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Perspective

Financial incentives for large-scale wetland restoration: Beyond markets to common asset trusts

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https://doi.org/10.1016/j.oneear.2021.06.006

SUMMARY

Wetlands provide ~$47.4 trillion/year worth of ecosystem services globally and support immense biodiversity, yet face widespread drainage and pollution, and large-scale wetlands restoration is urgently needed. Payment for ecosystem service (PES) schemes provide a viable avenue for funding large-scale wetland restoration. However, schemes around the globe differ substantially in their goals, structure, challenges, and effectiveness in supporting large-scale wetland restoration. Here, we suggest wetland-based PES schemes use common asset trusts (CATs) to build investment portfolios of wetlands across landscapes that sustain and enhance overall provision of multiple ecosystem services. CATs can meet the needs of multiple investors, permit bundled payments, and provide flexibility to invest in the restoration of numerous services/values, all using a coordinated, highly collaborative, prioritized, and transparent process. CATs would support financial viability, facilitate efficiency to reduce administrative burdens, and enable credibility and social licence building to restore wetland values and services globally.

INTRODUCTION

Wetland restoration can contribute significantly to meeting many global, national, and local goals and initiatives, including several United Nations (UN) Sustainable Development Goals (SDGs).[1,2] Using the Ramsar definition, wetlands include any inland, coastal, or marine waterbody, still or flowing, fresh or saline, permanent or temporary, to a depth of 6 m at low tide.[3] This includes fens, peat bogs, swamps, marshes, oyster reefs, rivers, lakes and artificial water bodies, mangroves, seagrass meadows, mudflats, and some coral reefs. In many cases, wetlands also include adjacent riparian and coastal zones.[3] Wetland ecosystems provide a range of ecosystem services (i.e., the benefits to humans from ecosystems), including water purification, carbon sequestration, food provision, flood regulation, storm surge protection, and ecotourism, and support biodiversity, and cultural and spiritual values.[1] The global value of wetland ecosystem services is estimated at ~$47.4 trillion/year, with estuarine and palustrine wetlands among the most service-rich ecosystems relative to extent.[4,5] The total value of ecosystem services to human wellbeing comprises both market (market price or exchange values) and non-market values. Estimates of the total value are required to truly recognize the contribution the wetlands make to human wellbeing, and to enable us to appropriately determine the ecosystem services most in need of protecting from degradation or loss.

Despite the well-established provision of ecosystem services, global wetland extent is still declining.[6] Davidson[7] estimates that 54%–57%, and possibly as much as 87%, of global wetlands have been lost as a result of land use change for agricultural, urban, and industrial expansion. Large-scale wetland restoration would directly support the UN SDGs by providing a critical buffer against global climate change, improving water quality, increasing infrastructure resilience to floods and storm surge, protecting or enhancing biodiversity, and addressing food supply crises.[2,8]

The protection and restoration of wetlands is being facilitated by many policy instruments, including outreach and education (e.g., awareness campaigns), international conventions (e.g., the Ramsar Convention and Convention on Biological Diversity), governance instruments (e.g., national policies and programs), regulatory approaches (e.g., environmental standards), covenants and easements, environmental taxes, restoration subsidies, and market-based approaches (e.g., environmental markets and eco-labeling).[9–11] Among these approaches, public/private funding schemes that include payments for ecosystem services (PES), provide a potential way of raising the financial capital needed to deliver large-scale wetland restoration.[12–14] PES schemes may be regulated (e.g., government-led programs to achieve legislated environmental limits) or voluntary (e.g., non-government organization-led programs to achieving non-binding goals), and seek to provide payment for the additional or sustained existing ecosystem services that restored ecosystems provide, often to offset impacts elsewhere.

PES schemes have primarily arisen from trading carbon for climate change mitigation or trading nutrients for water quality improvement, mitigation banking, or sale of habitat protection/restoration "stamps."[12,15] New scheme mechanisms (e.g., crowd funding), new support technologies (e.g., block-chain mechanisms and remote sensing), and new opportunities (e.g., blue carbon, property protection,[16] and bioenergy) are on the horizon and present options for schemes that endeavor to fund future wetland restoration within the UN "decade of ecosystem restoration (2021–2030)."[17]

While promising, PES schemes do not often deliver the expected benefits from wetland restoration.[15,18,19] These failures can arise where wetland restoration is a secondary objective or a tool supporting a primary objective (e.g., reducing carbon or improving water quality) and where the schemes face their own difficulties.[20] For example, a review of the effectiveness of four North American water quality trading schemes (in which, wetlands are one of many options for improving water quality) identified many challenges, including inadequacy in monitoring, low participant motivation,[21] difficulties in achieving and enforcing compliance, ill-defined property rights, and high administrative and transaction costs.[22] Similar challenges were also identified by a review of PES schemes across China.[20] It is likely that PES-based restoration schemes in other locations will face similar and scheme-specific challenges. If wetland restoration is to deliver a substantial contribution toward local ambitions and ultimately global SDGs,[1,2,23] it is imperative that financial incentive mechanisms, such as PES, are well designed to maximize success in achieving a chief objective of large-scale wetland restoration. This is in contrast to existing schemes that typically primarily focus on ecosystem service provisioning and have wetland restoration as a secondary objective.

Notable types of PES schemes providing incentives for wetland restoration include carbon markets; water quality trading; habitat stamps and wild harvesting; eco-labeling; crowd funding; and water funds. While each scheme has advantages, disadvantages, and room for improvement (Table S1), three cross-cutting challenges exist: (1) demonstrating sustained financial viability; (2) establishing credibility with effective verification and accounting; and (3) balancing trade-offs to achieve general acceptability, and to establish and maintain social license to operate (Table S1).[24–26]

Here, we suggest that PES schemes dedicated to, and specifically designed for, wetland restoration will be more effective than single-service-focused schemes and non-financed instruments in not only increasing the rate and extent of wetland restoration, but also increasing the flow of multiple ecosystem services. Taking on board the challenges faced by many PES schemes (Table S1), we propose using a common asset trust (CAT) approach as the platform for a PES scheme designed to enhance wetland restoration efforts. Below we analyze the three main challenges for PES schemes and how these challenges may be overcome. We then outline how a CAT could solve many of these challenges to enhance wetland restoration, and identify the roles and responsibilities of key stakeholders.

COMMON CHALLENGES ACROSS SCHEMES

The three key challenges across schemes are financial viability, credibility, and maintaining a social license to operate.

Financial viability

Financial viability is critical to the success of any PES scheme. Funding is often insufficient, intermittent, or highly variable, to confidently cover the costs of wetland restoration (including the opportunity cost of land use change), associated assessments, monitoring and administration, and on-going maintenance after construction.[27–29] Financial viability rests on sufficient, stable, and sustained payments for projects and acceptable rates of return for project investors (including public financers seeking societal benefits). Highly variable provision of services may lower investor confidence in returns, deter investors, and erode financial viability. In addition, sometimes measuring/estimating service flows requires complex and expensive assessments to boost confidence.[14,30,31] Often, schemes trade a single-service commodity (e.g., credits for carbon sequestration or nitrogen removal), rather than rewarding the provision of multiple services, where restored wetlands are designed and positioned to optimize cost-effective delivery of that service (Tables S1 and S2).[18,32]

As wetlands can deliver multiple ecosystem services,[1] schemes that focus on a single service (i.e., the primary benefit) do not value and reward the provision of co-benefits (i.e., the secondary benefits).[33] Carbon markets, for example, offer low and highly variable trading prices, with compliance markets having greater demand (driven by legislated limits) and offer better prices than voluntary markets (Figures S1–S3).[34–36] Wetland-based carbon sequestration projects are often only viable and competitive against other offset options in low-cost developing countries, e.g., the Sundarbans Mangrove Restoration in India (Note S1).[28,36,37] Even then, Vietnam's Markets and Mangroves project (Note S2) within the Mekong Delta initially sought funding by selling carbon credits, but were deterred by the administrative cost burden, and instead were funded by an organic eco-label.[38] Trading prices are often insufficient to deliver positive returns from wetland restoration in countries with developed economies.[36,37]

Quantification of ecosystem service provision in market-based schemes can often constitute a substantial cost that affects financial viability.[31,36,39] For example, Günther et al.[40] estimated in 2018 that assessing carbon for a 52 ha re-wetted fen in north-eastern Germany cost between €150,000 and €300,000 over 2–3 years. Several mechanisms, including standard setting, applying trading ratios and using direct fund investment, have been trialed to reduce the compliance costs of participating in wetland restoration projects. Germany's MoorFutures regional carbon trading scheme has increased the financial viability of peat-wetland restoration by reducing compliance costs through the setting of local assessment methods and standards (Note S3).[41,42]

North American point-nonpoint source water quality trading markets (e.g., Colorado's Cherry Creek and Ontario's South Nation River schemes; Notes S4 and S5, respectively),[22,43] and wetland biodiversity mitigation markets (e.g., Chicago's wetland mitigation market; Note S6),[44,45] often apply trading ratios, which tend to be conservative, to account for uncertainties in service delivery. Trading ratios are a policy mechanism that require polluters or property developers to offset more than the estimated discharge or loss. For example, Ontario's South Nation River phosphorus trading scheme requires polluters to offset four times the amount of phosphorus discharged (Note S5). Trading ratios could allow for less onerous assessment methods, improving the cost effectiveness of restoring larger wetlands.[22,43] However, very high ratios may render wetland projects uncompetitive against other offset options. Using trading ratios with complementary assessment models or simple estimates of efficacy, can increase certainty, ease monitoring costs, and thereby increase competitiveness compared with other offsets.[46–48] In California's carbon trading scheme (Note S7), wetland restoration has not been driven by credit-generating activities, but from direct investment by the Greenhouse Gas Reduction Fund (funded by the State's revenue from the scheme), which do not require credit generation, bypassing the need for carbon assessment altogether (Note S7).[49]

Fund-based schemes, such as the Latin American water fund (LAWF) schemes, such as those in Mexico, Colombia, Ecuador, Peru, Dominican Republic, and Brazil, and habitat stamp schemes, such as those in the US, Canada, and New Zealand (Note S8; Table S1), have both demonstrated financial viability and efficiency in supporting large-scale wetland restoration.[50–53] For example, the US Federal Duck Stamp, which must be purchased prior to hunting waterfowl, has restored over 2.4 million ha of wetlands.[50] Funds are pooled from multiple sources into a trust, managed by trustees tasked with strategically investing in restoration activities that support trust objectives (e.g., gamebird hunting or improving water quality/quantity). Multiple funding sources support financial resilience but do not guarantee immunity against financial variability.[51,52] Habitat stamp schemes are often funded through hunter licensing and are vulnerable to societal changes in hunting participation.[54,55] While LAWF schemes are funded from a range of public, utility, NGO, multilateral, and private investors, they remain vulnerable to loss of single, large funding sources.[52]

Restoration investment is often financed via a combination of a fund's principal and interest, depending on the size and pace of restoration required balanced against the need to buffer market and political volatility.[52,53] As funding is not dependent on trading revenues from the sale of rival and excludable goods/services (i.e., the goods and services the ecosystem produces; outputs), monetary transfers can be based on activities that generate increases in the provision of ecosystem services (i.e., wetland restoration; inputs). With habitat stamp schemes, restoration activities provide gamebird habitat and broader conservation value (input-based approach); however, hunters are not guaranteed a specific gamebird population size (output-based approach; Note S8). In LAWF schemes, restoration activities may support sediment reduction (input-based approach), but do not guarantee a downstream water quality standard (output-based approach). While outputs in such schemes are not traded, outputs are still measured to evaluate efficacy, support adaptive management, inform future investments, and entice new funding, and are important to ensure that environmental goals are achieved.[51,52] Fund structures that include a centralized agency means the assessment and administrative burden can be low relative to environmental market approaches.[31,39,53] Both habitat stamp and LAWF schemes offer many learnings that could be used to improve the success of PES schemes in restoring wetlands (Table S1).

In contrast to the LAWF schemes that bundle payments for multiple ecosystem services, schemes that stack payments (award discrete payments for multiple services) have rarely been implemented and are often prohibited. Stacking is largely an output-based approach where separate payments are given for each quantifiable service provided, which differs from bundling (largely input-based) where a single payment is given for a package of services.[39,56] Stacking can have high assessment and administrative burdens, as each service requires its own evaluation. This may be particularly burdensome when many services require assessment, reducing the cost effectiveness of the scheme (Table S1). Assessing additionality for stacking can be challenging. For example, if a carbon payment is already received for wetland restoration, an additional environmental improvement may be required to receive further payments for supplying nitrogen removal.[56–58] While stacking can improve financial viability and increase the broader conservation benefit via greater restoration, a potential downside is that increased supply of wetlands could devalue the credit trading prices for provision of individual services.[39,59,60] This, however, could be an advantage if reducing service provision costs is the goal. Simulated credit stacking within the Baltic Sea nutrient trading markets indicates a $\sim$20% reduction in nutrient credit costs as credit supply increases relative to demand.[61] The financial viability of output-based schemes rests heavily on the ability and credibility to provide and assess the additional ecosystem service desired.

Establishing and maintaining scheme credibility

For market-based schemes that incentivize the provision of ecosystem services to be credible, they must demonstrate at least four features[35,39]: (1) *additionality*, where projects need to demonstrate that the offset would not have occurred under a business as usual scenario (e.g., that the generated pollution abatement is additional to that accounted for when pollution discharge licenses and/or catchment load caps were set); (2) *leakage minimization*, where projects need to show a net gain in provision of ecosystem services; i.e., additional provision of ecosystem services has not been outweighed through adverse changes in practice or land use elsewhere; (3) *permanence*, where projects need to minimize the risk that future developments will reduce or remove the benefits delivered, such as a restored wetland being drained again; and (4) *verification*, where benefits need to be measurable and reported in a transparent fashion to ensure environmental gains are realized.[35,39]

The first three requirements can be strengthened (but not necessarily guaranteed) by having a robust accounting framework with baseline data on conditions (at a sufficiently broad scale), and legally binding covenants and safeguards where needed. The fourth requires cost-efficient and repeatable assessment methodologies (including models based on proxies) being available to projects via sound governance.[35,39] Many market-based schemes struggle to satisfy these four requirements, often lacking robust wetland mapping and accounting of the extent and condition, or requiring onerous assessment of ecosystem service provision (Table S1).

The delivery of ecosystem services by wetlands occurs at multiple scales, underpinned by complex processes that vary spatially and temporally, making quantification of ecosystem services difficult and costly. This can lead to distrust in service provision. Denitrification processes in wetlands, for example, is highly variable (both spatially and temporally) and dependent on inlet nutrient delivery concentrations, wetland size and shape, hydrology, hydraulic residence times, vegetation, temperature, and redox potential.[62] Accurate assessment of variability requires intensive monitoring. The estimation of carbon sequestration for carbon offsets, increased waterfowl population for hunters, sediment removal for drinking water supplies, species occurrences for biodiversity conservation, and other services would be similarly difficult to accurately assess.[31,63,64] Models can be used to estimate service provision; however, they would need to be underpinned by science, validated, reliable, peer-reviewed, robust, and used by appropriately trained operators to be acceptable.[65,66] New Zealand's water quality schemes demonstrate how uncertainties in assessment models can lead to skepticism about the benefits of wetland restoration (Note S9).[67] The use of robust and accepted proxies, models, and standards in Germany's MoorFutures carbon scheme (Note S3); the use of models and conservative estimates of service provision in North American water quality trading schemes (Notes S4 and S5); and the use of input-based assessments (i.e., wetlands meeting a predetermined design standard) rather than output-based assessments (i.e., estimation of service provision) in habitat stamp and water fund schemes,[31] all demonstrate alternative options for avoiding intensive, costly assessment of ecosystem service provision.

In addition to assessment, schemes that need to demonstrate additionality must establish baseline service provision and ensure that leakage is minimal (i.e., that losses are not occurring concurrently).[31,68] For example, an exhaustive survey of US biodiversity mitigation bank schemes in 2006 found that they consistently lacked a maintained database of wetland mitigation bank transactions and sufficient detail to allow third-party verification.[69] Furthermore, reviews of the schemes in Chicago and Florida observed that ~60% of credits have been sold without meeting prescribed ecological performance standards, suggesting that they are either sold immaturely, are poorly developed projects, or have suffered from natural uncertainty.[45,70] The lack of robust and transparent accounting, which is then communicated and used in decision-making, makes it difficult to establish social credibility as the community may be cynical about the validity of offsets and additionality provided.

Social license to operate

All schemes have the potential for both positive and negative impacts, and may create winners and losers, perceived or real. While consensus among stakeholders is highly unlikely, trade-offs need to be managed to ensure schemes are socially acceptable; schemes may be rendered unviable if their social licence is not established or is lost.[71,72] A social licence is the acceptance of an activity or system granted by the community to operate. This is critical for those schemes reliant on legislated environmental limits and legislated trading, as democratic political decisions are highly sensitive to societal appetite. Without a social licence, politicians in a modern democracy are unlikely to support a scheme, which ultimately threatens scheme viability. Trade-offs may arise at multiple points within a scheme as conflict can arise both within and between environmental, social, cultural, and economic goals, including the UN SDGs (Table S1). Contentious areas of trade-off may include differences in ecosystem service provision driven by wetland location and design, and the alteration of individual and/or community use rights.[73–75]

Wetlands differ considerably in the type and amount of ecosystem services generated.[64] Restored wetlands are typically designed to enhance the ecosystem service that attracted the funding for restoration (e.g., nutrient attenuation, carbon abatement, biodiversity payments, waterfowl hunting, or tourism; Table S2). Enhancing the delivery of one ecosystem service can reduce the delivery of other services, potentially creating conflict between goals.[74,75] For example, in Australia an earth wall removed on a floodplain allowed saltwater ingress inland (as an alternative to herbicides) to destroy freshwater aquatic weeds, and also delivered increased carbon sequestration from mangrove expansion, but at the expense of degrading freshwater wetland habitat, used by fish, turtles, and waterbirds.[76]

Likewise, wetlands designed to denitrify nitrogen loads can have low carbon storage and rely on hypoxic conditions that adversely affect wildlife.[77–79] Both examples show potential conflicts between different restoration goals, including the SDGs for carbon action, life below water, life on land, and for clean water and sanitation. Having clear objectives at the outset that are broadly agreed upon by stakeholders, with decision-making well informed of potential consequences, will be necessary for reducing unintended consequences and maintaining a scheme's social licence.[31,80]

Conflicts may arise between environmental and social goals. Poorly implemented restoration schemes—including those supported by PES can result in the loss (or perceived loss) of community use rights sometimes referred to as "green grabbing" and "blue grabbing" in terrestrial and aquatic conservation, respectively.[81,82] Despite good intentions and substantial consultation, agencies and organizations that carry out wetland restoration in areas where communal areas are a common pool resource can disrupt local social norms and displace users reliant on the resource.[83–85] Community displacement can also be exacerbated when developers, and their scientific support partners, make over-zealous promises of outcomes or provision of ecosystem services that are not realized.[86,87] Examples of community displacement have primarily been observed in Africa (e.g., Note S11), Asia, and South America.[88]

The alteration of individual use rights, such as the allocation of pollutant discharge rights/permits to individuals in water quality and carbon trading schemes, can also affect scheme acceptability and viability. By way of example, litigation over the nutrient

Table 1. Eight guiding principles of an effective ecosystem-based CAT, as proposed by Costanza et al.,[97] and the aligning WIF features

Guiding principle	Brief description	WIF features
1. Stewardship responsibility	The trustees have a mandate to sustainably manage the trust to ensure ecosystems are healthy and continually provide services for future generations.	Managed using a deliberative democratic approach with representatives from all stakeholders, including indigenous membership and scientific advisory, that set and work toward wetland restoration objectives that align with local values. Supported by a local scientific/technical support partner, local indigenous/traditional owners, government, and stakeholders.
2. Systems thinking	The scheme should consider the broad socio-ecological system, with a focus on improving the health and wellbeing of its beneficiaries. Economic, social, cultural, and ecological connectivity across the landscape is understood.	The WIF role includes the early and adaptive identification of values and objectives across the landscape, using spatial planning. This would be informed by working with support partners and stakeholders. Optimal restoration project design and locations would be guided by outputs from the scientific support partner, using tools, such as modeling and multi-criteria analysis.
3. Additionality	Scheme activities to increase ecosystem services should be additional to any in existence or being created by other initiatives and not be lost by destruction elsewhere.	Government would need to ensure legislation supports a no net loss of wetlands policy and operate a broader wetland accounting framework. The scientific support partner would operate a database on the condition, extent, and performance of portfolio wetlands. The WIF would also advocate for the protection of freshwater environments to ensure gains are not lost elsewhere and the integrity of the wetland portfolio is maintained or even improved.
4. Conditionality	Payments should be conditional to the successful provision of the outcomes agreed in contract.	Project developers would be required to demonstrate satisfaction of contracted deliverables by having a trained and approved assessor verify the project deliverables. The scientific support partner would audit assessors and carry out portfolio-wide monitoring with technologies, such as remote sensing would. Deliverables would be based on the provision of inputs, which are more easily verifiable than outputs.
5. Efficiency	The CAT should be efficient in achieving outcomes, with funds invested in high-return projects and maintain low transaction costs.	The WIF operating as a "one-stop shop" for the range of funders and developers to reduce administrative burden, and enabling bundling of funds allowing for large projects that benefit from efficiencies of scale. Spatial planning, supported by guidance on strategic restoration from the scientific support partner, allows for the design and position of wetlands that support optimal provision of desired ecosystem services. Verifying projects using contracted inputs, rather than highly variable outputs, increases assessment efficiency and financial return on investment.

(*Continued on next page*)

Table 1. ***Continued***

Guiding principle	Brief description	WIF features
6. Financial sustainability	The trust should secure sufficient funding to remain financially viable and be resilient to social and economic stressors.	The WIF is not limited to provision of a single ecosystem, but flexible to invest in any ecosystem service desired from wetlands. As a result, it can accept and aggregate funds from a wide range of potential sources (Table S2), and invest in a range of wetland restoration projects potentially supporting different services (Figures 1 and 2; Table S2), allowing the fund to hedge bets for both investors and investors. Fund managers can also choose the extent to which funds invested in restoration are sourced from principal or interest earned on principal, which helps to balance growth with resilience to political and market volatility.
7. Intersectoral participation	The trust should operate under a participatory approach, being inclusive of all stakeholders.	The WIF would have strong partnerships with a local scientific/technical support partner and local indigenous/traditional owners. There would also be strong participation by stakeholders, including investors, project developers, and local community.
8. Legally sound	The trust should be established and protected by a set of laws, regulations, policies, and contracts to sustain it over time.	In many jurisdictions, trusts or similar are legally well established. Legal assistance and a partnership with government can help ensure the scheme has adequate legal safeguards.

discharge allocation method in the regulatory limit has stalled the implementation of New Zealand's Rotorua Lakes nitrogen trading scheme (Decision [2019] NZEnvC 136) (Note S11). Contention arose over whether to grant the largest polluters large initial allocations of pollutant discharge rights (to minimize economic disruption) or whether the allocation of discharge permits should be based on land characteristics (to avoid rewarding polluters, incentivize land use positioning, and reduce inequality) (e.g., Decision [2019] NZEnvC 136 and Decision [2017] NZEnvC 037). Similar contentions over the preferred allocation method is also observed in carbon trading schemes, such as the EU ETS (Note S12),[89,90] and China's recent National Carbon Trading Scheme (Note S13).[91,92]

While there appears to be no "one-size-fits-all" approach to achieving general acceptability, the importance of indigenous partnerships and engaged participation of all local stakeholders, particularly when identifying scheme values and objectives, is important for PES schemes.[93] The early identification of catchment community values and scheme objectives, including how values vary temporally, spatially and existing dependencies on ecosystem services can reduce conflicts and trade-offs, increase acceptability and efficiency in achieving objectives, and minimize disruption of local norms.[94–96] Furthermore, moving from site-scale to landscape-scale PES schemes can allow for greater incorporation of diverse stakeholders as different sites can be tailored to meet different needs, which could be facilitated by applying spatial multi-criteria analysis.[31,73]

Forcing all ecosystem services to fit within conventional markets designed for rival and excludable goods is challenging[97] (Table S1). Ecosystem services differ substantially in the extent to which they are rival and excludable, which are conditions necessary for well-functioning markets.[14,72] Many ecosystem services provided by wetlands are not easily excluded (e.g., fish migration to the open ocean and pollutants), are non-rival (e.g., flood protection), and scarcity is often the result of legislatively imposed constraints. Given the variable nature of wetlands, promising a level of service provision to those seeking to purchase offsets *a priori* (e.g., 100 t of carbon will be sequestered over the next 10 years) will be fraught with risk and difficult to guarantee. Any promises of offset made would need to ensure they are meaningful and achievable, reliant on a solid understanding of the local context, ecosystem functioning, baseline conditions, natural feasibility, and social realities. By contrast, adopting a "pay by performance" approach, where fund income is dependent on the selling of credits realized over (say) the previous 5 years would provide variable and uncertain revenue streams, particularly when reliant on trading a single service (while multiple services allows hedge betting).[39,97] This can create an intense focus on assessment, to have confidence in ecosystem service delivery and financial returns. Assessments can be complex, have high uncertainty, and may reduce financial viability. Using models and conservative estimates of service provision can help alleviate the assessment burden but would require larger areas of wetlands to be restored to achieve financial viability.[65] Mechanisms that trade single services are also vulnerable to changes in buyer demand, which can occur if societal values change or legislated limits ("caps") are weakened, removed, or are met.

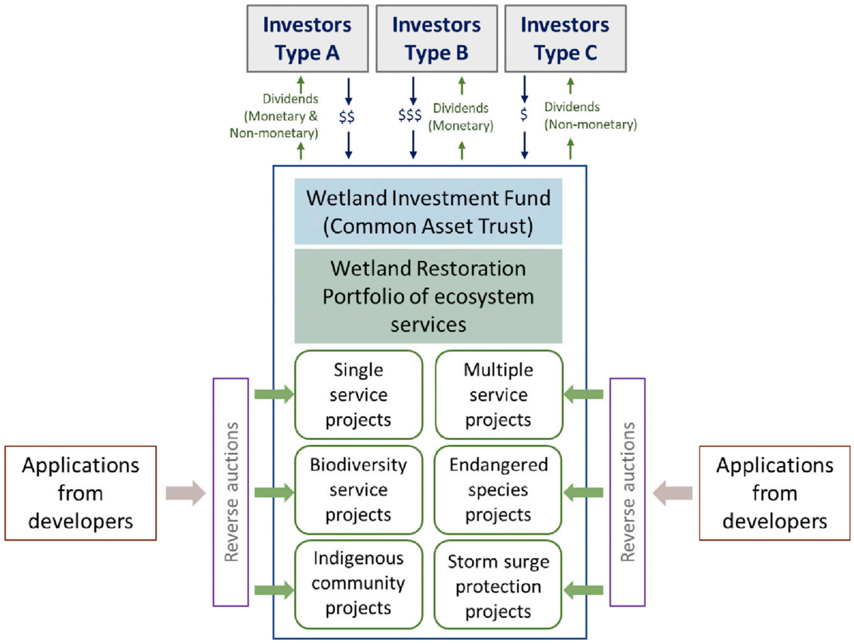


Figure 1. The monetary and service flows between investors, developers, and a proposed wetland restoration investment fund

MOVING FORWARD WITH CATs

An effective PES scheme would ensure the restored ecosystems, and those already in existence, are healthy and safeguarded from detrimental impacts. The scheme would need to support the "wise use" of wetlands, which is a central tenet of international wetland conservation and management policy, such as the Ramsar Convention.[98] Although the concept of wetlands wise use has developed from an ecological worldview, more recent views suggest that this should involve adopting a broader social-ecological worldview that includes social values. A social-ecological view of wise use requires the abiotic (physical components), biotic (biological components and processes), and resource user (individuals and communities that interact with the abiotic and biotic) variables of wetland character to be managed.[98] The scheme would have to be financially viable, requiring reasonably stable income sufficient for covering the costs of restoring and maintaining desired ecosystems. Estimation of service delivery would need to be reliable and credible; and the scheme would need to ensure it is socially and culturally acceptable in the jurisdiction in which it exists.[31,39] Early identification of values and objectives would be necessary to effectively and efficiently deliver outcomes that meet stakeholder expectations. The scheme may require strong indigenous partnership and community engagement to ensure the values, objectives, and projects are well informed and socially viable.[31,39] The objectives, guided by values, would need to recognize that not all wetlands provide the same services and allow for trade-offs in service provision. Restoration activities would need to be high quality and maintained in the long term to ensure continued service provision.

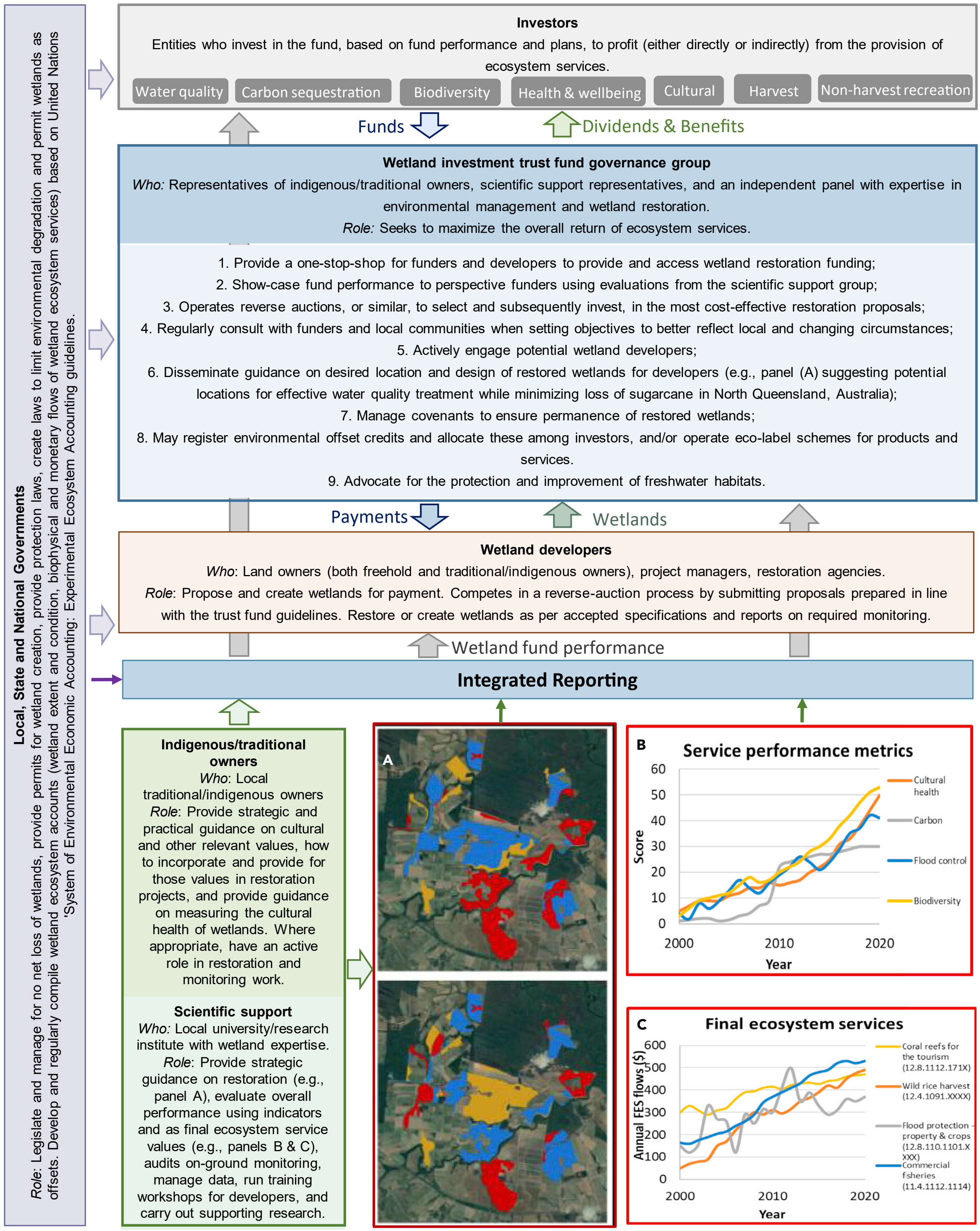
Recently, Costanza et al.[97] proposed thinking of ecosystems (natural capital) as common property, given that many ecosystem services are non-excludable and/or non-rival, and proposed that ecosystems are more effectively managed through CATs. A typical trust involves trustees managing assets on behalf of specific beneficiaries. In the context of ecosystems, a CAT would be a collection of agreements, institutions, and funds that sustainably manages ecosystems (assets) for their benefits (i.e., for delivery of ecosystem services). The implementation of CATs could have multiple benefits, including: having well-established legal mechanisms, with conflict resolution procedures; being objective-focused; permitting flexibility in the investors and investment decisions, enabling investment in multiple ecosystem services; flexibility when dealing with existing property rights by being able to support a mix of property right regimes; allowing a coordinated framework for strategic planning; providing a platform for high levels of collaboration; and supporting administrative and transaction efficiency.[97] In the context of wetlands restoration, a CAT (in contrast to individually managed projects) could manage multiple individual projects under a single unity to efficiently and strategically achieve landscape-scale objectives (Table 1), whereas individually managed projects would likely be ad-hoc and not benefit from the economies of scale.

While CATs present many benefits, the largest downside, as with any new cooperative institution, establishment may be hindered by resistance from vested interests who must be convinced that the new system will be broadly beneficial.[99] Effectively mitigating this risk will inevitably rest heavily on the ability of the CAT to practice deliberative democracy, inclusive policy-making, and identify the communities' values and goals comprehensively early on.

Schemes that focus on wetland restoration could benefit from using a CATs approach, similar to the LAWF and habitat stamp schemes, whereby wetlands are considered as common assets, rather than as providers of independent privitizable services. Here, we outline a Wetland Investment Fund (WIF) scheme structure that aims to: (1) drive large-scale wetlands restoration at multiple locations; (2) operate as an effective CATs, consistent with Costanza et al.'s[97] eight guiding principles (which are based on Ostrom's social-ecological systems approach[100]); and (3) to either avoid, remedy, or mitigate the challenges observed in existing non-wetland focused PES schemes (Figure 1; Table 1).

WIF

A WIF, functioning as a CATs, would aim to maximize the overall return of ecosystem service flows, both monetary and non-monetary, arising from a portfolio of wetland restoration projects (i.e., ecosystem service return on investment from wetland ecosystems; Figure 2).[101] Akin to a conventional managed fund, the



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WIF could accept investment from multiple *investors* and invest in multiple wetland restoration projects that support multiple scheme objectives,[101] with any benefits arising from the portfolio returned to investors as "dividends" either directly (where excludable and rival) or indirectly (where non-excludable and/or non-rival). For directly apportionable services, investors could choose whether to take their share of any credits generated or the proceeds from the sale of their credit share on a trading market. For example, an airline investor may wish to use their share of carbon credits generated to offset their greenhouse gas emissions, while a finance manager may seek payment from the sale of their share of carbon credits, and a conservation investor may wish the proceeds of their carbon credit share to be invested back into the fund. Under a WIF, fund managers (i.e., the trustees) would have the flexibility to invest in either individual restoration projects that capitalize on the provision of a single service (e.g., improving water purification), or others with multiple complementary objectives, which then collectively increase the overall value of ecosystem services flowing from the portfolio of wetland restoration sites (Figure 3). A local scientific/technical support agency could provide strategic guidance on restoration activities and assess the overall fund performance, based on both intermediate and final ecosystem services.[102]

The WIF could disburse payments to *project developers* (those restoring wetlands) using a reverse-auction format. Reverse auctions have been shown to deliver greater cost effectiveness for the delivery of other conservation and wetland restoration programs than uniform payments.[105,106] Reverse auctions are where individuals/organizations submit a bid for the minimum amount they are willing to accept to undertake a wetland restoration project. Bids are then ranked based on the ecosystem service provision generated by the project and the bid amount.[105,106]

The WIF's funding would come from *investors* who seek dividends from one or multiple ecosystem services generated by the portfolio of restored wetlands. Fund performance, in terms of trends in the ecosystem services return on investment, would attract new investors (Figures 1–3). Investors interested in single ecosystem services, such as airlines seeking carbon abatement, may choose to invest based on historical performance, and anticipated (but not guaranteed) future improvements based on restoration plans for their focal service (e.g., trends in estimated CO_2 equivalent abated). Additional complementary benefits generated (e.g., improvements in water quality, fisheries, tourism, or mental health) could be also be acknowledged in investor marketing, via integrated reporting,[107] to demonstrate the broader societal and environmental benefits generated compared with those initiatives where only one service improves (e.g., technological carbon offset projects).

WIF roles and responsibilities

Elements/components of a successful WIF would include those typical for trust funds.[97,100] A *fund management group (or board of trustees)*, and their supporting staff, would need to be established to manage the investment fund and be responsible for fund performance (i.e., increasing the overall return of ecosystem services on investment over time; Figures 1 and 2; Note S14). The group should include representatives from all stakeholders, including indigenous peoples, community, industry, and technical advisory, each committing to transparency and neutrality, with members focused on setting and achieving the WIF's objectives.[48] Although it can take time, practicing deliberative democracy and inclusive policy-making and programming is necessary for building trust, increasing participation, reducing stakeholder fatigue when consultation processes are bloated or ill-informed, and improving decision-making when stakeholders are divided or polarized.[108–110] Building trust and social capital is critical for building trustworthy institutions such as CAT.[99] Solving environmental issues is not only reliant on technical analysis, but also reliant on knowledge of societal functioning, stakeholder communication, and how activities are carried out and regulated, which all benefit from deliberative democracy.[111]

Roles of the fund management group would broadly include strategic planning, scheme operation, information dissemination, and advocacy. The group would identify values and restoration objectives (including regular consultation with stakeholders and local communities) and provide a one-stop shop for stakeholders, enabling the bundling of funding from multiple sources and reducing administrative burden.[31,72] The group would be responsible for show-casing fund performance to attract funders and then investing funding (via reverse auctions) into restoration projects that are likely to increase ecosystem services flows and support the group's agreed objectives. Where possible, the group would register any credits available (such as carbon credits) and permit and collect royalties from commercial activities (such as tourist operators), and disseminate these as dividends back to investors.

To ensure permanence of the wetland portfolio, the group would instate covenants and other site-specific property right agreements, set and maintain policy on assessment methods and reporting standards, and advocate more broadly in the best interests of protecting the assets (Figures 2 and 3; Note S14). This would include advocating for the protection and improvement of catchment and freshwater management to ensure external activities do not compromise the ability of the wetland portfolio to deliver ecosystem services (Figures 2 and 3; Note S14).

Supporting the WIF would be a *local scientific/technical support partner*, which may include a university, research institution, or consultancy with reputable wetland expertise. The local scientific/technical support partner would need to provide technical, strategic, and practical guidance regarding identification of values, the design and placement of wetlands for maximal delivery of the desired ecosystem services (e.g., using modeling or other analyses, such as multi-criteria analysis; Figure 2; Note

Figure 2. A proposed wetland restoration investment fund with entities, roles, and their relationships
Hypothetical information for demonstration purposes. (A) Mapping exemplifying guidance on strategically locating potential wetlands to maximize provision of a desired service (e.g., DIN removal across the Great Barrier Reef catchment by Waltham et al.[103]). (B and C) Examples of potential performance metrics that could be reported to investors, such as the performance in providing (B) final and (C) intermediate ecosystem services. Numeric codes within (B) are the NESCS-Plus codes for final ecosystem services.[104]

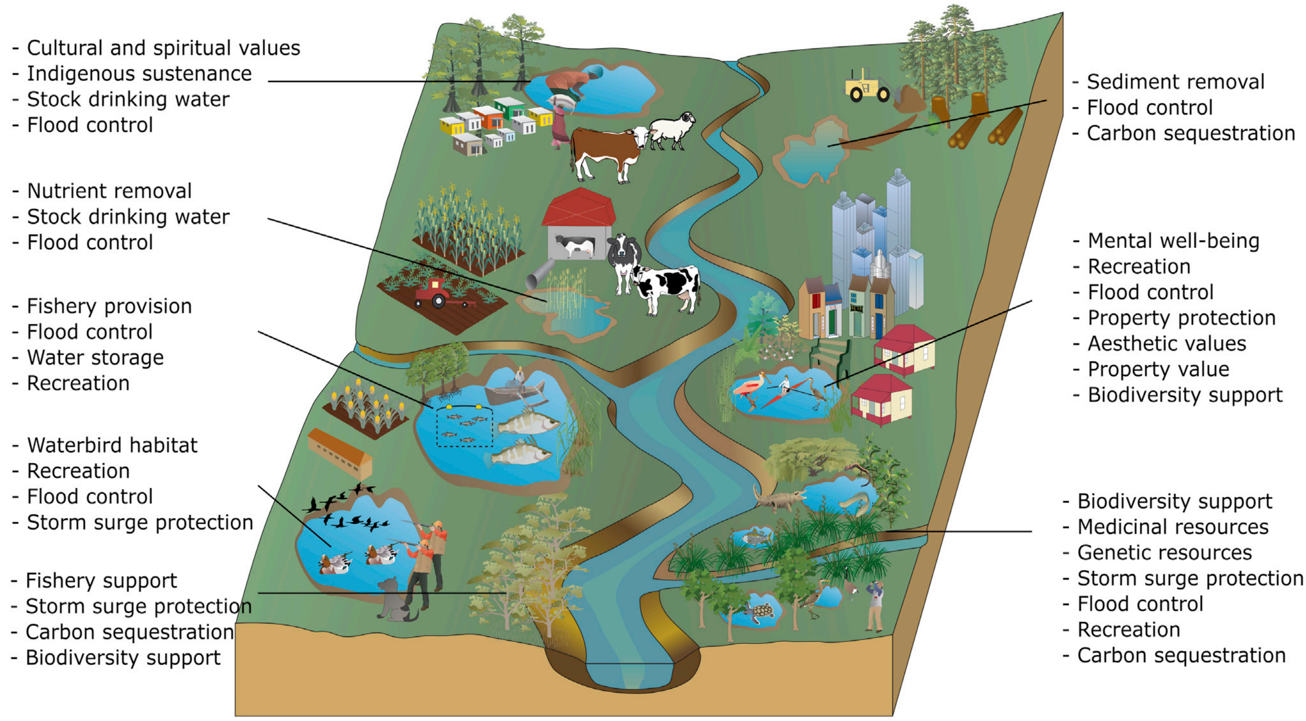

Figure 3. A hypothetical portfolio of wetlands, each wetland supporting a range of different ecosystem services depending on their type, design, and location

S15).[73] They would also be responsible for training wetland assessors, auditing their assessments, maintaining a database of the extent, condition, and function of the wetland portfolio, and providing regular ecological, social/cultural, and economic assessments of the portfolio performance to the fund management group. Portfolio performance should report on delivery of both intermediate and final ecosystem services,[102] as well as any other relevant indicators desired by the fund management group (Figure 2; Note S15). Where appropriate, *local indigenous/traditional owners* would have an active role in incorporating traditional environmental management, values, co-designing and delivering wetland restoration and maintenance, and assessing wetland performance.

Governments would be central and interacting with all groups (Figure 2; Note S16). To minimize leakage and help ensure additionality, government agencies would need to legislate and enforce a "no net loss of wetland extent and condition" policy. To help demonstrate additionality, leakage minimization, and permanence, governments would also need to develop and manage a broader wetland monitoring and accounting system for tracking wetland extent and condition. Governments could also support schemes by providing funding (directly or from Pigouvian taxes), recognizing investment in the fund in offset legislation, ensure legislative mechanisms are adequate for effective CATs functioning, and streamlining environmental approval pathways for wetland restoration projects (Figure 2; Note S16).

Investors enable the continued operation of a WIF. They vary the number of individuals, organizations, and companies, and the diversity of purchasers' changes.[112] Table S2 lists potential groups of investors and the ecosystem services they may desire. Investors become beneficiaries of the trust by purchasing non-refundable, but transferable, units or credits. Investors receive "benefits in the form of annual dividends" arising from the ecosystem services generated by their investment. Where excludable credits are registered, such as carbon or nutrient credits, investors would receive these as dividends (or cash when sold on their behalf), which could be used to offset their organizations' activities.

Royalties collected from commercial use of portfolio wetlands, or from property developers/insurers seeking strategic wetland placement for property protection, could also be returned to investors as dividends or reinvested back into the WIF (if the investor desires). Investors will also benefit more generally, or indirectly, from the provision of non-rival and difficult-to-exclude services. Investors would be able to examine the fund performance and plans, most likely in terms of the ecosystem service(s) they are most interested in, and make investments according to their ability, requirements, and/or desired return on investment. In addition to dividends, the WIF may also create eco-labels or certificates, such as those used/issued by Salmon Safe (Note S17), to attract and recognize large investors that may wish to convey social and environmental responsibility.

The investment providers, or *project developers*, may be landowners (freehold, indigenous/traditional owners, or an aggregation of landholders) or consultants/managers working on their behalf. Project developers propose and create wetlands for payment, competing with one another for funding via a reverse auction. Proposals should not only include wetland creation, but also monitoring and long-term maintenance of the wetland. If accepted, developers are responsible for managing the on-ground

Table 2. Key differences between market-based schemes and common asset trusts for facilitating the management of wetland ecosystem services

Feature	Market-based schemes	Common asset trusts
Community values	Often focused on the value of a single ecosystem service, this may affect community buy-in if it detracts from other non-scheme values.	Facilitates the inclusive identification of community values, necessary to achieve outcomes that build and maintain a social licence.
Objectives	Markets operate efficiently to allocate resources for producing goods and services that are both rival and excludable. When focusing on single ecosystem services that are rarely rival and excludable, artificial markets need to be created and upheld by regulators or governments. Such situations frequently suffer market failure, resulting in non-optimal outcomes, resulting in problems, such as perverse incentives, conflicts between goals, and failure to adequately manage trade-off decisions.	High flexibility allows multiple objectives on the provisioning of any and multiple services as can also accommodate non-rival and non-excludable services across a portfolio of wetlands.
Decision-making and stakeholder participation	Typically participate as traders, with little role in scheme management, may be involved if there is consultation during development. Decisions usually made by Government or a private entity.	Managed by a board of trustees that can include stakeholder representatives, and practice deliberative and inclusive democracy to navigate value trade-offs. Can leverage off well-established legal mechanisms for dispute resolution surrounding trusts.
Transparency	Transparency is often limited as trading a single service reduces the number of stakeholders involved that have direct access to information.	Transparency is embedded as the board of trustees is highly inclusive with multiple stakeholders that have direct access to information.
Financial viability	Rests heavily on performance in supplying (typically) a single ecosystem service. The combination of uncertain wetland performance in service delivery, and being vulnerable to low and volatile trading prices, make investments risky.	The ability to attract funding from multiple public and private sources for providing multiple services across a portfolio of wetlands, and the flexibility to invest either the principal or interest from pooled funds, both provide a buffer against the underperformance of revenue from providing a single service.
Environmental assessment, administration, accounting, and transaction costs	Assessment and administrative burden can be high as payments rely entirely on the delivery of a single service, requiring time-consuming and expensive assessments seeking a high level of estimate certainty from ecosystems that are naturally highly variable and uncertain. Difficult to ensure all assessments are of equivalent quality. Often lack robust environmental accounting and database management.	Has flexibility to use wetland indicators that indicate the performance in delivering multiple services. Assessment, administration, and accounting can all benefit from the economies of scale achieved by having one body overseeing multiple wetlands. Having a dedicated scientific partner allows for continued refining of metrics, consistent training, and quality control, and a central database manager.

construction, including identification of suitable sites, wetland design, organizing staff and machinery, partnering with volunteer organizations, assessment and reporting, and liaising with the fund management group and government. Project developers may design and assess wetlands internally, but *assessors* would require training, approval, and all assessments would be subject to audit against the provisions agreed by the local scientific/technical support partner (mediated by the WIF).

In summary, we have outlined challenges for large-scale wetland restoration using existing PES schemes. We present an alternative PES scheme framework, based on CATs, that could facilitate much-needed large-scale wetland restoration (Table 2). The common challenges identified include achieving financial viability, establishing credibility, and ensuring social acceptability. As a way forward, we propose that future PES schemes fund wetland restoration using an investment trust fund approach that aims to build a portfolio of wetlands across the landscape that maximizes the overall provision of ecosystem services (Figures 1, 2, and 3).[101] The trust fund would act as a single point of contact for all participants, simplifying administration and compliance monitoring for wetland developers, allowing for strategic planning of wetland restoration, and bundling of multiple funding sources to ensure wetland projects are viable. Fund managers could have the flexibility to invest in wetlands designed and positioned appropriately to support the suite of ecosystem services. Investors could make investment decisions based on the fund's performance in terms of the ecosystem services they desire. As the wetlands would be common assets, the investors would have a sense of ownership (helping with security and community acceptance) and be beneficiaries of all ecosystem services provided. A local scientific/technical support partner, with local network connections and trust among community, businesses, and government, could support the scheme by evaluating performance, providing guidance on restoration design and spatial planning, running workshops, and developing streamlined assessment methods. Governments could provide the enabling conditions for the scheme through broader environmental protection and environmental accounting legislative requirements. We consider that such a scheme will lead to greater wetland protection and restoration, one of the world's most service-rich, yet threatened, ecosystems, by being robust, efficient, easily accessible, credible, effective, and wetland focused.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2021.06.006.

ACKNOWLEDGMENTS

We thank Dr. Kurt Stephenson and Peter Wilson for their helpful feedback and conversations throughout manuscript development, Dr Jordan Iles and Alicia Castle for constructive feedback on figures, and two anonymous reviewers for their constructive feedback. Funding for this project was provided by the Australian Government's National Environment Science Program Tropical Water Quality Hub.

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One Earth, Volume *4*

Supplemental information

Financial incentives for large-scale wetland restoration: Beyond markets to common asset trusts

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Table S1. Summary of various market-based schemes driving wetland restoration, including positives, negatives and recommendations for managers of existing and future schemes.

Market scheme	Comments
Habitat stamps[1–7]	These involve the sale of stamps for the recreational use of wetlands. Most stamps are sold as part of a licencing requirement to carry out an activity (traditionally hunting and sometimes fishing), though many schemes operate either completely or partially voluntary. Funds from stamps are typically earmarked for wetland conservation or restoration activities *Positives* • Demonstrated to be highly effective at funding wetland restoration. E.g., 2.4 million ha restored in USA • Strong buy-in by farmers as many are also hunters, willingness to provide land and commit resources despite being voluntary • Synergistic benefits as more wetlands means more game birds, increasing habitat stamps, positive reinforcing cycle can continue • Cost-effective and flexible *Negatives* • Requires active and interested hunters or birders • Requires additional monitoring and management of game birds • Habitats developed will tend to favour the desired game bird • An aging hunter population • Increasing competition with other outdoor recreation and overall lack of time • Low waterfowl abundance or poor population resilience may erode sales • Requires social acceptance and reducing barriers to increase participation • Biodiversity benefits rarely measured *Recommendations* • Guide restoration to provide diverse habitats, rather than a mono-habitat for desired game species • Extend stamp sales to other wetland focused recreation, e.g., hikes and fishing in wetlands • For stamps reliant on hunting, increase hunting participation through the promotion of the conservation and economic benefits, and as an activity that creates deep appreciation for nature • Measure and promote biodiversity and other benefits arising from stamp sales
Mitigation banking[8–15]	These schemes allow landholders to carry out restoration work and then sell credits in the future for offsetting construction or clearance projects. *Positives* • Demonstrated track record of large-scale restoration • Large funding potential, typically sufficient make wetland restoration financially viable • Often reduces the permitting burden for construction projects • No or little cost to government *Negatives* • Seasonality, natural uncertainty, species growth rates, rainfall and staffing can make it difficult to ensure offsets provide the ecological quality required by the date developers require • Exchanges are often poorly planned • Difficult to ensure offset wetlands offer the same or better ecological values or place-specific functions to that lost, particularly when land values drive restoration to be distant from development works or the ecosystems are different • Historically poor record keeping of transactions or project information • Ecological requirements and assessment standards maybe highly onerous with considerable legal implications • Large initial capital outlay that relies on future development • May be used as an easier option to meet environmental regulation than minimise original environmental impact, rather than a last resort • Trading price may differ from that forecasted • Potential reputation damage if selling credits to offset an unpopular development *Recommendations* • Use trading ratios and incentive premiums to account for uncertainty in offset assessments, and to encourage desired proximity and habitat type • Make payments in stages to ensure sufficient start-up capital and milestone completion • Incentivise or direct the establishment of offset wetlands to be within the vicinity of anticipated future development, and create habitat similar to that anticipated to be lost. Manage this adaptively by regularly monitoring development rates and locations, adjust wetland offset directives accordingly • Use a database to record transactions and project information for evaluation • Establish endowments for maintenance costs

Table S1 cont. Summary of various market-based schemes driving wetland restoration, including positives, negatives and recommendations for managers of existing and future schemes.

Market scheme	Comments
Crowd funding[16–19]	Crowdfunding is where a project is funded by a large number of small contributions, typically via the internet *Positives* • Engages support from a large number of people • Makes contributions and participation easier by reducing financial barriers. There is typically no minimum contribution required, or where there is it is small • Project managers receive social validation of their ideas, which can be synergistic for project completion and future projects • Large project awareness as contributors typically share ideas through social media • Contributors enjoy seeing project managers achieve goals and community benefits • Creates a large support network for project managers as contributors are often keen to support projects through non-financial means too. Often contributors may have skills, knowledge or provide services that can assist the project manager. *Negatives* • Projects that fail to reach their financial goal, often fail by a long way. The average project that fails will only receive approximately 10% of desired funds • Most fully-funded projects, despite being completed, are often not completed on time. • Contributors may fear projects are fraudulent, or lack trust that the project manager has the competence/ability to complete the project • Non-governmental and not-for-profit organisations tend reach their funding goals easier than businesses *Recommendations* • Partner projects with a knowledgeable source to guide the restoration • Demonstrate success by sharing reputable verification of project completion and monitoring of outcomes to improve contributor confidence • Have projects be led by a not-for-profit non-governmental organization • Be informative about the project and intended goals on campaign pages • Consider using a platform, like Nutribute, to focus projects on an outcome and/or provide independent verification of projects. If the goal is to reduce nutrients or carbon, or increase biodiversity, then achieving a prescribed standard or measurement reporting using a prescribed method, may increase contributor confidence and scheme credibility.
Eco-labelling[20–26]	Eco-labels can generally take two forms: (1) for recognition of donation towards a conservation/restoration fund; and (2) for recognition of adoption of practices or carrying out conservation/restoration works. *Positives* • Cost effective and flexible • Give environmentally-beneficial goods and services a competitive advantage • Often preferred by industry over regulation-heavy approaches • Perform well in affluent, well-educated communities *Negatives* • Very few have demonstrated wetland benefits • Requires a critical mass to be well recognised by consumers • Scheme credibility difficult to establish, particularly as greenwashing increasingly common • Perform poorly in impoverished and poorly educated communities • Difficult to independently fund monitoring, verification and auditing • May have perverse social outcomes in the locations they claim to benefit as ability to participate may differ, drive a hyper-focus on achieving compliance rather than the desired outcome (increases social hierarchical stratification), which may exacerbate inequality • Eco-label markets are becoming increasingly crowded, potentially overwhelming customers *Recommendations* • Develop an alternative scheme to fund monitoring, verification and auditing, otherwise develop ways to increase the distance between funders and assessors. • Develop clear and open monitoring and compliance standards • Present detailed results openly and objectively independently of the schemes traditional marketing • Ensure labels are specific about programs desired outcome

Table S1 cont. Summary of various market-based schemes driving wetland restoration, including positives, negatives and recommendations for managers of existing and future schemes.

Market scheme	Comments
Carbon Markets (voluntary and compliance)[27–45]	Those emitting greenhouse gases pay for carbon credits to offset their emissions. Carbon credits can be gained through any activity that results in carbon sequestration and storage, including that stored by a restored wetland. *Positives* • Large potential funding pools • Regional markets with streamlined, locally-relevant and legislated standards show success in developed countries • Provide meaningful employment in developing countries • Co-benefits in developing countries, such as improved fisheries • Depending on the approach, initial allocation of carbon credits can reduce inequality and provide a new income source for low-emitters (in compliance markets) • High flexibility in design and offset methodology *Negatives* • Very few wetlands have been included to date • Uncertainty from highly variable spot price deters potential off-setters and buyers • Long term viability and abatement of wetlands difficult to predict and assess • Assessment costs and administrative burden is high • Managing a wetland for optimal carbon sequestration may limit other wetland uses, such as nutrient offsetting or fishing approaches • May drive land grabbing in common areas by effectively privatising the use of a publicly used space • Carbon prices often too low to cover restoration costs in developed countries, particularly with voluntary markets as prices are often substantially lower than in compliance markets • Risk of wetland loss elsewhere • National or regional inventories with extent and quality potentially expensive to develop and maintain • Buyers are often the price-setters and may withhold participating in schemes with high offset prices (in voluntary markets) • Depending on the approach, initial allocation of carbon credits can increase inequality and reward polluters by granting them large allocations, which may permit business as usual or provide large capacity to profit from reducing emissions (in compliance markets) • Viability of the scheme can depend on the pre-trade allocation of carbon credits *Recommendations* • Develop locally robust standards to reduce burden of proof costs • Investigate low cost, long term assessment and monitoring options, including aerial imaging/remote sensing approaches • Develop national or regional inventories of wetland extent and quality to track gains and potential loses outside project boundaries • Encourage funding wetlands by bundling payments from multiple benefits • Require surplus to expected wetland be created as a buffer on sequestration uncertainty • Develop and fund locally relevant approaches to discourage wetland degradation, e.g., policing wetlands, assist transitioning affected agricultural practices to alternatives and programs to increase community buy-in • Consider regional markets in developed countries for a higher market price, more cost-effective assessment and increased buy-in and trust as buyers can visit created wetlands • Consider aggregating multiple local small projects into one large project to reduce administrative burden and compliance costs • Increase certainty in the desired direction by introducing floor and/or ceiling prices • Investigate the broader implications of alternative carbon credit allocation methods and consider using the allocation system as a way to achieve both environmental and socially-desired goals, such as reducing inequality (in compliance markets)

Table S1 cont. Summary of various market-based schemes driving wetland restoration, including positives, negatives and recommendations for managers of existing and future schemes.

Market scheme	Comments
Water Quality Trading[46–52]	Those discharging nutrients, via point or non-point sources, pay for pollution offsets that involve the implementation of better agricultural practices or wetland restoration on another property. *Positives* • Can have multiple biodiversity benefits in addition to increased nutrient attenuation • Models can be used to estimate nutrient losses rather than measurement • Can help incentivise an efficient use of nitrogen as only the most profitable businesses will be able to afford high pollution costs. Though this is not always perceived as a positive. • Provides some farmers with a source of income to implement new practices to reduce pollution • Can (depending on allocation) cost farmers who pollute the most • Can achieve high trading prices, making wetland restoration more affordable • Can be designed to be effects-based, which assists in incentivising good practices and deterring poor practices • Integrates conservation and environmental practices as a normal part of daily business • Trading nutrients can help ease difficulties meeting initial allocation limits *Negatives* • Poor limits, or enforcement of limits, or the over-allocation of discharge permits often a main cause of failure. • Few examples of successful nonpoint-nonpoint nutrient trading • Initial allocation of nutrients can affect the viability of the scheme and have large economic, social and environmental implications • Models can have high uncertainty and may not cover all the potential offset mechanisms or wetland designs • Models may be updated frequently, which can stifle trading as verified credits also change • Requires a high degree of compliance and assessment, which may still be fraught with risk and expensive • Requires strong political will • Requires a trading agency • Large trading areas may result in degradation in some locations and improvements in others. Small trading areas may have too few participants for a viable and efficient market. • Can exacerbate issues of pollution rights if left unresolved • Trading may not necessarily result in nutrient pollution being spent on the most productive or nutritious foods • Trading costs may detract funding from improving on-farm systems *Recommendations* • Schemes are more likely to work when there is outside funding available for mitigations • Establish a trading agency, tasked with verification of offsets and facilitating credit trading • Implement caps that are achievable, if large reductions are required then consider phasing reductions in and/or providing additional funding for transitions • Lump any updates of assessment models into large changes at a pre-established date, rather than many small updates. Otherwise prescribe a model version in policy that can be superseded at an agreed interval • Model input variables need to keep a minimum and easily verifiable to reduce potential gaming and improve reliability • Models should be developed independent of beneficiaries and made open source • Consider the range of allocation systems available and the positive and negative implications on each economically, culturally, socially and environmentally. Use the allocation system to achieve desired goals and seek large community buy-in • Use trading ratios to buffer against uncertainty. It may be more cost-effective to oversize a wetland than prescribe expensive monitoring • Examine the potential to reduce verification and monitoring costs by simplifying assessment and redirecting compliance costs towards restoring larger wetlands • Establish an initial nutrient inventory to manage and track changes in nutrient loss • Establish an initial inventory of current wetlands and an accounting system to record all new wetlands developed as part of offsetting. If improving wetland condition is also considered in nutrient offsetting, then initial and ongoing monitoring will need to include condition assessments • Explicitly include wetlands, and a range of types, in nutrient trading to maximise their use • Provide a platform for bundling of funding avenues for wetland restoration, such as carbon and biodiversity payments • Establish legal pollution rights before scheme development as this will influence the allocation system • Establish the extent to which one sub-catchment's health can be reduced to improve another. This will inform the spatial extent to which trading can occur. • Consider increasing trading ratios as the distance between a discharge and offset increases • Consider broadening the participation in the market to non-traditional discharges or offsets to maximise market efficiency and ensure long-term viability • Establish with the local community their landscape-based values and seek to ensure goals of allocation align with these values

Table S1 cont. Summary of various market-based schemes driving wetland restoration, including positives, negatives and recommendations for managers of existing and future schemes.

<table>
<tr><th>Market scheme</th><th>Comments</th></tr>
<tr><td>Water funds[53–57]</td><td>Water funds pool public and private resources, primarily from downstream beneficiaries, to invest conservation, restoration and practice-change that benefits water within a catchment. All aim to restore and protect hydrologic ecosystem services, though differ in their desired objectives and funding sources.

Positives
• Can cover multiple biophysical and socio-economic goals
• Financial viability and stability is high as multiple ecosystem services can be supported by a diversity of funders. As at 2016, over 62 million had been obtained by the Latin American Water Funds Partnership.
• Are adaptable where privatization is impossible
• Relatively financially and politically stable
• Allows for strategic and spatial planning
• Can gain from improved efficiencies with scale
• Cost-effective and flexible
• Ability for partnerships that lower transaction cost and improve transparency
• Often science-based decision making for cost effective outcomes, such as using erosion models and multi-criteria analysis
• Demonstrated engagement with stakeholders and communities, often facilitated by engagement with representatives
• Assets are secured by a trust fund that is independently governed for long term benefits

Negatives
• Objectives are sometimes unclear, with some schemes not identifying the main environmental threats they wish to reduce
• Wide variation in environmental and social performance monitoring and reporting
• Little demonstrated efficacy in restoring palustrine wetlands. Schemes have largely focused on forest planting for reduced sedimentation and nutrient enrichment of rivers, or increasing surface and ground water quantity
• While monitoring occurs, it is often insufficient to demonstrate impacts or allow economic evaluation
• Many schemes include livelihood and socio-economic objectives, yet monitoring of these is often poor or non-existent
• Can be difficult determining the proportion of principal funds and/or interest that should be spent on projects. Schemes that only invest interest earned from funds may take a long time to deliver desired outcomes and deter funders. While schemes that invest the principal into projects may deliver larger outcomes faster, but be more vulnerable to market volatility
• The majority of transactions have contracts that lack a duration
• Most schemes only report on actions or inputs (e.g., area restored or fertilizer reduced), rather than outputs of ecosystem services. Where ecosystem services are reported, they are usually intermediary services (e.g., water quality improvement), rather the final services (e.g., the value of improved drinking water supply), which may deter some prospective investors and reduce blending into economic metrics and literature
• Can be difficult demonstrating additionality if there is no strong legal framework preventing concurrent degradation

Recommendations
• Have stakeholders, including the private sector and upstream communities, represented on governance or advisory boards. This will help recruit local knowledge, engage stakeholders and ensure that services delivered are in line with those desired by funders
• Monitor both biophysical and socio-economic impacts of the program, ensuring they are sufficiently rigorous to examine progress towards objectives and allow economic evaluations. Indicate on both the intermediate and final ecosystem services provided to ensure comprehension of benefits across a diverse audience
• Advocate for legislative safeguards to prevent improvements gained from fund investment being undermined by degradation elsewhere</td></tr>
</table>

Table S2. Potential ecosystem services included in a wetland payment for ecosystem service scheme, with their location and design traits, and potential investors seeking that service.

Ecosystem service	**Candidate final ecosystem service and NESCS-Plus[58] code (w=wetland type, x= industry type)**	**Traits of location and design**	**Potential investors**
Nitrogen attenuation	None	High DIN delivery; high hydrological residence time; large source of organic matter with high C:N stoichiometry; persistent hypoxia; rarely turbulent waters; warm water; sediment has low redox potential; large amounts of over-hanging vegetation; and aquatic macrophyte shoot heights between 1-2 m[59,60].	Agricultural companies, food companies, food retailers, environmental non-government organizations, philanthropists, reef tourism operators, sewage treatment plant operators and individuals
Sediment abatement	None	High sediment delivery; may contain baffles or sub-aquatic trenches; little riparian, straight edges and sloped banks for easy excavator access; and a large surface area and volume relative to inflow.	Agricultural companies, food companies, food retailers, environmental non-government organizations, reef tourism operators, bulk potable water suppliers, philanthropists, and individuals
Carbon abatement	12W.1.1105.3XXX	High organic matter delivery with high C:N stoichiometry; low nutrient delivery; large amounts of over-hanging vegetation and aquatic macrophytes; may contain baffles or sub-aquatic trenches; a large surface area and volume relative to inflow; moderate sediment loading; and located where sediments persist within an envelope of redox potential.	Airlines, cruise ship companies, petrol stations, freight and delivery companies, taxis, electricity and gas retailers, agricultural companies, retailers, environmental non-government organizations, philanthropists, reef tourism operators, and individuals
Water storage	None	Intermittent wetlands in areas with high seasonal rainfall variability and proximal to irrigated land.	Agricultural companies and government
Biodiversity provision	None	High habitat diversity (including depth and vegetation); are well connected within coastal floodplains; permanently wet; close to other diverse wetlands; little anthropogenic stress; and naturalized hydrological regimes	State government, local government, environmental non-government organizations, pharmaceutical companies, philanthropists, banks, tourism operators, developers, and individuals
Commercial fisheries	None	Within a catchment where commercial fishing occurs (e.g., for barramundi (*Lates calcarifer*) in Queensland, Australia), and habitat tailored to the requirements of the target fish and their prey.	State government, commercial fishing companies, fisheries processors, and retailers
Recreation	None	Close proximity to urban centres; habitat tailored to suit sport fish and their prey (for fishing), bird diversity (for bird watching); may have structures such as jetties and boat ramps for accessibility; tracks (for walking); huts (for hunting and bird watching); may have areas clear of vegetation for casting; and may have parking, toilet and picnic facilities.	State and local governments, anglers, recreation clubs (e.g., for angling, bird-watching, kayaking, boating, and hunting); and recreation gear retailers
Flood control	Wetlands protecting human property for real estate (12W.8.110Y.1531), crops (11212W.8.1110.1531 110Y.1532), and households (12W.8.110Y.2111)	Size and positioned to dampen large pulses and regulate outflows.	Local government, property developers and insurance companies
Indigenous harvest	(12W.4.109Y.2111)	May be located near indigenous settlements or at sites of cultural significance. Structure will vary depending on target species and capture method.	Government (all levels) and indigenous groups
Mental wellbeing	12W.8.109Y.2111 (households)	Located within, or very close to, urban centres; may have structures such as jetties and boat ramps for accessibility; may have parking, toilet and picnic facilities for use and comfort; may have community events or conservation activities; may have design features to cater for various recreation activities; may have thinned or short vegetation and cameras for security; and may have features designed to engender a sense of place or cultural connection.	State and local governments, mental health based not for profit organizations, individuals and philanthropists.

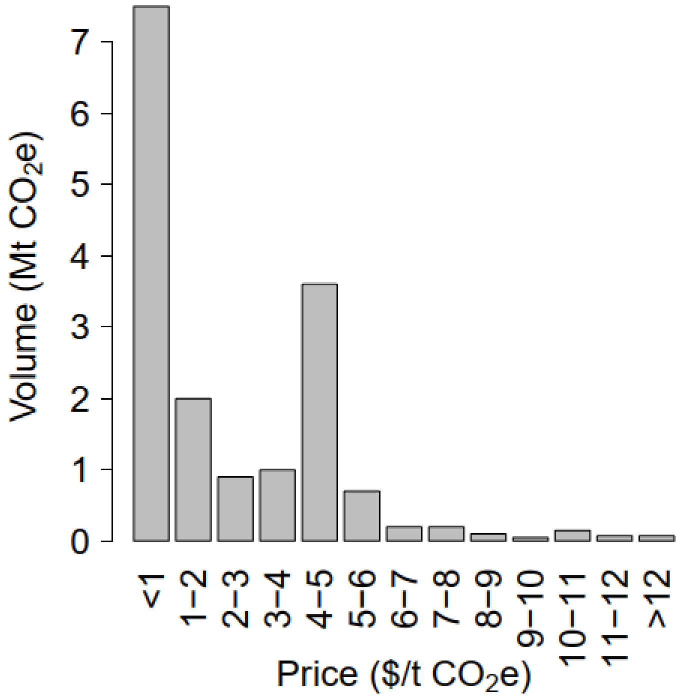

Figure S1. Carbon trading price through voluntary markets versus volume of carbon-equivalents traded during the first quarter of 2018[38].

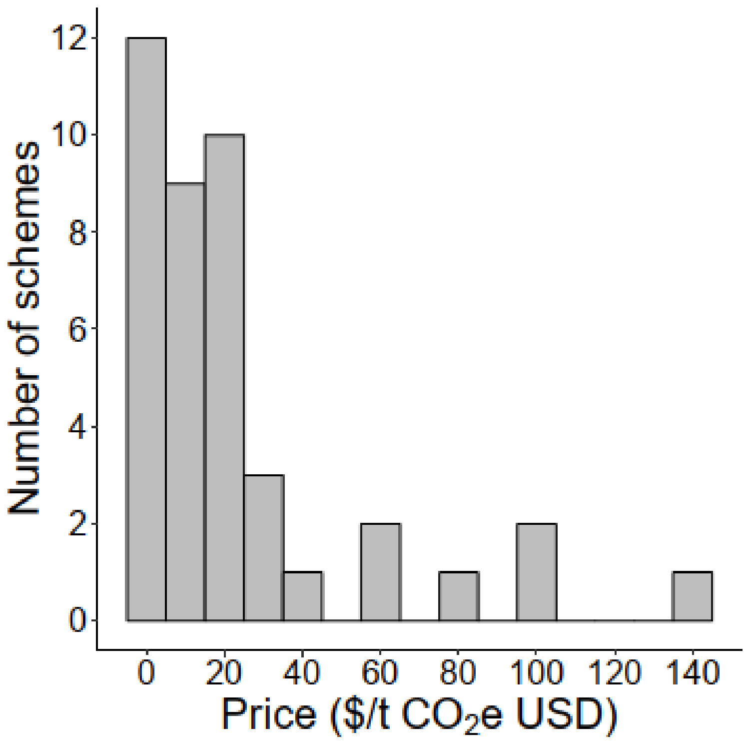

Figure S2. The carbon trading price for the compliance carbon trading schemes (n=41) active during the first quarter of 2018[61].

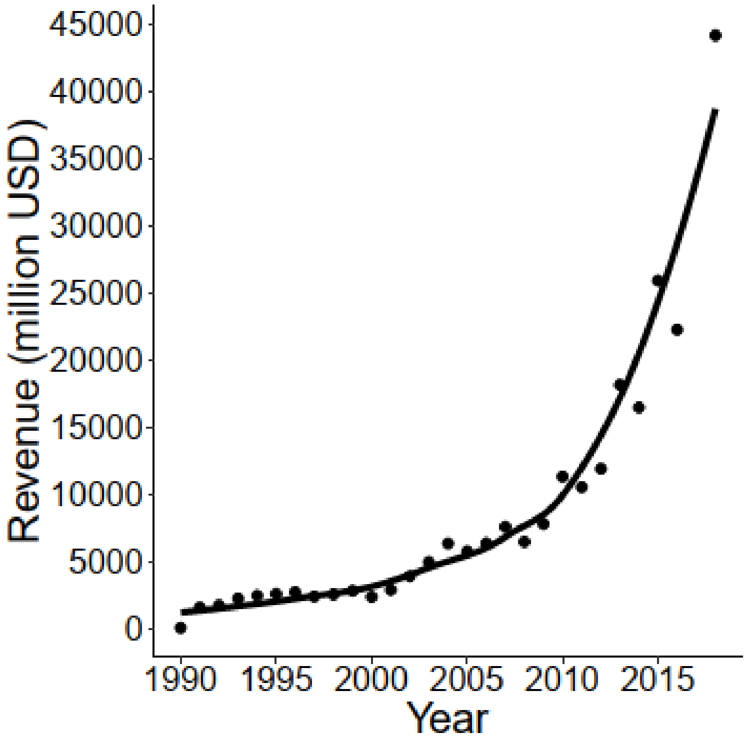

Figure S3. Revenue generated through compliance carbon markets globally since 1990[61].

Note S1

India's Sundarbans Mangrove Restoration

India's Sundarbans Mangrove Restoration used Verified Carbon Standard (VCS; now Verra) funding to restore 5600 ha of mangroves[30]. Workers doing the plantings would work four hours a day at ~$2.50 USD per day; those helping to protect the mangroves from pressures, such as grazing, were paid ~$45 USD per month to help offset travel costs; and those raising the seedlings were paid $0.015-0.0375 USD per sampling, depending on species. The project sequestered three times more carbon than expected, along with improving the shellfish habitat, benefiting local communities. Difficulties included: fishing activities degrading the mangroves (as they became productive nurseries for shrimp and fish); illegal deforestation; livestock grazing; and damage from extreme weather events. To mitigate these challenges, grazers were provided fodder grasses for livestock as an alternative feed, mangrove species were selected based on environmental suitability, and a guarding system was developed to prevent undesired activities[30].

Note S2

Vietnam's Markets and Mangroves (MAM)

The Markets and Mangroves (MAM) project in Ca Mau, one province within the Mekong Delta, Vietnam sought to conserve and restore 1715 ha of mangroves. The project did this through helping shrimp farmers gain organic certification, requiring that no further mangroves are destroyed for shrimp ponds, and requires that farmers have at least 50% mangrove coverage – encouraging planting by many. Before the project was implemented, the amount of carbon in the area was assessed with ambitions to claim future carbon funding through potentially UN-REDD, Plan Vivo or Verra[62]. However, to date, the project developers have avoided claiming carbon funding due to the length of time and administrative burden to fulfil the requirements. At present, gaining organic certification has been sufficient incentive for farmer adoption as global markets pay an approximate 10% premium for organic shrimp and increasing mangrove extent has increased shrimp production[30].

Note S3

Germany's MoorFutures regional carbon trading scheme

Germany's MoorFuture's is a regional carbon trading scheme that funds carbon offsets from small-scale peatland restoration projects. The scheme is adapted to regional conditions to make it more cost-effective for the relatively small projects within the region. Specifically, emissions are estimated before and after rewetting peatlands using Verra's Greenhouse gas Emissions Site Type (GEST) approach, including the measuring of gas flux at demonstration sites[28,63]. The GEST approach allocates emissions estimates to regionally-relevant vegetation types, dependent on water tables, land use and vegetation composition. Moorfutures fixes juridical standards, rules and regulations, allowing applicants to forgo the expense (often prohibitive) of having at least two independent consultants verifying the methodology, as required by Verra[28,63]. The verification and validation of projects are carried out by the Ministry of Agriculture and the Environment of Mecklenburg-Western Pomerania and the University of Greifswald. The permanency of projects are then secured as, by law, owners are required to maintain prescribed water levels, and projects are either covenanted or purchased through a trust[28,63]. Since inception in 2010, MoorFutures's has made relatively small projects within the region cost-effective and viable, with profitability achieved at ~€5400 EUR/ha, and has resulting in offsetting of over 17,000 t CO_2e and now expanded to include other ecosystem services, such as habitat provision and nutrient attenuation[64,65]. A benefit of having a regional scheme was that it created trust in the standards as buyers of credits could visit projects locally, rather than the project being anonymous and overseas. Furthermore, local projects allow for locally sensible pricing in developed countries, rather than the offset price being set at much lower rates by developing countries [28].

Note S4

Cherry Creek phosphorus trading scheme (Colorado, USA)

The Cherry Creek trading program in Colorado, USA, trades phosphorus offsets between point source and non-point source dischargers. Trades were facilitated by the Cherry Creek Basin Water Quality Authority (CCBWQA). A total maximum allowable annual load of 6473 kg of phosphorus was allocated to sources primarily using grandfathering, but with a slight skew allocating more towards municipal discharges to allow for continued urban growth. Trades between point sources began in 1985, with nonpoint sources included in 1989, and then the management plan updated numerous times since to reflect new water quality targets, policy and technical changes[66,67].

There are two sources of 'phosphorus credits' available for purchase by dischargers: (1) the phosphorus bank, these are credits developed by the CCBWQA between 1991 and 1997, that involved erosion control and wetland restoration; and (2) credits generated by third-parties from nonpoint source control projects[67]. In addition to numerous stream reclamations[66], the completed projects include the Cottonwood Wetlands Pollutant Reduction Facility (PRF) Rehabilitation project[68]. Initially developed as ponds in 1997 to capture sediment and attached pollutants from a stream before flowing into the Cherry Creek reservoir. Monitoring showed that by 2005, the effectiveness of the wetland to reduce pollutants had greatly reduced and wetland enhancement work was needed. By 2012, the Cottonwoods Wetland improvement project was complete, costing approximately $470,000 USD[68].

All eligible offsets must demonstrate effectiveness through monitoring and are subject to a trade ratio of at least 2:1. That is, a point source discharger must purchase at least twice the amount sought from nonpoint dischargers. Trading ratios are not only used to ensure a net benefit to the watershed, but also to buffer against uncertainty in efficacy, account for differences in the ratio between dissolved and particulate forms, and to discourage offsets far away from the discharge (reduces probability of one river being degraded, while another improves). Projects are reviewed every 3-5 years by the authority, and trading ratio adjusted depending on the projects performance – a project performing more poorly than anticipated could have a trading ratio increased[66,67].

Note S5

South Nation River phosphorus trading scheme (Ontario, Canada)

In in the 1990s, Ontario's South Nation River's phosphorus concentration was 3-5 times in excess of the provincial water quality guidelines[51,52,69,70]. In 1998, Ontario's Ministry of Environment ruled that there must be no net increase in phosphorus discharge from wastewater treatment plants to the South Nation River. To alleviate the ruling, they formed the Total Phosphorus Management Program (TPMP) which allows point source dischargers to offset their pollution by purchasing credits from farmers who implement practices that reduce their nonpoint discharge. The TPMP was administrated by the South Nation Conservation Authority (SNCA) – a local, charitable, not for profit water management body. The credit providers (i.e., farmers reducing phosphorus) are not legally bound or otherwise to attain nutrient reductions – actions are voluntary. The burden of proof that there is a no net increase in discharge remains with the point source discharger. To ensure compliance, the Ministry of Environment require a trading ratio of 1:4. That is, 1 kg of phosphorus discharged from a point source requires nonpoint source reduction actions estimated to reduce 4 kg of phosphorus. The actions a farmer can gain credit for are contained in a prescribed list, along with algorithms and supporting scientific information for determining the offset quantum. All payments for offsets are made through the SNCA, and are combined with government funding, meaning a farmer does not know the origin of the funding. Between 1994 and 2017, $2,300,000 CAD had been invested across 742 projects (composition of projects unavailable). Corresponding to approximately a 12 t reduction of phosphorus between 2000 and 2010. Projects typically received 50% funding. Whilst projects did not include the creation of palustrine wetlands, they did include bank erosion control, vegetated buffers (at least 3m) and livestock exclusion of waterways – all of which apply to, and help improve the health of, palustrine wetlands[51,52,69,70].

Note S6

Chicago wetland mitigation market

Robertson[71] examined the Chicago wetland mitigation market between 1994-2002, one of the oldest schemes in existence that is often used as a model for other schemes. In the Chicago scheme, credits are paid towards projects in four stages upon meeting performance standards. In the first stage, 30% of credits are awarded upon acquiring, bonding and protecting a site; at stage 2, 20% of credits are awarded after establishing wetland hydrology; at stage 3, 20% of the credits are awarded after planting vegetation; and the final stage awards 30% of credits when the ecological performance criteria are met[71]. Over the 9-year period, the price per wetland credit was reasonably stable between $50-60,000 USD, despite a US Supreme Court decision in 2001 that effectively reduced the demand for wetlands mitigation credits. Credit price does, however, exhibit a negative correlation with distance from Chicago (as land values drop). This likely results in inner-city developments being offset by rural projects, which may not mean offsets face difficulty replacing like-for-like as the environmental conditions are likely to differ substantially[12–14]. Further spatial asymmetry also arises between developments and projects as it is difficult to predict where further development will be located and at what rates it will be demanded. Any new schemes could consider adopting an adaptive management approach whereby approvals for new wetlands are based on a rough prediction of comparable habitat, future development and desired distribution of ecosystem services. The development rates and locations could be tracked and the approval area for wetland offsets adjusted accordingly[15].

Note S7

California's carbon scheme

California's scheme was developed with passing of the Global Warming Solutions Act in 2006, to reduce emissions to 1990 levels by 2020, with trading beginning in 2012[29]. Up until recently, wetland restoration have been unable to participate in the scheme; however, the ACR, in late 2017, approved an offset methodology that can be applied to wetlands, enabling wetlands to participate in California's cap-and-trade scheme. As of March 2020, California's scheme has approved 1121 projects, largely forestry-based (338 projects) or livestock-based (422), though no wetland-based credits have been issued. However, several forestry-based projects are in areas with wetland complexes that may benefit from forest restoration or improved forest management. For example, the Alder Stream Preserve Forest Carbon Project, an improve forest management project, owned by the Northeast Wilderness Trust, consists of 591 ha of lowland spruce-fir and conifer bog forests. The project spans along the Piscataquis River and Alder Stream (tributary), and contains several fens, marshes, bogs and beaver flowages[29,72]. Furthermore, all of California State's proceeds from the cap-and-trade scheme go into the Greenhouse Gas Reduction Fund, which as of 2019 has appropriated almost $12 billion USD into climate investments[29]. As of July 2018, approximately 1011 ha of wetlands had been enhanced or restored, including coastal tidal wetlands on the Sacramento-San Joaquin Delta and Mountain meadows[73].

Note S8

Habitat stamp programs

Since 1934, 98% of funds generated from the US Federal Duck Stamp, effectively a licence to hunt waterfowl, have been spent restoring 2.4 million hectares of wetlands. Wetlands restored under the scheme are primarily designed for waterfowl habitat and hunting, but also provide substantial biodiversity benefit. Annually, North American hunters donate an additional ~$1.6 billion towards hunting-related conservation[74]. Similar habitat stamp schemes are now in place in many US states and in Canada. Outside North America, New Zealand instigated a similar program in 1993 that has, despite having a small population, restored over 200 wetlands. The average restoration/creation cost between 2014 and 2019 was $11,000 NZD per hectare, with an average contribution from the New Zealand Game Bird Habitat Trust of $2,500 NZD per hectare and the remainder funded by the landowner (R. Sowman, personal communication, 2020).

Participation in waterfowl hunting is critical to scheme success. Historically, participation in waterfowl hunting largely followed waterfowl abundance; however, since the mid-1990s, the relationship between habitat stamps and wildfowl populations has weakened and participation has declined. If wetland is drained, waterfowl numbers reduce, and then fewer habitat stamps are sold, resulting in less funding conserving and restoring habitat, perpetuating the decline. On the contrary, if habitat increases, then so does waterfowl abundance, habitat stamps, resulting in more funding to increase habitat and so on. Vrtiska et al[5] estimated that, between 1995-2008, declining participation reduced gross revenue by $126 million USD, resulting in 42,500-80,900 fewer hectares of restored wetland. Drivers suggested for the reduced participation include an aging hunter population, changing societal values (though little tested), work-related responsibilities and time for other interests, and individual motivations and constraints[4,5,7,75]. The primary motivation for most hunters is being in nature, followed by social aspects and a desire to take retreat from civilization[6,7]. Ryan & Shaw[3] suggest increasing participation by promoting hunting an outdoor activity that creates a deep appreciation for nature and has conservation benefits. Furthermore, inclusion of non-hunters in hunting-related activities (e.g., eating game) can help improve social acceptance and provide an avenue for beginners to access mentors – both critical to recruitment. Given that the motivation to hunt is largely dependent on the desire to be in nature, the decline in hunting may also be compensated for by increases in other outdoor recreation, such as viewing wildlife, photography and kayaking[76–78]. Broadening habitat stamp sales to other outdoor enthusiasts, beyond hunters, such as in New York State's habitat and access stamp, may increase the revenue and resilience of the stamp scheme. In 2002, the New York State's Department of Environmental Conservation introduced a voluntary Habitat and Access Stamp, marketed towards anyone seeking to support increasing and conserving habitat or access to habitat, with the website stating "Whether you are an angler or hunter, birder or photographer" and "Outdoor enthusiast" – demonstrating their broad reach[79].

Note S9

Assessing wetlands in New Zealand's nonpoint nitrogen trading

In New Zealand's Lake Taupo nitrogen trading scheme, the world's first nonpoint-to-nonpoint nutrient trading scheme, nitrogen processing by wetlands is assessed and accounted for as a module within the farm-scale nutrient modelling[80]. Whilst this allows farmers to gain credit for having wetlands, there is little trust in the efficacy of the wetland module and, to a lesser extent, the farm nutrient budget model in general[81]. Much of this distrust arises because assessors are farm or fertilizer practitioners, with no training in assessing wetland condition; model updates are very frequent with predictions often changing considerably between updates; the lack of independent peer review and model transparency; the fact that the model is part-owned by a large fertilizer company; and a lack of model validation[81,82]. Even the purported success of the Taupo scheme is questionable, with in-situ nitrogen concentrations appearing to increase, not decrease, with April 2018 recording the highest nitrate-nitrogen concentrations since monitoring began in 1994[83]. Since trading began in 2007, the dairy cattle population within the Taupo district has also increased from 99,537 to 176,566 by 2017[84]. Distrust in the wetland module efficacy now means the new Rotorua Lakes nitrogen trading scheme will exclude palustrine wetlands (treated as either pasture or riparian depending on livestock exclusion), dis-incentivizing their restoration[85]. Quantifying wetland additionality is also difficult with scant national wetland accounting[86].

Note S10

Mangrove restoration in Senegal

Cormier-Salem & Panfili[87] argue that extensive mangrove restoration for carbon credits in Senegal by foreign organizations disempowered locals and potentially led to the poor performance of the restoration. The project saw 14,000 ha of coastal area planted with a single mangrove species (*Rhizophora mangle*). Local stakeholders felt the single species negatively affected the otherwise natural diversity of mangroves; they also felt there was a lack of prior consultation, with the only local participation being payment for tasks, such as collecting propagules and planting, which was perceived as a lack of recognition of local practices and knowledge; and the plantations reduced area traditionally used, primarily by women, for collecting shellfish. Essentially, the local community felt disempowered and as though they lost use while private enterprises gained. Unless there is community support for the project then there is risk the project or other nearby wetlands become degraded. Emphasizing the need for organizations seeking to complete foreign projects to develop meaningful partnerships with the local community[88].

Note S11

Nitrogen allocation difficulties in the Rotorua Lakes nitrogen trading

Litigation over the nutrient discharge allocation method has stalled the implementation of New Zealand's Rotorua Lakes nitrogen trading scheme. After ten years of consultation and development, the proposed allocation method sought to avoid grandfathering (future discharge rights based on historical use) and incentivize intensive land uses only on versatile soils. This was supported by local government, forestry, low-intensity mixed production agriculture and by local indigenous groups. However, intensive dairy lobbyists overturned this framework in the Environment Court as they favored grandfathering, arguing it was least economically disruptive and provides greater incentive for the biggest polluters to reduce (Decision [2019] NZEnvC 136). Grandfathering awards the highest polluters enhanced profit opportunities from trading, as they are likely to have the greatest capacity for the low-cost emissions reduction that will enable them to sell unused credits. Opponents of grandfathering argue that allocating nitrogen based on historical use effectively rewards the biggest polluters and punishes those who pollute the least. Furthermore, this can entrench financial and racial inequality as large emission allocations allow greater land use flexibility, driving higher land values and borrowing power[89,90]. Systemic inequality since New Zealand's colonization has meant that large areas of indigenous owned land remain undeveloped[91]. Grandfathering allocates very few discharge rights to undeveloped land, further entrenching inequality by constraining land use and suppressing land value. Similar debates have also stalled the implementation of nitrogen restrictions and restoration in the Manawatu region, with the governing body opting to ignore the agreed regulations and unlawfully granting discharge permits (Decision [2017] NZEnvC 037).

Note S12

EU ETS

The primary allocation method used for the EU ETS is auctioning (accounts for 57% of credits between 2013-2020), with some sectors receiving free allocations[92,93,95]. The manufacturing industry received 80% free allocation in 2013, gradually reducing to 30% by 2020. Some member states have been given free allocations to modernise their power sectors. Whilst airlines had the large majority of their emissions covered by free allocations. Auctions are an effective pricing mechanism for maximising the sale price, a positive for incentivising carbon offsets. A downside of auctions is the risk of collusion among bidders, though this can be mitigated by maximising the number and diversity of participants. Another downside is auctions strongly favour those with the greatest ability to pay and may exclude start-up businesses, small businesses and increase inequality. Furthermore, if those with the ability to pay high auction prices developed their capacity to do so from large historic emissions then it can effectively reward emitters for prior their historical emissions. Whereas a business may not be able to afford high carbon prices because they made choices before the scheme began that meant they did not profit from high historical emissions. Free allocations could be used to alleviate some of the inequality. In the EU ETS case, free allocations have primarily been used for political ambitions and to ease transitions as some industries may find reducing emissions more difficult than others[92,93,95].

Note S13

China's National Carbon Trading Scheme (NCTS)

China's National Carbon Trading Scheme (NCTS), the world's largest carbon trading scheme, follows a series of provincial or city level pilot schemes, and began in 2017 with spot trading likely to begin in 2020[33]. It is one of China's primary mechanisms to achieve their pledge of 60-65% reductions in emissions per unit of GDP by 2030. The scheme primarily allocates emissions freely based on historical emissions profiles (grandfathering). Whilst grandfathering is often viewed as the least impact option, the adoption of grandfathering has been criticized for poorly reflecting energy-economy-environment (E3) ambitions that seek to increase productivity and innovation but reduce energy and environmental costs. Grandfathering could result in rewarding the highest polluters with windfall profits as they have the greatest capacity to reduce emissions and sell unused credits, rather than reflecting polluter pays principles[36,37,44]. Like auctioning, grandfathering can, therefore, reward those who have profited from emitting the most and disadvantage those who have polluted the least, create a barrier to new-entrant businesses and entrench inequality. Several studies have used optimization models to suggest alternative allocation regimes, such as using an ability to pay approach[45] or allocating fewer credits to pollution-intensive provinces[36]. Whilst China's scheme is still in its infancy and its allocation system is criticized, it is still the poised to be the world's largest carbon trading scheme, with strong potential for funding blue carbon offsets. At present, blue carbon credits are possible as the scheme will accept Kyoto CDM credits, but only for projects based in China[33]. Tang et al[35] recommends that China accelerates efforts to develop and promote national standards for the assessment of blue carbon projects, along with laws and regulations, to assist incorporating blue carbon into the trading scheme.

Note S14

Management body roles

The management body would have numerous roles including:

1. Managing a common asset trust that collates funding from multiple sources and invests in a portfolio of wetland restoration projects that seek to maximize the overall delivery of ecosystem services.
2. Providing a one-stop-shop for funders and developers to provide and access wetland restoration funding, reducing the need for multiple parallel assessments and administration.
3. Showcasing fund performance to perspective funders using evaluations from the scientific support group. Rather than guaranteeing a certain level of provision for a given service, developers would be paid based on the provision of a desired wetland, while investors could get dividends based on overall fund performance. Dividends could be received directly for more quantifiable services, such as credits for nitrogen or carbon processed over the preceding year, or indirectly for non-excludable benefits provided to all of society. As the arising ecosystem service dividends would be variable, understanding past and predicted future performance of the return on investment would be a key factor in determining the size of investment that investors make, similar to conventional managed funds. The WIF would be responsible for registering any credits available and disseminating these as dividends to investors.
4. Engaging potential local wetland developers and operating reverse auctions, or similar, to invest in restoration proposals and increase overall fund returns. Local providers ensure local costs are reflected, allow for consistent and locally relevant assessment methods, and build trust in projects by ensuring wetlands are proximal and open for investors to visit [28]. Reverse auctions have been shown to deliver greater cost effectiveness for the delivery of other conservation and wetland restoration programs than uniform payments[94,96,97].
5. Regularly consulting with stakeholders and local communities to maximize the probability of investment wetlands aligning closely with funder and community demands, while minimising potential conflict with local values, ensuring social licence is maintained;
6. Disseminating guidance on the desired location and design of restored wetlands for developers[98];

7. Managing covenants to ensure permanence of restored wetlands, ensuring high confidence of continued provision;
8. Advocating for the protection and improvement of freshwater habitats. Poor catchment land use and freshwater management may compromise the provision of ecosystem services[99–101]. Weak environmental limits could also reduce the demand for ecosystem services.
9. Setting and maintaining scheme-wide policy on assessment methodologies and reporting standards to ensure consistency and efficiency in assessment. Assessment methodologies and standards should be based on advice from the local partner university/research institution. Updates to standards and methodologies scheduled at pre-defined intervals to increase certainty for developers.
10. Permitting and collecting royalties from commercial activities occurring within wetlands, such as fisheries harvesting, and reinvesting royalties back into the fund.

Note S15

Local scientific/technical support partner roles

Supporting the fund management body would be a *local scientific/technical support partner*, which may a university, research institution or consultancy with experience in wetland ecology, ecosystem service valuation and strong links in the local community, government and industry partners, and roles including:

1. Assisting with the technical aspects of mapping values, such as mapping current ecosystems, surveying human values and modelling optimal wetland positioning for delivery of different ecosystem service benefits;
2. Developing and refining simple, low-cost on-site and remote assessment methodologies. Streamlined, low-cost assessments that provide consistent standards, are robust to gaming, and scalable to inform overall fund performance adequately, rather than seeking perfection through costly and precise assessments, should be preferred. It would be preferable to have a greater wetland restoration and more certainty of service provision, rather than high certainty in service measurement and fewer restored wetlands. Updates to assessment methods should be scheduled well in advance to align with the frequency decided by the *management body* to ensure a balance between currency and scheme confidence. Ecosystem service performance metrics should include both intermediate and final ecosystems. Providing final ecosystem service provision estimates using established classification systems, such as the National Ecosystem Services Classification System (NESCS) Plus or the Common International Classification of Ecosystem Services, allows for more accurate and consistent reporting of ecosystem services, more seamless inclusion within national economic accounting and should improve the measurement of multiple ecosystem services from one site[102,104].
3. Developing guidance on wetland creation and design standards, potential restoration locations, specifically to maximize the provision of single ecosystem services, or the provision of complementary ecosystem services, and understanding trade-offs between managing for multiple services.
4. Running workshops to train wetland designers, community groups, and assessors. *Assessors* (who would be hired by the developer) should be certified with a training requirement that includes refreshers every time assessment methods are updated;

5. Auditing the assessment reports submitted by developers to the governance body, including carrying out random site visits, and maintaining an open database of assessment data. Reporting from the *local scientific/technical support partner* would only be to the *management body,* and not to the *developer* or *assessor,* to maintain independence and minimize cynicism that developers have paid for false or weak assessment.

Note S16

Role of government

Governments would be central and interacting with all groups, with roles including:

1. Legislating and enforcing policy that requires no net loss of the extent and condition of natural wetlands to help ensure additionality and minimize outside leakage[32].
2. Developing and managing a wetland accounting system, supported by data provided by the local university/research institution. A wetland accounting system will help the scheme demonstrate additionality, leakage minimisation and permanence[32]. Adopting the United Nations System of Environmental-Economic Accounting guidelines would improve data parity between countries[103].
3. Potentially establishing a legislated mechanism that recognizes investment in the fund as an option for offsetting environmental impacts, such as for carbon emissions or water quality degradation. This could involve introducing Pigouvian taxes on agricultural inputs, such as fertilizer or water takes, and urban rates, or directing environmental fines towards the fund.

Note S17

Salmon Safe eco-label

Salmon Safe is an NGO spanning across North America's west coast catchments from Alaska to Northern California[105]. Salmon Safe provide peer-reviewed certification and accreditation for farmers, urban developers, vineyards, corporations, land managers and builders that go above and beyond required regulation to protect water quality and wildlife habitat. Independent expert assessors carry out a land management assessment, that is then repeated regularly (typically 3-5 years depending on industry), those that comply with the certification can use the Salmon-Safe eco-label. In many cases, wetland restorations and good management of wetlands are certified. Whilst there is assessment and verification audits, the extent of wetland restoration efforts could not be assessed and the projects are not made public on Salmon Safe's website.

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