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Influence of Agricultural Land Conversion on the Ecological Integrity of Inland Wetland Networks

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Abstract: Inland wetlands are components of landscape networks, which are dynamic – they manage water dynamics, sequester nutrients, contribute to biodiversity and help maintain rural livelihoods. Hydrological changes to wetlands, including drainage, infilling, bunding, channel modification, and increasing areas of cultivation is a recurring stress on these systems, as it can lead to a loss of wetland habitat and to a loss of the hydrological links needed to maintain the functions of wetlands. This paper critically synthesizes evidence from 2014 to 2022 on the impact of agricultural conversion on the ecological integrity of inland wetland networks. The review compiles pathways connecting land-cover change and wetland area loss, fragmentation, altered hydroperiod, water quality decline, and habitat simplification and changes in ecosystem services. It also develops a conceptual assessment framework that integrates landscape configuration, hydrological connectivity, water quality, habitat condition and biological response. The reviewed evidence also shows that the ecological impacts of conversion can occur outside the reclaimed area, such as changes to the surrounding farmland, drainage infrastructure and flow control, which may have impacts on remnant wetlands via flow modification, sediment delivery and movement between habitat patches. A network perspective provides more information than a wetland-area accounting perspective. The paper calls for watershed-scale land-use planning, conservation of seasonally flooded wetlands and land-use transition corridors, nutrient management in agriculture, and restoration of hydrological processes. The proposed framework can serve as a guide for future geospatial and field-based assessments, but acknowledging that the impact level is dependent on the type of wetland, climate, topography and management history.

Keywords: Agricultural Land Conversion; Inland Wetlands; Ecological Integrity; Landscape Connectivity; Hydrological Alteration; Ecosystem Services.

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I. Introduction

Inland wetlands are found in lakes, marshes, floodplain depressions, oxbow systems, peatlands, and seasonal pools and other water-dependent habitats within terrestrial habitats. They are not only influenced by the presence of water, but also the timing, duration and spatial distribution of inundation. Wetlands hold back flood water, control sediment and nutrient flows, create breeding grounds, feeding grounds, and fisheries, and help to supply water and cultural practices. These functions are a product of the interactions of hydrology, soils, and vegetation and biological communities. The effects on the ecological health of a wetland network are therefore not limited to the area that is converted to intensive agriculture, but can extend to an entire network.

Historically, agricultural expansion has been one of the most significant causes of reclamation of wetlands. Typical conversion activities include drainage, levelling, embankment construction, canalization, water diversion and clearing of native wetland vegetation. In other landscapes, conversion is direct, such as when wetland basins are drained and used for cultivation. In others, wetlands are mapped as water or marsh, but are indirectly modified through irrigation withdrawals, run-off from fertilizers and pesticides, sediment delivery, grazing pressure and changes in flood pulses. The transition from wetlands to farmland is a widespread issue in China, as geospatial analysis shows, with agriculture encroaching on natural wetlands on a massive scale (Mao et al., 2018). Similarly, agricultural extension and flow regime changes have been found to act synergistically to make wetlands more vulnerable and break the external and internal linkages in the Punarbhaba basin (from the evidence) (Pal & Talukdar, 2018).

The relationship is especially significant in wetland ecosystems that are seasonally flooded and dry, such as in monsoon and floodplain areas, where wetlands may be farmed when dry, but flooded when wet. Areas that may appear to be underused or empty in one season could be interpreted as utilized or built in the next. The effect of agricultural expansion on the hydrology of the Atreyee River basin is shown, where agricultural use has contributed to the conversion of seasonally inundated wetlands to farms (Saha & Pal, 2019). Other studies in the Sanjiang Plain also make connections between the surrounding pattern of the farming landscape and soil and vegetation indicators of wetland degradation (Luo et al., 2022). The results suggest that conversion and the spatial distribution and intensity of agricultural use surrounding remnant wetlands affect ecological integrity.

The main issue that is addressed in this paper is the fact that traditional assessments usually rely on area statistics and neglect to consider wetland network integrity. If water inflow is prevented, water levels are not maintained stable, nutrient loads increase, or habitat patches are separated, a wetland might remain in place but cease to provide an ecological service. Small seasonal wetlands can play an disproportionate role in connectivity and biodiversity, and can do so despite their relatively small footprint. The paper thus looks at the impact of agricultural conversion on the structure, hydrological functioning and ecological condition of inland wetlands (networks).

The goals are to: (i) outline the key pathways by which agricultural land conversion impacts inland wetland integrity; (ii) synthesize evidence of changes in wetland extent, fragmentation, hydrology, water quality, biodiversity and ecosystem services; (iii) create a conceptual toolbox to assess the impacts of this change on the wetland network; and (iv) propose planning and restoration options that balance agricultural production with wetland conservation. The contribution is a synthesis effort that brings together pressures of land conversion, measurable ecological indicators, and management responses, with the focus on a network orientation.

II. Literature Review

Agricultural Land Conversion as a Landscape Process

Land-use change is not one single action, but a series of decisions and actions that alter the pattern of land cover and the processes that occur within a catchment. Agricultural conversion can take the form of permanent reclamation, seasonal cultivation, and extension of irrigated land or drainage of low-lying land and intensification of an existing agricultural area. Spatial location of the conversion pathway, sensitivity of the receiving wetland, and the nature of the conversion pathway all influence the ecological impact. A review of land-use change and ecosystem services highlights that transitions in land-cover affect provisioning, regulating, supporting and cultural benefits, and that social reactions to change are not always well documented (Hasan et al., 2020).

The difference between direct and indirect conversion is of critical importance to wetland networks. Wetland habitat is lost and network nodes are lost or decreased in number. Indirect conversion alters the matrix of wetlands, which may cause more edge effects and/or disruption of water and organism flow. Drainage ditches can lower local water tables; levees can separate floodplain basins from rivers; roads and field bunds can divide shallow flow paths; and irrigation withdrawals can reduce downstream hydroperiods. The cumulative effect can be a network with isolated wetland remnants that is no longer a functioning natural network.

Hydrological Connectivity and Wetland Function

Hydrological connectivity refers to the flow of water, sediment, nutrients and organisms from one aquatic and semi-aquatic habitat to another. It may be longitudinal, lateral or vertical and is subject to seasonal variation. Agricultural drainage and abstraction of water can decrease the connectivity between rivers, floodplains and depressional wetlands both in terms of their frequency and duration. A synthesis of the hydrologic-connectivity restoration of wetlands suggests that restoring wetlands should be approached

as a network and water-balance process instead of a single-channel or single wetland-unit restoration (Meng et al., 2020). This is important to agriculture as drainage processes implemented at a local level can have downstream impacts which do not show on parcel level land-cover maps. Functional properties are also connectivity. If embankments, dry barriers or poor water conditions block the movement of wildlife between two wetlands, the Euclidean distance will not suffice to determine if they are effectively connected. However, a series of temporary pools can facilitate movement for a brief time of the year. The value of assessing connectivity in an inland wetland under water-stressed conditions is illustrated by the Kaabar Tal wetland (Singh et al., 2017). For agricultural conversion studies, this means that network analysis must not only include spatial proximity, but also inundation and seasonal requirements for species dispersal.

Habitat Condition, Biodiversity and Ecosystem Services

The health of vegetation, soils, water and biological communities are all critical to the integrity of a wetland. Conversions can make vegetation simpler, decrease native vegetation coverage, increase disturbance and benefit generalist or invasive species. Under certain conditions, agricultural runoff can increase nitrogen and phosphorus levels, promote algal growth and cause decreases in dissolved oxygen. Sediment inputs may cause shallow basins or changes in substrate, pesticide exposure may impact aquatic invertebrates, amphibians, fish and waterbirds. These effects are possible to interact, e.g. water depth reduction and nutrient loading can act synergistically in altering food-web structure and plant communities.

The impacts are also registered on the people as inland wetlands provide fisheries, fodder, water regulation, recreation and other livelihood services. There is also a close linkage between wetland ecosystem services and local resource use and livelihood situation, as reported in the Maguri-Motapung wetlands case study of Assam (Bhatta et al., 2016). There is a suggestion that ecological integrity cannot be expressed by just one biodiversity measurement. An assessment that is defensible should take into account ecological processes that support habitat and services that communities rely upon, and should not assume that all services can be replaced by agricultural production.

Research Gap and Inference

There is significant evidence in the literature of loss of wetlands due to agricultural expansion, alteration of the hydrology, and alteration of ecosystem-service delivery. But there are three points of importance that are left. First, land-cover studies frequently fail to account for transitions, but do not determine whether any persisting wetland patches are hydrologically connected. Second is that ecological assessments can be conducted at specific sites with no consideration of the wider catchment and network configuration. Third, agricultural productivity and wetland functions are often seen as competing uses of the land rather than as goals that can be achieved in tandem by buffers, nutrient controls, zoning and restoration of flowpaths for timing of land use, etc. From the literature reviewed, it is inferred that the process of agricultural land conversion should be considered as a coupled landscape–hydrological process. The maintenance of network integrity is not solely through the maintenance of wetland area, but also the maintenance of the links, hydroperiods and eco/environmental characteristics that allow wetland patches to operate as a network.

III. Methodology

Review Design and Scope

The method used in this study is Critical Narrative Review and Conceptual Synthesizing. The evidence window is limited to peer reviewed literature from the literature requested period 2014-2022. As the primary discovery source, scholarly records indexed by Google Scholar were used, and the DOI and bibliographic information were cross-referenced with the corresponding scholarly-index and/or publisher information when available. The concepts for searching were such as “agricultural conversion”, “wetland loss”, “farmland”, “inland wetland”, “hydrological connectivity”, “landscape fragmentation”, “ecological integrity”, “ecosystem services” and “land-use change”. The studies emphasized are studies that

specifically address wetland–agriculture transitions and wetland network connectivity, hydrological alteration, ecological condition or ecosystem-service consequences.

This review does not take the form of a systematic review or meta-analysis. No pooled effect size is computed and no attempt is made to conclude that the 12 studies selected represent the full body of knowledge. Rather than this, the chosen research studies offer complementary evidence for a conceptual framework. The distinction is significant because there are ecological indicators and analytical methods, as well as wetland type and spatial scale, and study duration all vary between the studies.

Analytical Framework and Variables

The framework considers pressure from agricultural conversion as the key factor and ecological integrity as the multi-dimensional consequences. There are five dimensions considered: extent and configuration (wetland area, patch number and edge density, core area, inundation frequency and hydroperiod, flow-path continuity and connection to river or groundwater); water and soil condition (nutrient concentration, turbidity, dissolved oxygen, sedimentation and soil disturbance); habitat and biotic condition (presence of native vegetation, habitat heterogeneity, indicator taxa and biological diversity); ecosystem functioning and services (flood storage, nutrient retention, fisheries and livelihood support). The conceptual composite integrity score can be stated as equation (1):

$$EI = w_1E + w_2HC + w_3WQ + w_4BC + w_5EF \qquad (1)$$

where EI stands for ecological integrity, E for extent and configuration, HC for hydrological connectivity, WQ for water and soil quality, BC for biotic condition, EF for ecosystem functioning and $w_1 - w_5$ are weights that add up to one. This equation is a proposed organizing model, not a validated index. Weight should be chosen to be transparent for a given wetland type and tested on field observations. The proportion of converted wetland area to cropland, the rate of change in cultivated area within a specified buffer or catchment, drainage density, irrigation intensity and proportion of wetland edge in contact with cultivated land are all measures of agricultural conversion pressure. Landscape measures should be done on uniform spatial units and should be repeated across several dates. Seasonal imagery is suggested to avoid classification of temporary wetlands as dry land.

Synthesis Procedure

Evidence was compiled by causal pathway: direct area conversion; fragmentation and edge effects; hydrological alteration; pollution and sedimentation; biological response; and consequences to ecosystem services. Study contexts were conceptually compared to determine if impacts were a direct result of reclamation or due to land-use pressure or flow regulation in the surrounding area. These pathways and ecological response are summarized by the two figures below. The figures are conceptually explicit and not based on a common data set or a common measurement scale in the source studies.

IV. Results and Analysis

Direct Wetland Loss and Fragmentation

The evidence reviewed consistently links reclamation for agriculture as a direct route to loss of wetlands. Conversion decreases the overall habitat area for those species dependent on wetlands and may fragment large wetlands into smaller patches. The ecological impact is not necessarily greater for losing a larger area. Fragmentation raises edge-to-interior ratios and may open up interior habitat to agricultural development and may separate breeding, feeding and refuge areas. A wetland network consisting of many small disconnected wetlands, for example, may thus have a lower functional capacity than a network of similar area wetlands that are connected.

These effects are particularly strong if low-lying areas are cultivated during drought. Wet-seasons function of seasonal wetlands can be for flood storage, fish recruitment and amphibian breeding, yet they

can be drained or embanked. Due to this, wetland inventories need to separate permanent water from seasonal inundation and temporarily dry wetland soils. It is better to have a multi-season classification than a single date land cover map.

Hydrological Alteration and Loss of Network Function

Agricultural conversion alters hydrologic flows into, through and out of a wetland system. Drainage channels can also decrease the water holding period and seasonal storage. Shallow overland flow can be interrupted by field bunds and roads. Irrigating can result in reduced flow downstream and return flow can add nutrients, salts and agrochemicals. Channel modifications and embankments can lead to less frequent and longer periods of non-flooding in wetlands that rely on flood pulses. These processes can impact not only the converted parcel but can also have cumulative impacts in the catchment. The main pathways are summarised in figure 1. Conversion pressure impacts on the integrity of the wetland both directly and indirectly. Direct Disturbances: physical habitat removal or fragmentation. The altered runoff, delivery of nutrients and sediments, and reduced hydrological exchange are mediated routes. The framework emphasizes the need to consider the wetland network and the contributing catchment as the ecological unit of analysis instead of an individual wetland boundary.

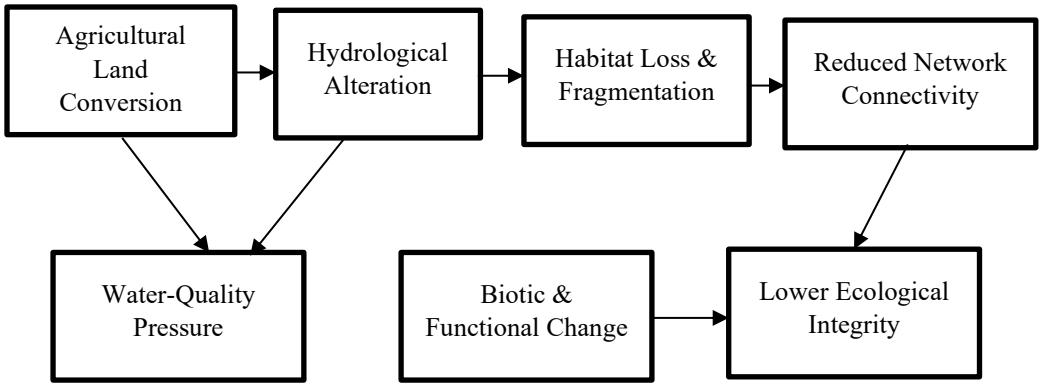


Figure 1: Conceptual Pathways through Which Agricultural Land Conversion Can Influence the Ecological Integrity of Inland Wetland Networks

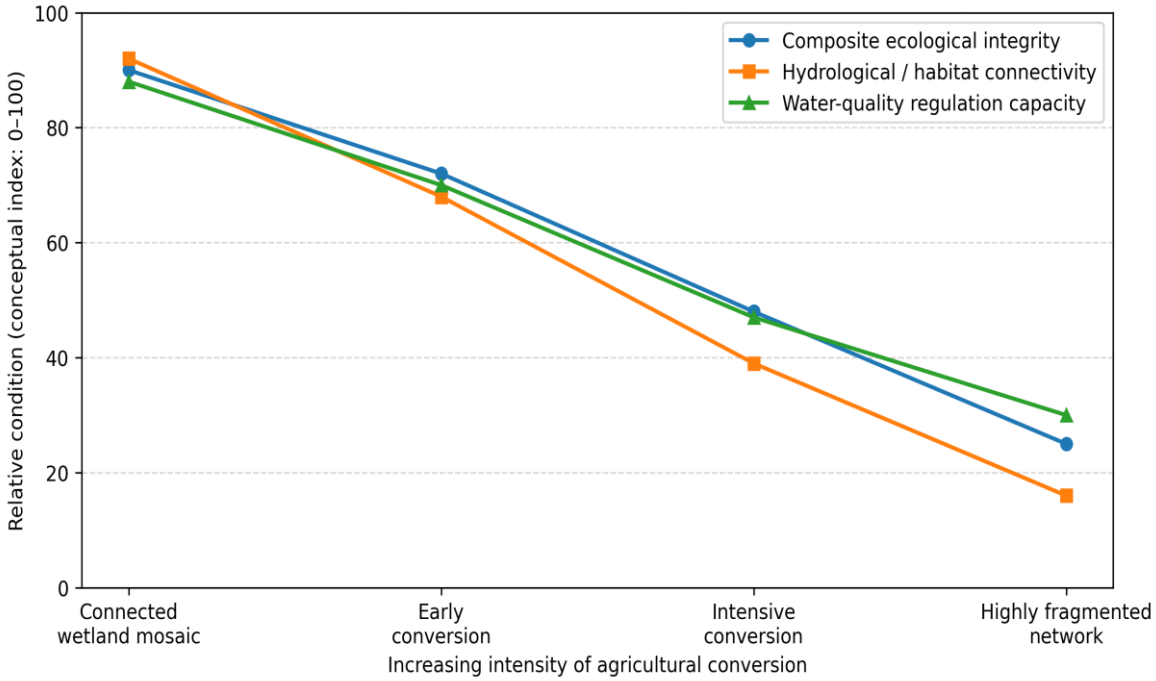
Water Quality, Habitat Condition and Ecological Response

Intensification has the potential to increase nutrient and sediment loads via fertilization, soil disturbance, livestock access, and discharge from drainage. The magnitude of these effects depends on soil type, slope, rainfall, crop management, buffer vegetation and wetland residence time. Nutrient enrichment can stimulate primary productivity initially, but can also lead to eutrophication, loss of oxygen and alteration of the composition of aquatic communities. Sedimentation can cause a reduction in the depth of basins and change the ratio of open water to emergent vegetation. Exposure and biological effects of pesticides and other agrochemicals can be different, and may be an added stress. Loss of native riparian and wetland vegetation also influence habitat condition. Vegetated margins reduce the speed of runoff, catch sediment, offer cover and promote terrestrial–aquatic interactions. Removal of these can increase edge effects and decrease habitat heterogeneity. When multiple stressors are present, ecological responses can be nonlinear – an ecologically healthy wetland may tolerate moderate nutrient additions, but become vulnerable if nutrients increase along with decreased flushing and habitat isolation.

Integrated Interpretation of Ecological Integrity

As agricultural conversion increases, the direction of change is shown in figure 2 and table 1. The relative-condition curves are conceptual and presented to convey the hypothesized pattern, not to imply measured values, or a universal response. The framework implies that connectivity and ecological integrity will decrease with increasing and increasing fragmentation of conversion. The water-quality regulation

capacity may also diminish, but local responses can vary due to buffer condition, wetland size, hydrological residence time, and agricultural practices.



Illustrative conceptual relationship synthesized from the reviewed literature; values are not observed measurements.

Figure 2: Conceptual Relationship Between Agricultural Conversion Intensity and Selected Dimensions of Wetland Ecological Condition. Values Are Illustrative Only and are not Empirical Measurements.

Table 1: Proposed Indicator Set for Future Empirical Assessment

Dimension	**Candidate indicators**	**Interpretation**
Extent and configuration	Wetland area; patch number; edge density; core area; nearest-neighbour distance	Measures habitat amount, fragmentation and spatial arrangement
Hydrological connectivity	Inundation frequency; hydroperiod; flow-path continuity; river–floodplain connection	Measures water exchange and seasonal network function
Water and soil condition	Total nitrogen; total phosphorus; turbidity; dissolved oxygen; sedimentation	Captures pollution and physical habitat stress
Biotic condition	Native vegetation cover; macroinvertebrate diversity; fish/amphibian occurrence; waterbird use	Indicates habitat quality and biological response
Ecosystem functioning	Flood storage; nutrient retention; fishery support; local resource use	Links ecological processes with services and human dependence

V. Discussion

The synthesis shows that conversion of agricultural land impacts inland wetland networks in terms of both habitat removal and the reduction and degradation of environmental quality. These mechanisms should not be considered independent. A drainage network can reclaim wetland area and increase the movement of nutrients; a field embankment can isolate habitat and alter flood storage; while irrigation withdrawals can decrease the hydroperiod of the wetlands and increase the concentration of pollutants in the water that remains. The ecological response is a result of the combined pressure intensity and pressure distribution.

The first is that a measure of wetland area is not a sufficient measure of ecological integrity. Remaining patches must be evaluated by the use of landscape metrics and hydrological indicators to decide if they are a connected network. This is confirmed by evidence, which suggests that the values provided by the ecosystem and the transitions in land-cover may also vary mutually in a wetland landscape, but the direction and amount of ecosystem-service change will depend on the specific land-cover transitions and on the specific approach to ecosystem services valuation (Badamfirooz & Mousazadeh, 2019). This interpretation is that changing the land-cover class might create an increase in one provisioning benefit, but not necessarily an increase in other regulating or supporting benefits; thus, single-value assessments may be misleading.

The second is that connectivity is an important intervening variable between land-use pressure and ecological response. Developing policy and reviewing landscape configuration simultaneously is highlighted by research into the role of landscape fragmentation in habitat connectivity (Luo et al., 2020). Connectivity needs to be viewed dynamically in wetland systems, as water and organisms flow through the system at varying times and conditions. As a result, the conservation of seasonal wetlands, shallow channels and riparian corridors can also be important where they are not permanently wet. The third implication is related to the size of the assessment. A small section of a wetland can be legally protected, but still be subject to catchment scale alterations in flow regimes, drainage and agricultural runoff. Results from tropical floodplains indicate that water-resource development can impact connectivity and productivity over a larger floodplain system (Molinari et al., 2022). Water allocation, floodplain management and catchment restoration should be accordingly planned to go hand in hand with agricultural land-use planning. This is important for wetlands that are reliant on a seasonal river connection or groundwater recharge.

The fourth implication is that interpretation of biodiversity responses should be done in the context of multiple drivers and evidence quality. Land-use change is a key pressure on biodiversity, but the validity of the inferences depends on taxonomic scope, spatial scale, temporal data and capacity to separate out the pressures of land-use change from climate and other pressures (Davison et al., 2021). The integration of remote sensing with field measurements and biological monitoring should be performed in future studies. Changes in extent and landscape metrics of wetlands can be captured from satellites, and change in ecological function can be determined from water-quality sampling and biological indicators. The results suggest a hierarchy of actions from a management point of view. Avoidance should be used first: ensure preventative measures are taken to avoid draining and conversion of high value wetlands, seasonal flood basins and connecting corridors. Minimize pressure where agriculture is in place by using vegetated buffer strips, nutrient budgeting, IPM, soil conservation and managed livestock access. Hydrological restoration can involve the elimination or modification of barriers, restoration of floodplain channels, restoration of environmental flows and elimination of unnecessary drainage. Restoration should be guided by a criterion of water level needed for the restoration of the wetland, and not an average water level. Another priority is to integrate agricultural and wetland policy. If the value of wetlands is not reflected in land valuation and planning, agricultural incentives can often be used to spur drainage or cultivation of seasonally wet land. Ecosystem services, community-based stewardship, conservation easement payments and compensation for maintaining flood-storage areas are potential ways to incentivize private land-use choices that benefit the public good. These instruments need to involve local participation, secure tenure arrangements and monitoring to make sure that benefits are delivered to landholders and to wetland dependent communities. Conceptual framework has some drawbacks. The studies chosen represent a variety of regions and wetland types and the results are not all comparable in terms of numerical effect estimates. The proposed composite integrity model needs to be calibrated and validated by making the indicators normalized before being used in operations. Furthermore, the relative significance of each of the hydrology, water quality and habitat configuration will vary between peatlands, floodplain marshes, seasonal pools and shallow lakes. Therefore, the framework should be tailored to the local ecological and management goals.

VI. Conclusion

Agricultural land conversion impacts the ecological integrity of inland wetland networks in a variety of ways including the direct loss of wetland habitat, changes in hydrology, water quality, habitat structure and biological connectivity. The review validates the fact that area statistics do not provide an adequate understanding of wetland degradation. Drainage, embankments, irrigation withdrawals and agricultural runoff may break linkages between wetland patches, change seasonal inundation, and lessen the ability of any remaining wetlands to buffer water quality and quantity, hold floodwater and provide habitat for biodiversity. These effects can be felt not just on converted land but over the whole of a catchment. Thus, it is essential to develop a network-based assessment procedure that incorporates wetland extent and configuration, hydrological connectivity, water and soil quality, biotic condition and ecosystem functioning. The conceptual framework proposed in this paper offers a foundation to integrate remote sensing data, landscape metrics, and hydrological observations and ecological field indicators in future studies. On the ground, the best way to respond is to not convert high-value wetlands and connecting hydrologic corridors, preserve seasonal connections, adopt vegetative buffers on farms, minimize nutrient and pesticide losses, and restore hydrologic processes if possible. Planning for agriculture and the conservation of wetlands needs to be considered as a landscape objective rather than competing uses for land. Future empirical studies are needed to validate the proposed indicators on a variety of inland wetland types and to investigate the interactions between climate variability, agricultural intensity and local governance and the integrity of inland wetlands. This evidence can inform catchment planning to increase resilience and long-term conservation of wetland networks.

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