnarukkit, A., Chauhan, K. R., Chitwood, D. J., & Meyer, S. L. F. (2018). Activity of Vetiver Extracts and Essential Oil against Meloidogyne incognita. *Journal of Nematology*, *50*(2), 147–162. https://doi.org/10.21307/jofnem-2018-008

[60]. Joy, R. J., & Evans, D. O. (2012). *Obtaining Seeds and Plants for Conservation*.
[61]. Joyce, M. A., Crotty, S. M., Angelini, C., Cordero, O., Ortals, C., Battisti, D. de, & Griffin, J. N. (2022). Wrack enhancement of post-hurricane vegetation and geomorphological recovery in a coastal dune. *PLOS ONE*, *17*(8), e0273258. https://doi.org/10.1371/journal.pone.0273258
[62]. Kelmenson, S. R. B. of, BenDor, T., & Lester, T. W. (2016, June 2). *The Economic Impacts of the US Ecological Restoration Sector*. Federal Reserve Bank of Boston. https://www.bostonfed.org/publications/communities-and-banking/2016/summer/the-economic-impacts-of-the-us-ecological-restoration-sector.aspx
[63]. Khan, S., Ivoke, J., & Nobahar, M. (2019). Coupled Effect of Wet-Dry Cycles and Rainfall on Highway Slope Made of Yazoo Clay. *Geosciences*, *9*(8), 341. https://doi.org/10.3390/geosciences9080341
[64]. Khan, S., Whalin, R., Spears, A., & Chakraborty, A. (2023). *Bio-Inspired Stabilization of Levee Slope on Expansive Yazoo Clay at the Maritime and Multimodal Transportation Infrastructure in Mississippi*. https://trid.trb.org/View/2317371
[65]. Kim, K., Riley, S., Fischer, E., & Khan, S. (2022). Greening Roadway Infrastructure with Vetiver Grass to Support Transportation Resilience. *CivilEng*, *3*(1), 147–164. https://doi.org/10.3390/civileng3010010
[66]. Kim, T.-G., & Petrolia, D. R. (2013). Public perceptions of wetland restoration benefits in Louisiana. *ICES Journal of Marine Science*, *70*(5), 1045–1054. https://doi.org/10.1093/icesjms/fst026
[67]. Knapik, E., Brandimarte, L., & Usher, M. (2024). Maintenance in sustainable stormwater management: Issues, barriers and challenges. *Journal of Environmental Planning and Management*. https://doi.org/10.1080/09640568.2024.2325041
[68]. Kochnower, D., Reddy, S. M. W., & Flick, R. E. (2015). Factors influencing local decisions to use habitats to protect coastal communities from hazards. *Ocean & Coastal Management*, *116*, 277–290. https://doi.org/10.1016/j.ocecoaman.2015.07.021
[69]. Krol, A., Kokotkiewicz, A., Krolicka, A., Hinc, K., Badura, A., Lorenc, A., Marzec-Wroblewska, U., Bucinski, A., Kuzma, L., & Luczkiewicz, M. (2025). Adventitious and Hairy Root Cultures of Salvia apiana as a Source of Rosmarinic Acid. *International Journal of Molecular Sciences*, *26*(7), 3138. https://doi.org/10.3390/ijms26073138
[70]. Kumar, A., Anand, A., Singh, R. V., Kumar, R., & Gohil, M. (2025). Vegetation hydrology and slope interaction under variable infiltration: A state-of-the-art review. *Journal of Infrastructure Preservation and Resilience*, *6*(1), 33. https://doi.org/10.1186/s43065-025-00152-0
[71]. Lan, B., Jia, B., Wu, Y., Yi, X., Feng, W., & Li, Y. (2025). Strength characteristics in saturation process and rainfall-induced landslide failure mechanism of granite residual soil. *Frontiers in Earth Science*, *13*. https://doi.org/10.3389/feart.2025.1578923
[72]. Landry, C. E., & Hindsley, P. (2011). Valuing Beach Quality with Hedonic Property Models. *Land Economics*, *87*(1), 92–108. https://doi.org/10.3368/le.87.1.92
[73]. Lann, T., Bao, H., Lan, H., Zheng, H., Yan, C., & Peng, J. (2024). Hydro-mechanical effects of vegetation on slope stability: A review. *Science of The Total Environment*, *926*, 171691. https://doi.org/10.1016/j.scitotenv.2024.171691
[74]. Łaszkiewicz, E., Heyman, A., Chen, X., Cimburova, Z., Nowell, M., & Barton, D. N. (2022). Valuing access to urban greenspace using non-linear distance decay in hedonic property pricing. *Ecosystem Services*, *53*, 101394. https://doi.org/10.1016/j.ecoser.2021.101394
[75]. Leshchinsky, B., Olsen, M. J., Mohney, C., O'Banion, M., Bunn, M., Allan, J., & McClung, R. (2019). Quantifying the Sensitivity of Progressive Landslide Movements to Failure Geometry, Undercutting Processes and Hydrological Changes. *Journal of Geophysical Research: Earth Surface*, *124*(2), 616–638. https://doi.org/10.1029/2018JF004833
[76]. Li, J., Abukhalaf, A. H. I., Bean, E., Brisotto, C., Clark, M. W., Von Meding, J., Otalora, A., & Barry, S. (2025). Community perception and stewardship of public coastal infrastructure in Cedar Key, Florida. *Frontiers in Marine Science*, *12*. https://doi.org/10.3389/fmars.2025.1639887
[77]. Li, J., & Nassauer, J. I. (2020). Cues to care: A systematic analytical review. *Landscape and Urban Planning*, *201*, 103821. https://doi.org/10.1016/j.landurbplan.2020.103821
[78]. Liu, W., Liu, J., Yao, M., & Ma, Q. (2016). Salt tolerance of a wild ecotype of vetiver grass (Vetiveria zizanioides L.) in southern China. *Botanical Studies*, *57*, 27. https://doi.org/10.1186/s40529-016-0142-x
[79]. Lovseth, A. (2018, September 18). From Grey to Green: Developing the Guidelines for Natural Infrastructure — Environmental Science Associates. *ESA*. https://esassoc.com/news-and-ideas/2018/09/from-grey-to-green-developing-the-guidelines-for-natural-infrastructure/
[80]. Luu, T. D. (2010). *Supercritical CO2 extraction of vetiver essential oil & economic incentive for use of vetiver grass in phytoremediation* [Thesis, UNSW Sydney]. https://doi.org/10.26190/unsworks/23121
[81]. Mahannopkul, K., & Jotisankasa, A. (2019a). Influence of root suction on tensile strength of Chrysopogon zizanioides roots and its implication on bioslope stabilization. *Journal of Mountain Science*, *16*(2), 275–284. https://doi.org/10.1007/s11629-018-5134-8
[82]. Mahannopkul, K., & Jotisankasa, A. (2019b). Influences of root concentration and suction on *Chrysopogon zizanioides* reinforcement of soil. *Soils and Foundations*, *59*(2), 500–516. https://doi.org/10.1016/j.sandf.2018.12.014
[83]. Marchal, R., Piton, G., Lopez-Gunn, E., Zorrilla-Miras, P., van der Keur, P., Dartée, K. W. J., Pengal, P., Matthews, J. H., Tacnet, J.-M., Graveline, N., Altamirano, M. A., Joyce, J., Nanu, F., Groza, I., Peña, K., Cokan, B., Burke, S., & Moncoulon, D. (2019). The (Re)Insurance Industry's Roles in the Integration of Nature-Based Solutions for Prevention in Disaster Risk Reduction—Insights from a European Survey. *Sustainability*, *11*(22), 6212. https://doi.org/10.3390/su11226212
[84]. Martin, J. G. C., Scolobig, A., Linnerooth-Bayer, J., Irshaid, J., Aguilera Rodriguez, J. J., Fresolone-Caparrós, A., & Oen, A. (2025a). The nature-based solution implementation gap: A review of nature-based solution governance barriers and enablers. *Journal of Environmental Management*, *388*, 126007. https://doi.org/10.1016/j.jenvman.2025.126007
[85]. Martin, J. G. C., Scolobig, A., Linnerooth-Bayer, J., Irshaid, J., Aguilera Rodriguez, J. J., Fresolone-Caparrós, A., & Oen, A. (2025b). The nature-based solution implementation gap: A review of nature-based solution governance barriers and enablers. *Journal of Environmental Management*, *388*, 126007. https://doi.org/10.1016/j.jenvman.2025.126007
[86]. Mazzotta, M. J., Besedin, E., & Speers, A. E. (2014). A Meta-Analysis of Hedonic Studies to Assess the Property Value Effects of Low Impact Development. *Resources*, *3*(1), 31–61. https://doi.org/10.3390/resources3010031
[87]. Meki, M. N., Kiniry, J. R., Worqlul, A. W., Kim, S., Williams, A. S., Osorio, J. M., & Reilley, J. (2020). Field and simulation-based assessment of vetivergrass bioenergy feedstock production potential in Texas. *Agronomy Journal*, *112*(4), 2692–2707. https://doi.org/10.1002/agj2.20226

[88]. Meyer, L. D., Dabney, S. M., & Harmon, W. C. (1995). *Sediment-trapping Effectiveness of Stiff-grass Hedges*. https://doi.org/10.13031/2013.27895
[89]. Mickovski, S. B., & van Beek, L. P. H. (2009). Root morphology and effects on soil reinforcement and slope stability of young vetiver (Vetiveria zizanioides) plants grown in semi-arid climate. *Plant and Soil*, *324*(1), 43–56. https://doi.org/10.1007/s11104-009-0130-y
[90]. Miller, D. L., Thetford, M., & Yager, L. (2001). Evaluation of Sand Fence and Vegetation for Dune Building following Overwash by Hurricane Opal on Santa Rosa Island, Florida. *Journal of Coastal Research*, *17*(4), 936–948.
[91]. Mitchell, M., & Bilkovic, D. M. (2019). Embracing dynamic design for climate-resilient living shorelines. *Journal of Applied Ecology*, *56*(5), 1099–1105. https://doi.org/10.1111/1365-2664.13371
[92]. Mohammad, S. N., Masoud, N., Mohammad Sadik, K., Alzeghoul, O., & Henry Kini, C. (2022). Vetiver Grass Performance on a Distressed Highway Slope of High-Plastic Clay under Excessive Rainfall. *Geo-Congress 2022*, 268–278. https://doi.org/10.1061/9780784484067.028
[93]. Morgan, D. (2025, November 19). New Report Shows Conservation Is a High-Return Investment for Communities, Jobs, and Growth. *Theodore Roosevelt Conservation Partnership*. https://www.trcp.org/2025/11/19/new-report-shows-conservation-is-a-high-return-investment-for-communities-jobs-and-growth/
[94]. Muller, J. R. M., Borsje, B. W., Werf, J. J. van der, Dermentzoglou, D., Hofland, B., Antonini, A., & Hulscher, S. J. M. H. (2026). Wave-driven hydrodynamics around a saltmarsh cliff under storm conditions: The role of cliff height and vegetation. *Coastal Engineering*, *204*, 104875. https://doi.org/10.1016/j.coastaleng.2025.104875
[95]. Na Nagara, V., Sarkar, D., Neve, S., Saleh, H., Boufadel, M., Giri, S., & Datta, R. (2024). Repurposing spent biomass of vetiver grass used for stormwater treatment to generate biochar and ethanol. *Chemosphere*, *358*, 142196. https://doi.org/10.1016/j.chemosphere.2024.142196
[96]. Nassauer, J. I. (1995). Messy Ecosystems, Orderly Frames. *Landscape Journal*, *14*(2), 161–170. https://doi.org/10.3368/lj.14.2.161
[97]. Netusil, N. R., Lavelle, L., Dissanayake, S., & Ando, A. W. (2022). Valuing the public benefits of green roofs. *Landscape and Urban Planning*, *224*, 104426. https://doi.org/10.1016/j.landurbplan.2022.104426
[98]. Noaa. (2025, December 16). *Nature-Based Solutions*. https://coast.noaa.gov/states/fast-facts/natural-infrastructure.html
[99]. Nolan, S., Rossini, M., Knight, C., & Nanni, A. (2021). New directions for reinforced concrete coastal structures. *Journal of Infrastructure Preservation and Resilience*, *2*(1), 1. https://doi.org/10.1186/s43065-021-00015-4
[100]. Noorasyikin, M. N., & Zainab, M. (2016). A Tensile Strength of Bermuda Grass and Vetiver Grass in Terms of Root Reinforcement Ability Toward Soil Slope Stabilization. *IOP Conference Series: Materials Science and Engineering*, *136*(1), 012029. https://doi.org/10.1088/1757-899X/136/1/012029
[101]. Nordstrom, K. F., Hartman, J., Freestone, A. L., Wong, M., & Jackson, N. L. (2007). Changes in topography and vegetation near gaps in a protective foredune. *Ocean & Coastal Management*, *50*(11), 945–959. https://doi.org/10.1016/j.ocecoaman.2007.04.004
[102]. Ocenar, J., Arizala, D., Boluk, G., Dhakal, U., Gunarathne, S., Paudel, S., Dobhal, S., & Arif, M. (2019). Development of a robust, field-deployable loop-mediated isothermal amplification (LAMP) assay for specific detection of potato pathogen Dickeya dianthicola targeting a unique genomic region. *PLOS ONE*, *14*(6), e0218868. https://doi.org/10.1371/journal.pone.0218868
[103]. Oshunsanya, S. O., Li, Y., & Yu, H. (2019). Vetiver grass hedgerows significantly reduce nitrogen and phosphorus losses from fertilized sloping lands. *Science of The Total Environment*, *661*, 86–94. https://doi.org/10.1016/j.scitotenv.2019.01.129
[104]. Palinkas, C. M., Bolton, M. C., & Staver, L. W. (2023). Long-term performance and impacts of living shorelines in mesohaline Chesapeake Bay. *Ecological Engineering*, *190*, 106944. https://doi.org/10.1016/j.ecoleng.2023.106944
[105]. Pandey, K., Kumar, S., Sekar, K. C., & Roy, C. (2025). Vetiver grass as a nature based solution for soil and water conservation in the Garhwal Himalaya. *Discover Sustainability*, *6*(1), 1148. https://doi.org/10.1007/s43621-025-02014-x
[106]. Panja, S., Sarkar, D., Zhang, Z., & Datta, R. (2021). Removal of Antibiotics and Nutrients by Vetiver Grass (Chrysopogon zizanioides) from a Plug Flow Reactor Based Constructed Wetland Model. *Toxics*, *9*(4), 84. https://doi.org/10.3390/toxics9040084
[107]. Papadakis, G., Pantazis, A. K., Fikas, N., Chatziioannidou, S., Tsiakalou, V., Michaelidou, K., Pogka, V., Megariti, M., Vardaki, M., Giarentis, K., Heaney, J., Nastouli, E., Karamitros, T., Mentis, A., Zafiropoulos, A., Sourvinos, G., Agelaki, S., & Gizeli, E. (2022). Portable real-time colorimetric LAMP-device for rapid quantitative detection of nucleic acids in crude samples. *Scientific Reports*, *12*(1), 3775. https://doi.org/10.1038/s41598-022-06632-7
[108]. Petrolia, D. R., Interis, M. G., & Hwang, J. (2014). America's Wetland? A National Survey of Willingness to Pay for Restoration of Louisiana's Coastal Wetlands. *Marine Resource Economics*, *29*(1), 17–37. https://doi.org/10.1086/676289
[109]. Pompe, J. J., & Rinehart, J. R. (1994). Estimating the effect of wider beaches on coastal housing prices. *Ocean & Coastal Management*, *22*(2), 141–152. https://doi.org/10.1016/0964-5691(94)90016-7
[110]. Prasetyaningtiyas, G. A., Kamchoom, V., Leung, A. K., & Likitlersuang, S. (2024). Hydromechanical behaviour of a slope reinforced by grass roots under rainfall conditions. *Ecological Engineering*, *209*, 107427. https://doi.org/10.1016/j.ecoleng.2024.107427
[111]. Rahardjo, H., Satyanaga, A., Leong, E. C., Santoso, V. A., & Ng, Y. S. (2014). Performance of an instrumented slope covered with shrubs and deep-rooted grass. *Soils and Foundations*, *54*(3), 417–425. https://doi.org/10.1016/j.sandf.2014.04.010
[112]. Rahman, F., Chakraborty, A., Khan, S., & Salunke, R. (2024). Impact of Vetiver Plantation on Unsaturated Soil Behavior and Stability of Highway Slope. *Geosciences*, *14*, 123. https://doi.org/10.3390/geosciences14050123
[113]. Rajamanthri, K., Jotisankasa, A., & Aramrak, S. (2021). Effects of Chrysopogon zizanioides root biomass and plant age on hydro-mechanical behavior of root-permeated soils. *International Journal of Geosynthetics and Ground Engineering*, *7*(2), 36. https://doi.org/10.1007/s40891-021-00271-0
[114]. Rödl, A., & Arlati, A. (2022). A general procedure to identify indicators for evaluation and monitoring of nature-based solution projects. *Ambio*, *51*(11), 2278–2293. https://doi.org/10.1007/s13280-022-01740-0
[115]. Rojas-Sandoval, J. (2020). Chrysopogon zizanioides (vetiver). *CABI Compendium*, *CABI Compendium*, 18528934. https://doi.org/10.1079/cabicompendium.18528934
[116]. Sadiq, A.-A., Tyler, J., & Noonan, D. (2020). Participation and non-participation in FEMA's Community Rating System (CRS) program: Insights from CRS coordinators and floodplain managers. *International Journal of Disaster Risk Reduction*, *48*, 101574. https://doi.org/10.1016/j.ijdrr.2020.101574

[117]. Salauddin, M., & Pearson, J. M. (2019). Experimental Study on Toe Scouring at Sloping Walls with Gravel Foreshores. *Journal of Marine Science and Engineering*, *7*(7), 198. https://doi.org/10.3390/jmse7070198

[118]. Sánchez-Garrido, A. J., Navarro, I. J., García, J., & Yepes, V. (2023). A systematic literature review on modern methods of construction in building: An integrated approach using machine learning. *Journal of Building Engineering*, *73*, 106725. https://doi.org/10.1016/j.jobe.2023.106725

[119]. Scyphers, S. B., Beck, M. W., Furman, K. L., Haner, J., Josephs, L. I., Lynskey, R., Keeler, A. G., Landry, C. E., Powers, S. P., Webb, B. M., & Grabowski, J. H. (2019). A Waterfront View of Coastal Hazards: Contextualizing Relationships among Geographic Exposure, Shoreline Type, and Hazard Concerns among Coastal Residents. *Sustainability*, *11*(23), 6687. https://doi.org/10.3390/su11236687

[120]. Scyphers, S. B., Picou, J. S., & Powers, S. P. (2014). *Participatory Conservation of Coastal Habitats: The Importance of Understanding Homeowner Decision Making to Mitigate Cascading Shoreline Degradation*. https://doi.org/10.1111/conl.12114

[121]. Scyphers, S., Picou, S., & Powers, S. (2015). Participatory Conservation of Coastal Habitats: The Importance of Understanding Homeowner Decision Making to Mitigate Cascading Shoreline Degradation. *University Faculty and Staff Publications*, *8*(1), 41–49. https://doi.org/10.1111/conl.12114

[122]. Shah, S. S., & Asghar, Z. (2023). Dynamics of social influence on consumption choices: A social network representation. *Heliyon*, *9*(6), e17146. https://doi.org/10.1016/j.heliyon.2023.e17146

[123]. Shen, B., Shi, J., & Barton, N. (2018). An approximate nonlinear modified Mohr-Coulomb shear strength criterion with critical state for intact rocks. *Journal of Rock Mechanics and Geotechnical Engineering*, *10*(4), 645–652. https://doi.org/10.1016/j.jrmge.2018.04.002

[124]. Shi, J., Zhang, N., Sun, Y., Jiang, J., Duan, H., & Gao, W. (2025). The impact of virtual images of coastal landscape features on stress recovery based on EEG. *Scientific Reports*, *15*(1), 17369. https://doi.org/10.1038/s41598-025-02224-3

[125]. Smith, C. S., Puckett, B., Gittman, R. K., & Peterson, C. H. (2018). Living shorelines enhanced the resilience of saltmarshes to Hurricane Matthew (2016). *Ecological Applications*, *28*(4), 871–877. https://doi.org/10.1002/eap.1722

[126]. Smith, C. S., Rudd, M. E., Gittman, R. K., Melvin, E. C., Patterson, V. S., Renzi, J. J., Wellman, E. H., & Silliman, B. R. (2020). Coming to Terms With Living Shorelines: A Scoping Review of Novel Restoration Strategies for Shoreline Protection. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00434

[127]. Stafford, S. L. (2020). Encouraging Living Shorelines over Shoreline Armoring: Insights from Property Owners Choices in the Chesapeake Bay. *Coastal Management*, *48*(6), 559–576.

[128]. Su, J., Qiu, Y., Yang, X., Li, S., & Hu, Z. (2021). Dose–Effect Relationship of Water Salinity Levels on Osmotic Regulators, Nutrient Uptake, and Growth of Transplanting Vetiver [Vetiveria zizanioides (L.) Nash]. *Plants*, *10*(3), 562. https://doi.org/10.3390/plants10030562

[129]. Sun, H., Xu, J., Zhang, S., Li, G., Liu, S., Qiao, L., Yu, Y., & Liu, X. (2022). Field observations of seabed scour dynamics in front of a seawall during winter gales. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.1080578

[130]. Tanaka, K., Nelson, H., McCullar, N., & Parulekar, N. (2022). Citizens' preferences on green infrastructure practices and their enhancement in Portland, Oregon. *Journal of Environmental Management*, *318*, 115415. https://doi.org/10.1016/j.jenvman.2022.115415

[131]. Tangren, S., Toth, E., & Siegel, S. (2022). A survey of native plant materials use and commercial availability in the Eastern United States. *Native Plants Journal*, *23*(1), 17–54. https://doi.org/10.3368/npj.23.1.17

[132]. Tessema, B., Wilson, B., Daniel, H., Kristiansen, P., & Baldock, J. A. (2022). Functional Links between Biomass Production and Decomposition of Vetiver (Chrysopogon zizanioides) Grass in Three Australian Soils. *Plants*, *11*(6), 778. https://doi.org/10.3390/plants11060778

[133]. Tresballes, N. (2003, October 30). VETIVER (VETIVERIA ZIZANIOIDES L.) ECOTYPES ASSESSMENT FOR SALINITY TOLERANCE. *SABRAO Journal of Breeding and Genetics*. https://sabraojournal.org/vetiver-vetiveria-zizanioides-l-ecotypes-assessment-salinity-tolerance/

[134]. Truong, Dr. P., & Hengchaovanich, D. (1997). *Vetiver Grass System in Land Stabilisation, Erosion and Sediment Control in Civil Construction*. https://www.vetiver.org/AUS_stabilization.htm

[135]. Van Berkel, D. B., Tabrizian, P., Dorning, M. A., Smart, L., Newcomb, D., Mehaffey, M., Neale, A., & Meentemeyer, R. K. (2018). Quantifying the visual-sensory landscape qualities that contribute to cultural ecosystem services using social media and LiDAR. *Ecosystem Services*, *31*, 326–335. https://doi.org/10.1016/j.ecoser.2018.03.022

[136]. Veylon, G., Ghestem, M., Stokes, A., & Bernard, A. (2015). Quantification of mechanical and hydric components of soil reinforcement by plant roots. *Canadian Geotechnical Journal*, *52*(11), 1839–1849. https://doi.org/10.1139/cgj-2014-0090

[137]. Wang, G., Huang, Y., Li, R., Chang, J., & Fu, J. (2020a). Influence of vetiver root on strength of expansive soil-experimental study. *PLoS ONE*, *15*(12), e0244818. https://doi.org/10.1371/journal.pone.0244818

[138]. Wang, G., Huang, Y., Li, R., Chang, J., & Fu, J. (2020b). Influence of vetiver root on strength of expansive soil-experimental study. *PLoS ONE*, *15*(12), e0244818. https://doi.org/10.1371/journal.pone.0244818

[139]. Wang, G., & Sassa, K. (2003). Pore-pressure generation and movement of rainfall-induced landslides: Effects of grain size and fine-particle content. *Engineering Geology*, *69*(1), 109–125. https://doi.org/10.1016/S0013-7952(02)00268-5

[140]. Wang, G.-Y., Huang, Y.-G., Li, R.-F., Chang, J.-M., & Fu, J.-L. (2020). Influence of vetiver root on strength of expansive soil-experimental study. *PloS One*, *15*(12), e0244818. https://doi.org/10.1371/journal.pone.0244818

[141]. Wang, R., Brent, D., & Wu, H. (2022). Willingness to pay for ecosystem benefits of green stormwater infrastructure in Chinese sponge cities. *Journal of Cleaner Production*, *371*, 133462. https://doi.org/10.1016/j.jclepro.2022.133462

[142]. Wen Chen, X., Fung Wong, J. T., Wang, J.-J., & Hung Wong, M. (2020, March 14). *Vetiver grass-microbe interactions for soil remediation: Critical Reviews in Environmental Science and Technology: Vol 51 , No 9—Get Access*. https://www.tandfonline.com/doi/full/10.1080/10643389.2020.1738193

[143]. Wetli, P. (2024, November 11). *Turf Grass Is America's Default Lawn Setting. Chicago Researchers Are Rethinking the Possibilities*. WTTW News. https://news.wttw.com/2024/11/11/turf-grass-america-s-default-lawn-setting-chicago-researchers-are-rethinking

[144]. White, A. E., Cohn, N., Davis, E. H., Hein, C. J., & Zinnert, J. C. (2024). Coastal dune management affects above and belowground biotic characteristics. *Scientific Reports*, *14*(1), 22688. https://doi.org/10.1038/s41598-024-73312-z

[145]. Whittet, R., Cottrell, J., Cavers, S., Pecurul, M., & Ennos, R. (2016). Supplying trees in an era of environmental uncertainty: Identifying challenges faced by the forest nursery sector in Great Britain. *Land Use Policy*, *58*, 415–426. https://doi.org/10.1016/j.landusepol.2016.07.027

[146]. Wieczerak, T., Lal, P., Witherell, B., & Oluoch, S. (2022). Public preferences for green infrastructure improvements in Northern New Jersey: A discrete choice experiment approach. *SN Social Sciences*, *2*(2), 15. https://doi.org/10.1007/s43545-022-00315-w

[147]. Wu, S. C., Wong, C. C., Shu, W. S., Khan, A. G., & Wong, M. H. (2011). Mycorrhizo-remediation of lead/zinc mine tailings using vetiver: A field study. *International Journal of Phytoremediation*, *13*(1), 61–74. https://doi.org/10.1080/15226511003671353

[148]. Xie, S., Lin, H., Chen, Y., & Ma, T. (2024). Modified Mohr–Coulomb criterion for nonlinear strength characteristics of rocks. *Fatigue & Fracture of Engineering Materials & Structures*, *47*(6), 2228–2242. https://doi.org/10.1111/ffe.14278

[149]. Zahran, S., D. Brody, S., E. Highfield, W., & Vedlitz, A. (2010, February 24). *Non-linear incentives, plan design, and flood mitigation: The case of the Federal Emergency Management Agency's community rating system: Journal of Environmental Planning and Management: Vol 53 , No 2—Get Access*. https://www.tandfonline.com/doi/full/10.1080/09640560903529410

[150]. Zalejska-Jonsson, A., Wilkinson, S. J., & Wahlund, R. (2020). Willingness to Pay for Green Infrastructure in Residential Development—A Consumer Perspective. *Atmosphere*, *11*(2), 152. https://doi.org/10.3390/atmos11020152

[151]. Zhang, Y., Bi, K., Pan, J., Xi, X., Zhang, D., Miao, S., & Cai, M. (2023). Study on Hydro-Mechanical Coupling Failure and Permeability Enhancement Mechanisms for Sandstone with T-Shaped Fractures. *Materials*, *16*(8), 3118. https://doi.org/10.3390/ma16083118

[152]. Zheng, S., Zhang, G., Yuan, X., Ye, F., & Fu, W. (2020). Failure characteristics of shallow soil slope considering surface runoff and interstitial flow. *Geomatics, Natural Hazards and Risk*, *11*(1), 845–868. https://doi.org/10.1080/19475705.2020.1758222

[153]. Zhu, K. (2023, October 30). Grass lawns: An outdated and wasteful aesthetic. *The UCSD Guardian*. https://ucsdguardian.org/2023/10/30/grass-lawns-an-outdated-and-wasteful-aesthetic/