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Abstract

Mountainous abandoned paddy wetlands act as crucial biodiversity hotspots formed through secondary ecological succession, yet they face severe threats from climate-driven wildfires. This study evaluated the spatial severity patterns and multi-taxonomic biodiversity responses following a high-intensity wildfire in March 2025 at the Yeongyang Janggumegi Protected Wetland Area, South Korea, where agriculture was abandoned approximately 25 years ago. Topographic-meteorological interactions led to distinct spatial burn severity: steep upslope western slopes suffered complete canopy combustion, whereas the central standing water and deep valley floors functioned as vital micro-refugia. Post-fire monitoring revealed a 15.0% reduction in total species richness (from 472 to 401 species) and a 50.0% decline in endangered species (from 6 to 3 species). Significant population collapses were observed in birds (-56.9%), benthic macroinvertebrates (-56.9%), amphibians and reptiles (-55.6%), mammals (-21.4%), and terrestrial insects (-17.1%), driven by canopy destruction, microclimate desiccation, and water quality degradation. Conversely, plant species richness increased by 9.9% (from 222 to 244 species) due to the rapid influx of heliophilic weeds and

non-wetland annuals, signaling an alarming risk of transition toward a non-swamp state. To mitigate post-fire degradation, we propose four operational adaptive management strategies: (1) installing soil erosion barriers on high-severity slopes to prevent ash influx, (2) establishing Ecosystem Protection Zones around central hydrological micro-refugia, (3) controlling invasive weeds to promote native wetland flora (Salix and Alnus spp.), and (4) deploying artificial micro-refugia alongside long-term biological monitoring targeting EPT taxa and amphibians.

Key words

Abandoned paddy wetland, Wildfire severity, Vegetation succession, Micro-refugia, Species turnover

1. Introduction

Freshwater wetland ecosystems occupy a minor fraction of the Earth's surface yet serve as critical hotspots of global biodiversity (Strayer and Dudgeon, 2010). However, global climate change, habitat fragmentation, and anthropogenic disturbances increasingly compromise wetland ecological stability. In particular, large-scale wildfires occurring under severe drought conditions have emerged as a primary threat that destabilizes the physicochemical environment and structural integrity of wetlands (Pugh et al., 2022). The Yeongyang Janggumegi Protected Wetland Area, a mountainous abandoned paddy wetland located in South Korea, has maintained unique hydrological conditions and exceptional biodiversity through natural secondary succession. Nevertheless, a recent high-intensity wildfire inflicted extensive ecological damage across its catchment. Wildfire disturbances in wetland ecosystems exert impacts that extend beyond immediate species loss, driving long-term shifts in ecotonal interactions and food web dynamics (Mason et al., 2023). Consequently, a comprehensive post-fire evaluation of biodiversity dynamics is urgently required to establish scientific restoration and management strategies (Han et al., 2025).

As primary producers, wetland plant communities face immediate risks from aboveground biomass combustion and drastic hydrological shifts following wildfires (Mason et al., 2023). Post-fire vegetative recovery trajectories depend heavily on local water availability, species-specific hydrological niches, and regenerative traits (Mason et al., 2023). In wetlands

experiencing drought or reduced water tables, vegetative recovery is severely retarded, accelerating the loss of obligate wetland species and promoting desiccation toward a non-swamp state (Mackay et al., 2024). Furthermore, fire disturbance facilitates the reduction of native species while creating opportunities for invasive species influx (Sonnier et al., 2023). Plant life-form functional groups exhibit differential recovery rates and compositional shifts, which can fundamentally reconfigure vegetation structure under recurrent fire regimes (Sapkota et al., 2025).

Amphibians and reptiles are exceptionally sensitive to microclimatic and hydrological alterations due to their cutaneous respiration and complex biphasic life cycles (Suriyamongkol et al., 2021). High-severity wildfires destroy canopy cover in riparian forests, causing elevated ground temperatures and acute microclimatic desiccation that severely restrict amphibian survival and dispersal (Suriyamongkol et al., 2021). Under such severe fire disturbances, unburned habitat patches within the wetland landscape act as indispensable micro-refugia, allowing sensitive herpetofauna to escape thermal stress and persist (Bailey et al., 2025).

For vertebrate fauna, wildfires induce direct mortality while inducing long-term structural habitat fragmentation (Tomas et al., 2021). The loss of mature forest canopy and structural complexity leads to sharp density declines in forest-dependent avian and mammalian taxa (Baltzer et al., 2025). Conversely, persistent aquatic surface water and associated prey resources within wetland cores serve as crucial ecological buffers that sustain higher trophic predators during severe post-fire droughts (Eriksson et al., 2025).

Terrestrial insect assemblages respond rapidly to host-plant loss and physical habitat destruction caused by fire (Dole et al., 2023). The destruction of specific host plants results in the local collapse of forest-specialist insects, driving community simplification toward disturbance-adapted generalist taxa (Sustek et al., 2017).

Benthic macroinvertebrates serve as vital bioindicators for assessing aquatic ecosystem health and water quality shifts (Han et al., 2025). Post-fire run-off transports substantial volumes of pyrogenic ash and sediment into stream channels, causing abrupt increases in water temperature, electrical conductivity (EC), total suspended solids (TSS), and nutrient concentrations (Elliott et al., 2024). Such physicochemical stress causes severe declines in sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa while favoring pollution-tolerant non-insect taxa (Williams Subiza and Brand, 2018). Furthermore, the loss of riparian

canopy disrupts coarse particulate organic matter (CPOM) inputs and alters leaf litter decomposition pathways, inducing long-term perturbations in stream food webs (Chandler et al., 2021).

The primary objective of this study is to quantitatively evaluate the ecological impacts of a high-severity wildfire across multiple biological taxa in the Yeongyang Janggumegi Protected Wetland Area. By integrating spatial burn severity, vegetation mapping, and pre- (2022) versus post-fire (2025) field monitoring data across six taxonomic groups (flora, amphibians/reptiles, birds, mammals, terrestrial insects, and benthic macroinvertebrates), we diagnose the extent of biodiversity loss and habitat degradation. Ultimately, this study provides actionable insights to formulate science-based, adaptive wetland management and restoration policies (Adaptive Wetland Management Policy) for fire-affected mountainous wetlands in an era of climate uncertainty.

2. Materials and Methods

2.1 Study Site and Wildfire Event

The Yeongyang Janggumegi Protected Wetland Area is a representative mountainous abandoned paddy wetland located in Yeongyang-gun, Gyeongsangbuk-do, South Korea (36°N, 129°E). Following agricultural abandonment in approximately 2000, the site underwent 25 years of unmanaged secondary succession, developing complex hydric soils, woody canopy vegetation, and high biodiversity. On March 22, 2025, a wildfire ignited in adjacent Yeongdeok/Uiseong counties and propagated into the Janggumegi catchment on March 25 due to strong winds. The fire burned continuously until containment on March 28, causing variable combustion across the riparian forest, canopy, soil organic layers, and aquatic habitats.

2.2 Vegetation and Burn Severity Mapping

Field vegetation surveys were conducted in July (20 plots) and September (13 plots) 2025 using the Braun-Blanquet relevé method(Braun-Blanquet, 1965) within 10 m × 10 m quadrat samples. Phytosociological data were compiled to construct an actual vegetation map consisting of 14 land-cover classes. Spatial burn severity was evaluated by combining high-resolution drone aerial photography with ground-truth field validation, categorizing severity

into four classes: No damage, Surface damage, Half-burned crown, and Whole burned crown.

2.3 Multi-Taxonomic Biological Surveys

Pre-fire baseline data (2022) were compared with post-fire monitoring data (2025) across six taxonomic groups using standardized sampling protocols:

Flora: Total plant species were recorded along standardized transects covering all vegetation units.

Amphibians and Reptiles: Line transect visual encounter surveys (VES) and nocturnal calling surveys were conducted along stream reaches and standing water pools.

Birds: Line transects and passive acoustic monitoring using autonomous audio recorders (Song Meter-mini) were deployed across burn severities.

Mammals: Infrared camera traps and field sign track/scat searches were conducted along animal trails.

Terrestrial Insects: Sweep netting, pitfall trapping, and visual search methods were standardized across habitat types.

Benthic Macroinvertebrates: Quantitative benthic sampling was performed using Surber nets (30 cm × 30 cm, 300 μm mesh) and Dredge samplers across pool and riffle microhabitats, following National Wetland Survey Guidelines (National Institute of Ecology, 2020).

3. Results and Discussion

3.1 Vegetation Distribution and Management Implications

Spatial analysis of actual vegetation revealed a north-to-south valley hydrological gradient with 14 distinct plant communities and land-use types (11 woody communities, 1 herbaceous community, and 2 land-use types) (Table 1). The wetland landscape reflects a classic developmental trajectory of a wooded abandoned paddy wetland (Wooded Abandoned Paddy Wetland) shaped by 25 years of unmanaged secondary succession following farming cessation (Mackay et al., 2024; Mason et al., 2023).

The southern inlet region is dominated by pure Alnus incana subsp. hirsuta stands (Ai.),

which transition downstream into mixed woody canopies of Alnus incana–Salix pierotii (Ai-Sp.), Alnus incana–Alnus japonica (Ai-Aj.), and Alnus japonica–Salix pierotii (Aj-Sp.). This longitudinal zonation along historical paddy terraces demonstrates natural hydrological succession from wet herbaceous fields to closed woody canopy forest (Sonnier et al., 2023).

The central wetland core consists of dense woody matrices of Salix pierotii–Alnus incana (Sp-Ai.) and Salix pierotii–Salix triandra Subsp. nipponica (Sp-Sn.) surrounding standing water pools, interspersed with small patches of Scirpus karuizawensis–Persicaria thunbergii (Sk-Pt.) and Salix koriyanagi (Sk.). These high-moisture central pools provided essential breeding grounds and micro-refugia for aquatic organisms prior to and during the fire (Suriyamongkol et al., 2021; Han et al., 2025).

The surrounding hillslopes are occupied by Quercus mongolica (Qm.) and Castanea crenata–Alnus incana (Cc-Ai.) forests, bounded by agricultural fields (Ag.) and abandoned fallows (AP.) along the southwestern boundary. While these fallows record the site's agricultural history, they present potential pathways for nutrient runoff and invasive plant establishment (Sonnier et al., 2023).

The 25-year-old closed canopy of Salix and Alnus species buffered stream flow and maintained humid microclimates. However, this high woody biomass and continuous canopy fuel structure created elevated physical vulnerability to crown fires during extreme drought (Sapkota et al., 2025). The widespread loss of canopy cover has dramatically increased ground solar irradiance and soil drying, posing severe risks of native obligate wetland displacement and rapid infestation by opportunistic heliophilic weeds—a trajectory indicating a dangerous transition toward a non-swamp state (Mackay et al., 2024; Sonnier et al., 2023).

Management Implications: Adaptive wetland management must focus on constructing vegetative buffer strips along southwestern agricultural borders to intercept nutrient runoff. Furthermore, active weed monitoring and hydrological conservation measures (e.g., small check dams) are required to maintain water tables and foster natural regeneration of native Salix and Alnus canopy trees (Sonnier et al., 2023; Granath et al., 2016).

3.2 Wildfire Severity Patterns and Spatial Management

The wildfire entered the protection area under severe fire weather conditions: persistent northwesterly winds (1.6–4.1 m/s) and relative humidity below 50%. These conditions rapidly desiccated forest floor litter and fuel beds, accelerating fire propagation and intensity (Sapkota et al., 2025; Koralewski et al., 2021).

The catchment fuel matrix exhibited contrasting fire behavior: eastern coniferous ridge forests dominated by resinous Pinus densiflora facilitated intense crown fire spread (Sapkota et al., 2025), whereas western deciduous slopes (Quercus mongolica, Q. variabilis) supported heavy ground fuel loads that sustained deep surface burning (Delcourt et al., 2021).

Spatial severity mapping demonstrated marked burn heterogeneity. The steep western upslope experienced complete crown fire destruction (Whole burned crown / High Severity). This severe damage resulted from the alignment of northwesterly winds with steep slopes, creating a strong convective chimney effect (Topographic Slope Effect) that amplified fire line intensity and rate of spread (Miller and Yool, 2002; Delcourt et al., 2021).

In stark contrast, the central wetland core located in the valley bottom maintained standing surface water and sustained minimal burn damage (No damage to Surface damage). Similarly, the southwestern agricultural buffer suppressed fire advancement due to low fuel loads. High soil moisture and open water acted as an effective thermal buffer zone and natural firebreak (Bailey et al., 2025; Mason et al., 2023). In the narrow northern outlet valley, strong wind currents caused the fire front to jump across upper canopy ridges (Valley Jumping Effect), leaving the valley floor stream and riparian microhabitats largely unburned (Fraser et al., 2017; Han et al., 2025).

Thus, burn severity was governed by complex interactions among wind direction, topography, land use, and moisture regime (Delcourt et al., 2021). The unburned central standing water pools and northern valley floor functioned as critical ecological micro-refugia that enabled amphibians, macroinvertebrates, and mobile mammals (Prionailurus bengalensis, Martes flavigula) to survive (Suriyamongkol et al., 2021; Eriksson et al., 2025).

Spatial Management: Post-fire management must prioritize soil erosion control on severely burned western slopes. Installing log erosion barriers and sediment retention basins is essential to prevent pyrogenic ash and sediment from washing into central pools during summer rains (Elliott et al., 2024; Pugh et al., 2022). Additionally, the central standing water core should be designated as a strict Ecosystem Protection Zone with controlled access to

safeguard its hydrological integrity as a biodiversity refuge (Garcia et al., 2021; Tomas et al., 2021).

3.3 Faunal Dynamics and Adaptive Habitat Management

Comparison between pre- (2022) and post-fire (2025) surveys demonstrated severe biodiversity losses. Total species richness declined by 15.0% (from 472 to 401 species), and legally protected endangered species decreased by 50.0% (from 6 to 3 species) (Table 1).

Taxonomic group responses revealed pronounced dissimilarity:

Birds: Richness collapsed by 56.9% (51 to 22 species), with the complete loss of three endangered canopy-dependent species (Accipiter gentilis, Pitta nympha, and Terpsiphone atrocaudata) due to complete canopy destruction (Harrison et al., 2024).

Benthic Macroinvertebrates: Richness plummeted by 56.9% (65 to 28 species). Pyrogenic ash influx, elevated TSS, and increased electrical conductivity eliminated sensitive EPT taxa (Ephemeroptera, Plecoptera, Trichoptera), shifting community structure toward tolerant non-insect taxa (Williams Subiza and Brand, 2018; Elliott et al., 2024).

Amphibians and Reptiles: Species richness dropped by 55.6% (9 to 4 species). Loss of riparian shade and microclimatic desiccation severely restricted amphibian breeding and survival (Suriyamongkol et al., 2021).

Mammals: Richness decreased by 21.4% (14 to 11 species). While canopy-dwelling Pteromys volans was extirpated, terrestrial carnivores (Prionailurus bengalensis, Martes flavigula) persisted by utilizing unburned aquatic refugia (Eriksson et al., 2025).

Terrestrial Insects: Richness declined by 17.1% (111 to 92 species) due to host-plant loss. Notably, the endangered dung beetle Copris tripartitus newly colonized open post-fire clearings, exploiting increased solar radiation and mammalian dung resources (Šustek et al., 2017).

Plants: Plant richness unexpectedly increased by 9.9% (222 to 244 species). However, this increase was driven by an influx of ruderal annuals and heliophilic weeds, signaling ecological degradation and non-swamp state risk rather than true recovery (Mason et al., 2023; Sapkota et al., 2025).

Habitat Management: To assist amphibian recovery in canopy-cleared areas, artificial micro-refugia (e.g., PVC pipes and wet log structures) should be deployed near water margins to mitigate thermal stress (Suriyamongkol et al., 2021). Furthermore, an adaptive biological monitoring framework targeting EPT taxa and amphibians should be established to track long-term aquatic recovery and guide intervention measures (Han et al., 2025).

4. Conclusion

This study provides a comprehensive quantitative diagnosis of wildfire impacts on the Yeongyang Janggumegi Protected Wetland Area, a high-value mountainous abandoned paddy wetland shaped by 25 years of natural succession.

1. Fire Behavior and Micro-Refugia: Burn severity was strongly dictated by interactions between wind, topography, and hydrology. Steep western upslopes suffered complete canopy destruction due to convective slope alignment, whereas central standing water pools and deep northern valley floors acted as vital micro-refugia due to thermal buffering and valley jumping effects.

2. Quantified Biodiversity Collapse: The wildfire caused a 15.0% reduction in total species richness (472 to 401 species) and a 50.0% collapse in endangered species (6 to 3 species). Severe population declines occurred in birds (-56.9%), benthic macroinvertebrates (-56.9%), amphibians/reptiles (-55.6%), mammals (-21.4%), and insects (-17.1%). The apparent increase in plant richness (+9.9%) reflects ruderal weed invasion and non-swamp state risk.

3. Four Operational Wetland Management Strategies: To align with the scope of Wetlands Ecology and Management, we propose four concrete management recommendations:

(1)Catchment Soil Stabilization: Construct log erosion barriers and sediment basins on high-severity western slopes to prevent ash and sediment deposition in aquatic habitats. (2)Hydrological Protection and Zoning: Establish a strict Ecosystem Protection Zone around central standing water pools to preserve hydrological micro-refugia. (3)Invasive Weed Control and Revegetation: Conduct active weed control in canopy-cleared zones while encouraging natural regeneration of native Salix and Alnus trees. (4)Adaptive Biological Monitoring: Deploy artificial micro-refugia (e.g., PVC pipes) for amphibians and establish long-term monitoring centered on EPT bioindicators to guide adaptive restoration.

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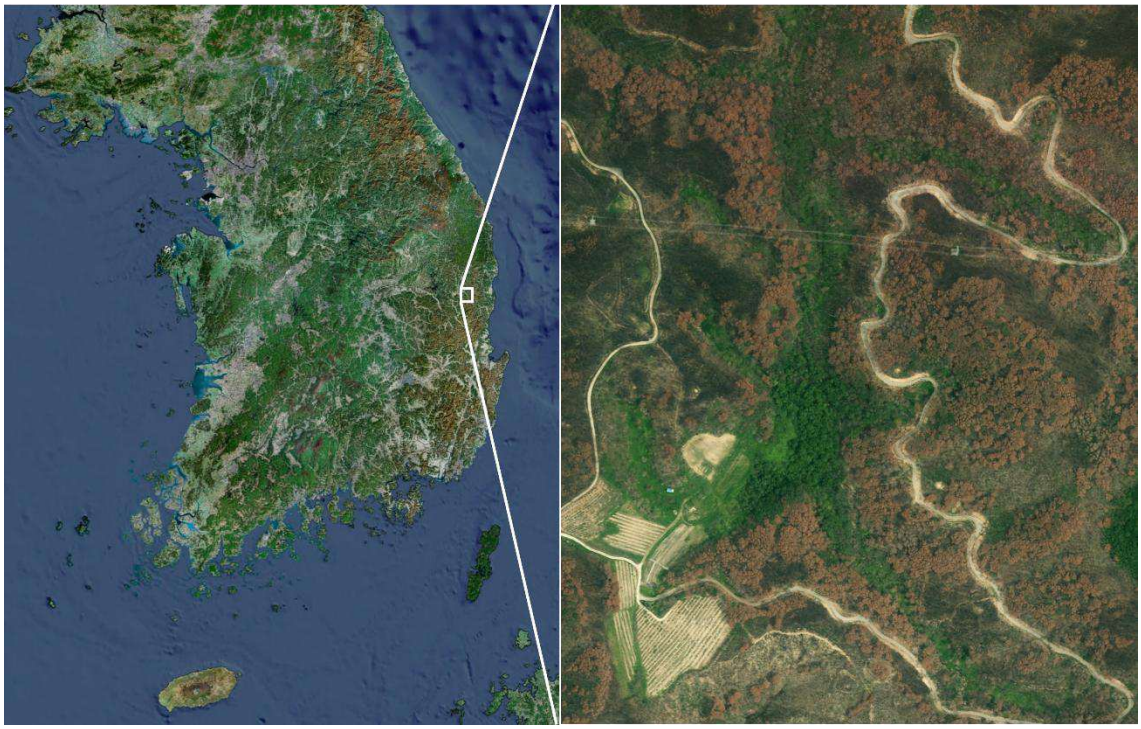
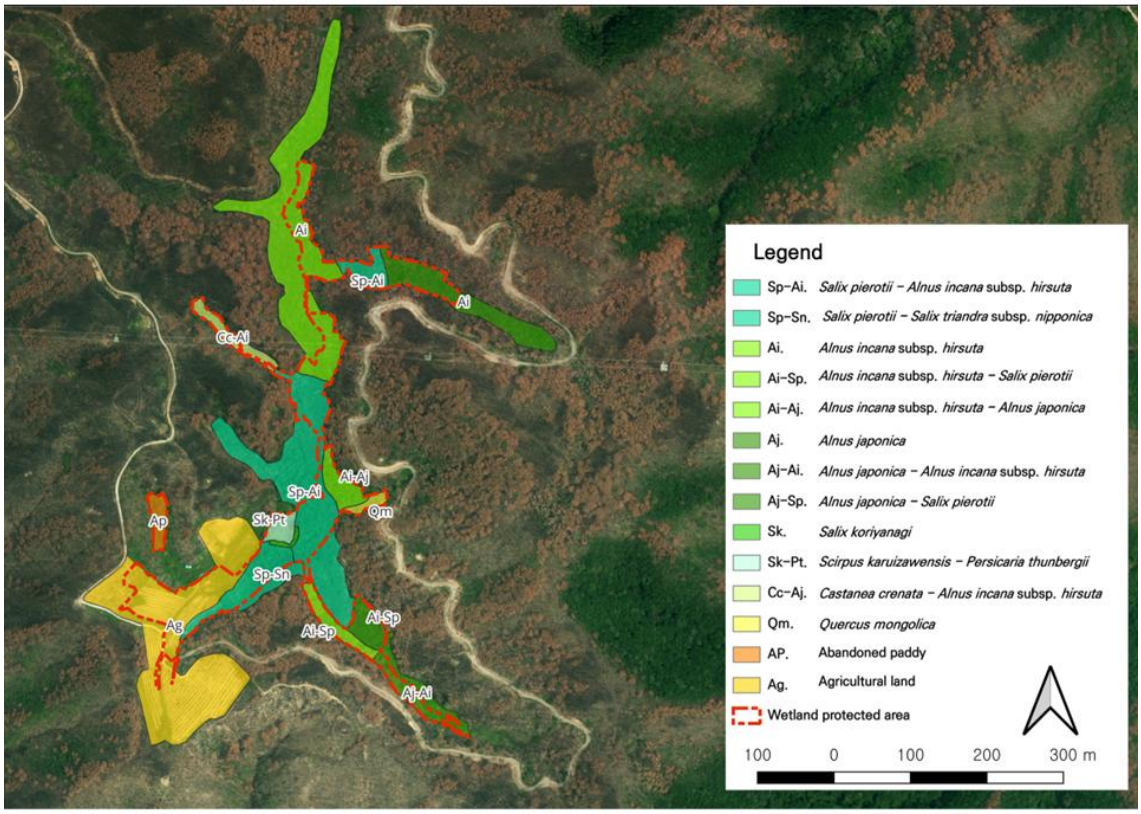


Figure 1. Study area

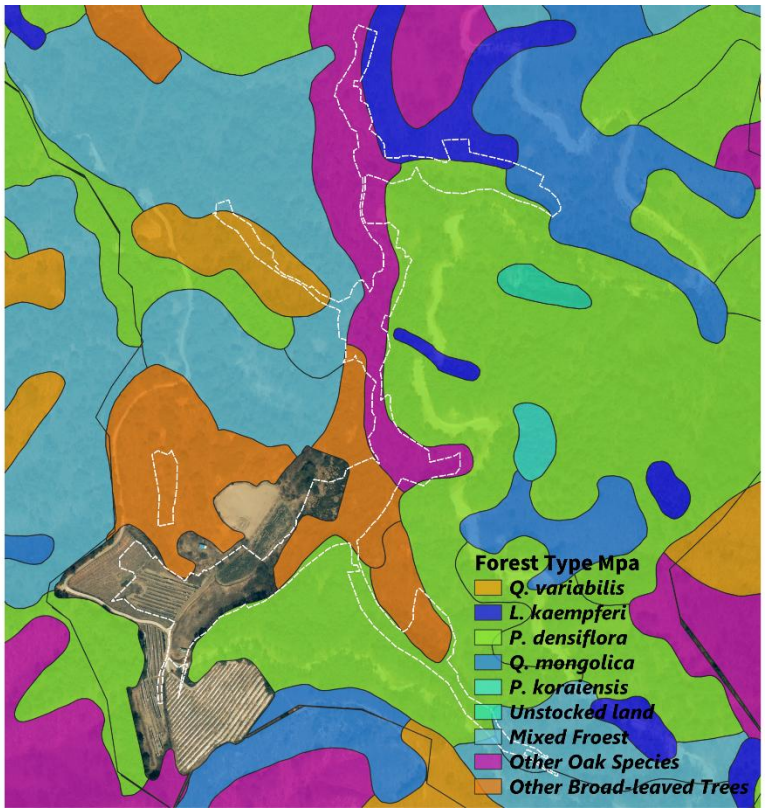


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372 Figure 2. Current Status of Vegetation Distribution in Yeongyang Janggumegi Wetland.

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376 Figure 3. Current status of forests in Yeongyang Janggu-megi Wetland

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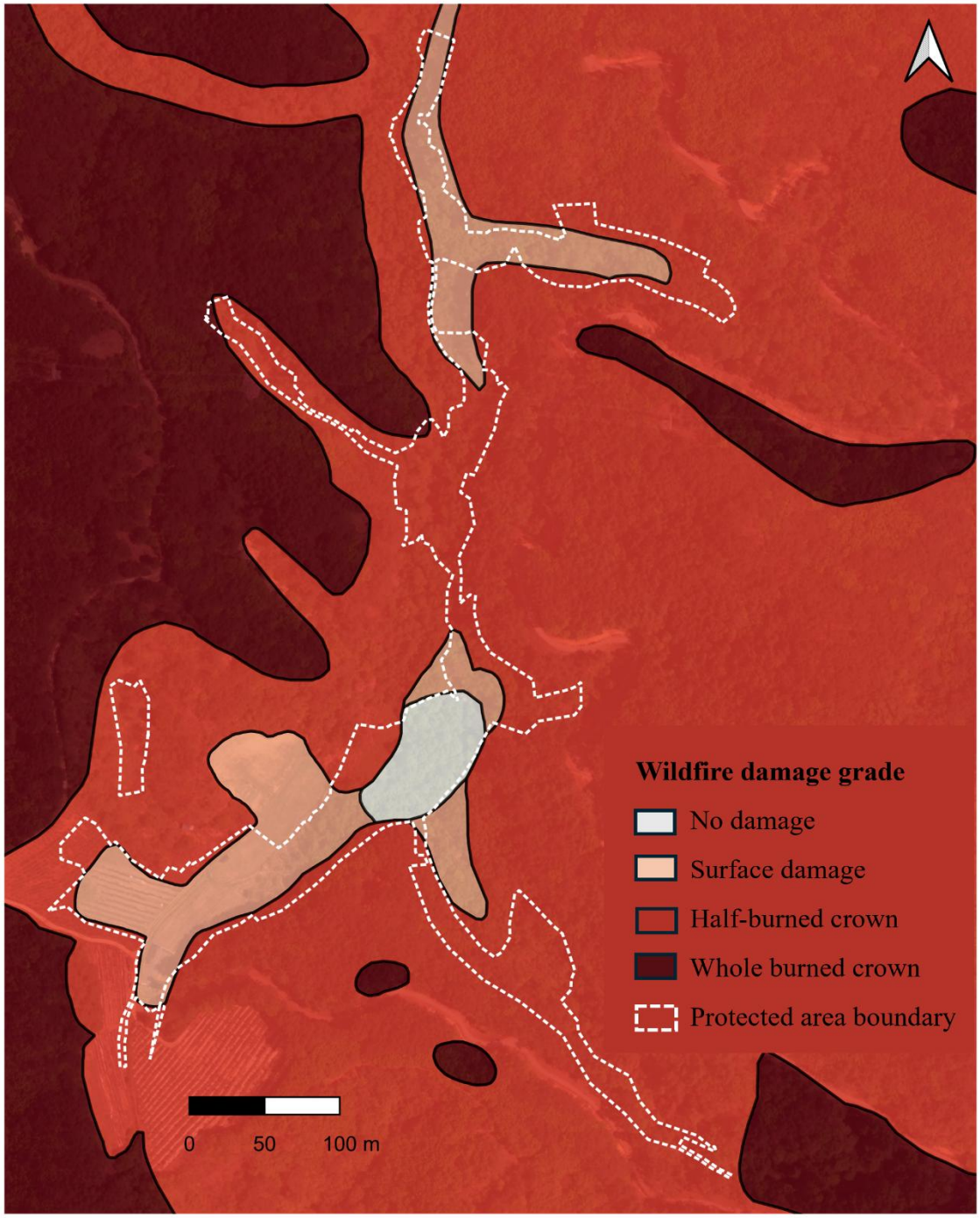


Figure 4. Yeongyang Janggu-megi Wetland Wildfire Damage Grade

Table 1. Changes in biological species before and after the Yeongyang Janggumegi Wetland wildfire

	Species (2022)	**Species (2025)**	**Endangered wildlife(2022)**	**Endangered wildlife(2025)**
Total	**472**	**401**	**6**	**3**
Plant	222	244	-	
Ampibials & Reptiles	9	4	-	
terrestrial insects	111	92	-	*Copris(Copris) tripartitus*
birds	51	22	*Astur gentilis, Pitta nympha, Terpsiphone atrocaudata*	
mammalia	14	11	*Martes flavigula, Prionailurus bengalensis, Pteromys volans*	*Martes flavigula, Prionailurus bengalensis*
Benthic macroinvertebrates	65	28	-	