Inland Wetland Habitats
20. Peatland Restoration

DEFINITION

Peatlands are a type of inland wetland where waterlogged soils prevent plant material from fully decomposing. There are two types of peatlands: *tropical peatlands*, characterized by high precipitation and temperature, and *northern peatlands,* which are interspersed among boreal forests and coastal areas (IPS n.d.b.). The United States is home only to northern peatlands, which are primarily found in Alaska, the Great Lakes region, New England, and the Atlantic Coastal Plain (MN DNR 2023, Minasny et al. 2019). Sphagnum moss is the building block of peatlands, with layers of moss growing over water and providing a foundation on which other plants can grow (Andreozzi n.d.). Peatlands, which include bogs, fens, and peat swamps, are vital carbon sinks, with twice as much carbon stored in peatlands as in all the world's terrestrial forests. Peatlands are on the decline, with 35% of peatlands lost globally since 1970 (Kopansky 2019). To reverse this trend, peatland restoration and conservation projects aim to rehabilitate peatlands to their natural state as carbon sinks. Most peatland restoration projects involve altering the hydrology of the site to rewet the peat. Techniques often used include installing peat dams, plastic piling and bundling, water control structures, and transferring sphagnum moss into the site (IPS n.d.a)

TECHNICAL APPROACH

Peatland restoration is tailored toward sites that have experienced peat mining or have been drained for agriculture. Individual restoration techniques should be selected based on the site-specific factors. However, most peatland restoration projects first remove drivers of peatland degradation, then restore peatland hydrology, and finally reintroduce plants.

1. **Removing drivers of peatland degradation:**
    - **Invasive species removal:** Altered hydrology and eutrophication can create conditions that favor invasive species. Invasive species increase the risk of fire, outcompete native species and impede the peat forming process. Common invasive species in peatlands include glossy buckhorn (*Frangula alnus*), reed canary grass (*Phalaris arundinacea),* and the common reed (*Phragmites australis*) (Cohen et al. 2020).
    - **Pollution control:** Peatlands are negatively impacted by airborne soot pollutants from nearby industrial facilities and poor water quality from nutrient pollution. The unique soil structure of peatlands is negatively impacted by high nitrogen and phosphorus concentrations, leading to the release of carbon in the soil (Li et al. 2022). Limiting the amount of airborne and waterborne pollution that enters a peatland is necessary before introducing more water to the area as a part of hydrological restoration (Monteverde et al. 2022). This involves siting projects away from heavy industry and working with landowners upstream to install riparian buffers.

- **Grazing control:** While limited grazing can benefit peatlands by removing invasive species and excess fuel, intense grazing pressures can degrade peatlands. Grazing reduces the amount of carbon stored in peatlands and alters the plant community composition (Ward et al. 2007). Limiting grazing gives peatlands the opportunity to naturally regenerate.
- **Fire control:** Fire management in peatlands is a highly controversial issue, with many organizations arguing that prescribed burns should be eliminated from peatlands (IUCN UK PP 2023). Prescribed burns on peatlands should be low intensity, located away from bare peat, in flat areas, and performed during wet conditions. Prescribed burns are meant to remove excess vegetation that could cause larger catastrophic peatland fires in the future (Ashby and Heinemeyer 2021). Other fire control measures such as forest thinning and invasive species removal should be considered before a prescribed burn is conducted.
- **Forest to bog restoration:** Once peatlands are dried out, the sphagnum moss is often replaced by trees that are better adapted to the new hydrological system. Tree harvesting clears the way for peat to be reintroduced, with dead trees left on-site and mulched to keep the biomass within the ecosystem. Furrow blocking and ground smoothing are then performed to restore the flat topography of the peatland. This technique is often combined with plastic piling or peat dams (descriptions follow) to keep water in the peatland (NatureScot 2020).

2. **Restoring peatland hydrology:** For drained peatlands, restoration involves blocking drainage outlets to keep water in the peatland (Figure 1). This promotes the waterlogged conditions that make peatlands such effective carbon sinks (IPS n.d.a).
    - **Peat dams:** Plugging the mouths of ditches and channels with peat can help keep water in the peatland. *Peat dams*, which are walls of peat blocking water drainage out of the peatland, are common rewetting tools. Working under dry conditions, damming the most upstream part of the system first and spacing dams closer together as slopes get steeper is vital to project success (Joosten and Duene 2021).
    - **Plastic piling and bundling:** In areas where it is not feasible to create a peat dam, plastic piling and bundling can help block drainage points. Large sheets of plastic are sunk into the drainage ditch and the surrounding peat, preventing any leakages. The sheets are often reinforced with timber to ensure stability (Mainprize 2021).
    - **Wood piling dams:** Alternatively, wood piling dams can be used to regulate runoff. A dam built with planks inserted deep into the soil is placed perpendicular to the ditch. During construction, the ditch should be drained using temporary dams or bypass channels to promote stability (Joosten and Duene 2021).
    - **Metal dams:** In areas that experience significant water pressure and frequent inundation, metal dams can be used to alter hydrology. Panels of sheet metal can be used to replace wood or plastic piling in dams. While metal is more durable, it can also be more expensive (Joosten and Duene 2021).

Figure 20.1 Water control structure to block a drainage outlet in Great Dismal Swamp, VA

Photo courtesy US Fish and Wildlife Service Northeast Region

- **Stone dams:** In areas where buoyant materials such as peat or wood are not suitable, stone dams can be used to keep water in the peatland. Stones can be used to reinforce peat dams or plastic piling. Stone *gabions*, metal cages filled with stone, can be placed in the middle of culverts. The gabions will get clogged with peat, which will then block water from flowing out of the peatland (Joosten and Duene 2021).
- **Bunding interventions:** Bunding aims to keep water on the peat restoration site by constructing a retaining wall around the perimeter. The wall can be made of a variety of materials, but commonly consists of peat. Deep bunding is done to prevent water from leaking out of cracks in the peat. To slow down water flow, surface bunding is installed in areas of wide, but shallow, water flow (NatureScot 2020).
- **Backfilling:** *Backfilling*, also known as *infilling*, involves filling up entire drainage ditches with substrate. While the substrate does not have to be peat moss, it should be nutrient-poor and impermeable. Further compacting the material increases impermeability. To prevent erosion, the surface should be covered with vegetation (Joosten and Duene 2021).

3. **Reintroducing plants:**
   - **Moss layer transfer technique (MLTT):** *MLTT* is the process of transferring moss from a donor site to the restoration site. Ensuring that donor sites have a similar species makeup to the restoration site is critical for success. Furthermore, certain species have been identified as *recalcitrant*, meaning they fail to become established once transplanted. Recalcitrant species vary by region; researching and avoiding the use of these plants in MLTT will help promote peatland growth (Hugron et al. 2020). To protect the newly transferred sphagnum moss, it is recommended that the restoration site is covered by a thin layer of straw to increase water availability and regulate temperature conditions.
   - **Seeding:** If the desired post-restoration ecosystem is a peat swamp with trees, then seed dispersal may be necessary. Selected seeds should be from pioneer species that have adapted to the conditions of primary succession. Once these plants have become established, then the seeds of more shade-tolerant plants should be planted in a second phase (Joosten and Duene 2021). If plant growth is struggling, phosphorus fertilizer can also be applied. This aids the growth of vascular plants that will stabilize the moss as it gets established (Rochefort et al. 2003).
4. **Post-restoration clean-up:** Once the restoration activities have been completed, it is important to repair damage caused by temporary access roads that serviced the restoration site. Heavy machinery is needed to conduct peatland restoration and access to the site is often a challenge. Soil in peatlands is unstable and muddy, meaning that damage will be done moving equipment to the site. Restoring track sites after the project is done is important to ensure that the temporary access roads are not turned into permanent passageways for unauthorized users (NatureScot 2020).

OPERATIONS AND MAINTENANCE

Operations and maintenance will typically center around continued removal of invasive plants (if needed) and ensuring that water control structures are operating properly to maintain proper hydrological conditions within the peatland site.

FACTORS INFLUENCING SITE SUITABILITY

- ✓ **Locations where peat has been previously mined:** Sites that have experienced peat mining still have the elements of functioning hydrological processes. Mined sites just need donor peat material to replace the peat that has been extracted (MN DNR 2012).
- ✓ **Ample water supply:** Water is the driving force behind a successful peatland ecosystem. If there is not enough water in the area or the site does not naturally hold water, then peatland restoration should be reconsidered (Quinty and Rochefort 2003).
- ✓ **At least 50 cm of peat remaining:** Sites with at least 50 cm of remaining peat still have bog conditions, meaning that they can support a functioning peatland. However, thinner layers of thoroughly decomposed peat are an exception to this rule, as this often also indicates bog conditions (Quinty and Rochefort 2003).

- ✓ **Water pH of 5.1 or lower:** While some fens can have higher pH than this, acidic conditions are often what distinguishes peatlands from other inland wetland habitats. For areas with more basic pHs, wetland restoration is recommended instead (Quinty and Rochefort 2003).
- ✓ **Flat topography:** Peatlands need poor drainage and low levels of runoff to remain waterlogged. Flat topography slows water flow and allows water to stay in the peatland.
- ✗ **Limited site access:** Because of their hydrologic conditions, peatlands are often inaccessible for significant portions of the year. Attempting to haul heavy equipment to a remote restoration site may cause more harm than good to the ecosystem (Artz et al. 2019).
- ✗ **Mineral-rich soils:** Peatlands are nutrient- and mineral-poor ecosystems. Peatland soils have high carbon content instead of minerals. Therefore, mineral-rich soils will not support a peatland (SEPA 2019).
- ✗ **Near sources of nutrient pollution:** Nutrient pollution significantly hinders the ability of a peatland to function. Unless the source of the nutrient pollution is being mitigated, then peatland restoration should not occur near discharges of nutrient pollutants (Schumann and Joosten 2008).
- ✗ **Near waste disposal sites:** Rewetting peatlands as part of a restoration project has the potential to expose water to toxic waste buried in the soil. This is problematic because the mixing of water and toxic waste could contaminate the drinking water supply (Schumann and Joosten 2008).
- ✗ **Completely inundated site:** While peatlands thrive in waterlogged conditions, sites that are frequently completely inundated are more suitable for aquatic habitats than peatlands. Rapid inundation of a peatland may cause carbon to be released. Slow rewetting is a better strategy to maintain the peatland as a carbon sink (Zak and McInnes 2022).

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Global Peatland Restoration Manual	Guidebook	2008	Greifswald University	Global	This guide categorizes peatland restoration activities by their benefits. The authors also include information about monitoring, site suitability, and stakeholder involvement.	✓	✓	✓	—
Practical Peatland Restoration	Technical report	2021	Office of the Secretariat of the Ramsar Convention	Global	Focused on techniques for peatland restoration, this document outlines designs for blocks and bunds as well as methods for revegetation. Reducing leakage and tree removal are also covered.	✓	—	—	—
Guidelines for Wetland Restoration of Peat Cutting Areas	Guidebook	2004	Bridge Project	Designed for Europe but most of the information is more broadly applicable	This guide is tailored to restoration projects following commercial peat extraction. The authors cover restoration strategies based on the starting condition of the peatland, setting goals for the restored peatland, and the environmental impacts of rewetting peatlands.	✓	✓	—	✓
Minnesota Wetland Restoration Guide	Guidebook	2019	Minnesota Department of Natural Resources	Designed for the Great Lakes region but most of the information is more broadly applicable	Allowing managers to dive deeply into every aspect of the restoration process, this guide sequentially leads readers from planning to monitoring. The engineering design section is especially helpful for manipulating peatland hydrology. An additional guidance document is also available.	✓	✓	✓	—
Peatland ACTION – Technical Compendium	Guidebook	2022	NatureScot	Designed for Scotland but most of the information is more broadly applicable	This guide covers a variety of restoring techniques, including artificial drains, bunding, peat stabilization and forest to bog restoration. Also included are helpful links to additional resources.	✓	—	—	—

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Petland Restoration Guide: Second Edition	Guidebook	2003	Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Energy.	Designed for Canada but most of the information is more broadly applicable	Encompassing both peatland ecology and restoration strategies, this guide provides troubleshooting advice for common problems that projects often encounter. Additional topics covered include monitoring, alternative management strategies, and descriptions of common North American peatland species.	✓	✓	✓	—
Conserving Bogs: The Management Handbook	Guidebook	2019	International Union for Conservation of Nature National Committee for the United Kingdom Peatland Programme	Designed for the United Kingdom but most of the information is more broadly applicable	This guide focuses on conserving peatlands, highlighting management strategies such as limiting grazing, fires, access, and erosion. The authors also provide a framework for creating peatland-specific management strategies.	✓	✓	✓	—
Best Practice Book for Peatland Restoration and Climate Change Mitigation	Guidebook	2021	LIFE Peat Restore Project	Europe	Outlining the principles of peat rewetting, this guidebook recommends the best practices for a successful project. Additional topics covered include monitoring, creating floating islands and reintroducing sphagnum moss.	✓	—	✓	✓
An Overview of Peatland Restoration in North America: Where Are We After 25 Years?	Journal article	2017	Rodney A. Chimner, David J. Cooper, Frederic C. Wurster, and Line Rochefort	North America	The authors overview trends of peatland restoration in North America, highlighting spatial and strategic shifts. Specific techniques for unique ecoregions across the continent are also discussed, as well as case study projects.	✓	—	—	✓

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Reduced wildfire risk:** Wet peat is less flammable than dry peat. Even in a large area of dry peat, small patches of wet peat can stop the spread of smoldering flames. Thus, rewetting peat via restoration activities can significantly reduce wildfire risk (Prat-Guitart et al. 2016). This is especially important because peat fires can burn underground for many months and release copious quantities of carbon during combustion.

- **Carbon storage and sequestration:** Peatlands are the world's largest terrestrial carbon store, storing more carbon than all other vegetation types despite only covering 3% of global land surface (IUCN 2021). While functioning peatlands are powerful carbon sinks, degraded peatlands can become carbon sources. Peatland restoration can avoid enormous amounts of carbon emissions from the large net difference in carbon fluxes between degraded and functioning peatlands. Net carbon emissions reductions could reach 24.5 metric tons CO_2/ha/year of peatland restored, making restoration an efficient way to combat climate change (Richardson et al. 2022).

- **Heat mitigation:** Peatland vegetation can have a cooling effect on the surrounding environment. Wet peat decreases evaporation rates during dry and hot periods, keeping water in the environment. However, once a peatland is dried out, it displays higher rates of evaporation. Therefore, peat rewetting is key to lowering surface temperatures around peatlands (Weiss and Vlček 2023).

- **Drought mitigation:** During droughts, peatlands can regulate water loss. As conditions get drier, the peat increases surface tension, which maintains the moisture content in the peat. Wet peatlands are better able to weather droughts, with surplus water allowing them to shut down evaporation and retain water (Kettridge and Waddington 2014).

- **Reduced flooding:** During heavy rainfalls, local tributaries are often overwhelmed with excess water. Peatlands can help attenuate floodwaters by retaining water during flood peaks. Peatlands often serve as a piece in the larger floodplain (see summary) puzzle, working with nearby wetlands and forests to absorb water (Tanneberger et al. 2021). In addition, land subsidence, which increases flood vulnerability, often occurs when peatlands are developed into agricultural or mining sites. When the peatland is drained, the moisture that gives peat soils its unique characteristics is taken away, causing the soil to compress (Bonn et al. 2016). Restoring peatlands reduces elevation loss and flood risk.

Social and Economic

- **Jobs:** Contractors will need to be hired to perform the restoration activities, stimulating the local economy.

- **Recreational opportunities:** Restored peatlands are ideal sites for a variety of recreational activities including hunting, birdwatching, and hiking.

- **Cultural values:** Peatlands are often misunderstood by the public. Peatland restoration and conservation provides an opportunity for greater awareness and appreciation of the vital ecosystem services peatlands provide.
- **Mental health and well-being:** Peatlands enhance greenspace, boosting mental health and psychological well-being.
- **Reduced erosion:** Erosion in peatlands is particularly problematic because it results in more carbon emissions. Peatland restoration projects can help remediate erosion by revegetating eroded sites, altering the topography to soften slopes, and fertilizing bare spots of peat to induce growth (Milner et al. 2021).

Ecological

- **Enhanced biodiversity:** The Ramsar Convention identified peatlands as the most important type of wetlands for the conservation of biodiversity. The diversity of peatland ecosystems means that means a greater variety of species are present. Peatlands support biodiversity in other habitats as well, providing refuges to species displaced from nearby developed areas, supporting breeding birds, providing rest stops for migrating birds, and buffering watersheds. Restoring peatland vegetation can help protect peatland biodiversity (Minayeva et al. 2016).
- **Improved water quality:** Drained peatlands can leach nutrients such as ammonia, contributing to nutrient pollution further downstream. By preventing peatlands from being drained or rewetting peatlands, these excess nutrient discharges can be mitigated (Holden et al. 2006). Peatlands also effectively absorb excess nutrients and suspended sediments from nearby waterbodies (Limpens et al. 2006; Nieminen et al. 2015).
- **Reduced runoff:** Peatlands can control runoff by absorbing excess water into the soil. When runoff filters through peatlands, peatlands increase the amount of dissolved organic carbon in the water. This helps enhance the water chemistry in surrounding waterbodies (Tunaley et al. 2017).

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Common Barriers

Several barriers are common across many of the nature-based solutions strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about the barriers specific to peatland restoration are included here.

- **Expense**
- **Capacity**
- **Public opinion:** Peatlands are often misunderstood as barren and desolate ecosystems, contributing to a lack of awareness about the biodiversity, carbon sequestration and water quality benefits they provide. Educating residents about the benefits of peatland restoration will enhance community buy-in for the project (Moxey et al. 2021).

- **Conflict with other land uses:** The most significant threat to northern peatlands is conversion to arable land. Conversion involves draining the peatland, which aerates the soil and increases respiration, resulting in an increase of carbon emissions (Qiu et al. 2021). Peatlands are often targeted for cultivation because of their flat topography and proximity to water sources. While peatland restoration is not expensive compared to restoring other ecosystems (ranging between $1200–$3000 per acre), it does not directly generate revenue like agriculture does (MN BWSR 2012). Peat mining is still common in the United States because of its diverse uses in turf maintenance, agriculture, and sewage treatment. While most peat consumed in the United States is imported from Canada, large amounts are still mined in Florida, Michigan, Minnesota, and Maine (USGS 2023). Mined peatlands seldom recover without restoration (Rochefort et al. 2003).
- **Regulation:** In the past, many peatland restoration projects have been initiated in response to Clean Water Act (CWA) requirements. The CWA requires that peatland restoration must occur after peat extraction or to offset the degradation of a peatland elsewhere (Chimner et al. 2017). However, the Supreme Court decision *Sackett v. Environmental Protection Agency* significantly narrowed the scope of the CWA, excluding many wetlands that are not connected to a larger riverine system (Puko and Barnes 2023). Some peatlands may no longer be protected, curtailing this driver of restoration.
- **Lack of effectiveness data**

Community

- **Vehicle trails:** Informal vehicles trails across peatland are becoming increasingly common as off-road vehicle usage increases. While many off-road vehicles enter a peatland merely for recreational purposes, others use peatlands as entry points for construction or mining projects. Vehicle trails, which are often reinforced by plastic mesh or wooden planks, disturb the hydrology of the peatland and deposit chemical contaminants (Williams-Mounsey et al. 2021). Vehicular access to a restoration site needs to be limited.

Ecological

- **Variable greenhouse gas emissions fluxes:** While peatland restoration can store vast amounts of carbon in the long term, it generally takes around 20 years for a peatland to return to a carbon sink after restoration. Projects often encounter a trade-off between sphagnum growth and methane (CH_4) emissions. A higher water table allows for the sphagnum to grow faster, but risks higher CH_4 emissions. A lower water suppresses CH_4 emissions but also inhibits Sphagnum growth. This trade-off varies spatially, often depending on the plant community involved (Nugent et al. 2018).

- **Impact on donor sites:** To extract peat from a donor site, the peatland must first be dewatered. Then, heavy machinery removes the desired peat layers. This process results in significant damage to the donor site, fragmenting the peat layers and disturbing hydrological processes (Nwaishi et al. 2015). However, these impacts can be limited by using a high ratio of peat surface collected to peat surface restored (between 1:10 and 1:15). This also aids plant establishment at the restoration site (Rochefort et al. 2003).
- **Limited storage of peat:** Because of logistical constraints, extraction of peat from the donor site often cannot occur at the site same time as restoration. Thus, peat blocks are often stored until the restoration team is ready to plant them. However, during storage, peat blocks can dry out, causing the peat to shrink and develop large pores. This reduces the water storage capacity of the peat and increases the likelihood of peatland flooding. Limiting storage time is critical to a successful restoration project (Lehan et al. 2022).

EXAMPLE PROJECTS

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Pocosin Lakes Pocosin Lakes National Wildlife Refuge Restoration Project	Pocosin Lakes National Wildlife Refuge, NC	**US Fish and Wildlife Service (USFWS)**	Peat dams and dikes, wood dams (flashboard risers), ditch plugging	30,000	1.5 million	20	Farmers had previously drained the peatlands for agriculture. The team used a variety of dams and dikes to block drainage canals and rewet the peatlands.	Wildfire, drought	After the project was completed, the frequency and severity of wildfires significantly decreased.
Sax-Zim Bog Restoration Project	Northern Minnesota	The Nature Conservancy, US Department of Agriculture Forest Service, Minnesota Department of Natural Resources, Ecosystem Investment Partners	Backfilling ditches	23,220	Not provided	Not provided	This peatland was previously ditched for timber production. Contractors are now working to restore the peatland hydrology by backfilling the ditches.	Wildfire	The project is financed through carbon markets. Amphibious excavators are being used to navigate the difficult terrain.
San Joaquín River Delta Restoration Project	Central California	Sacramento-to-San Joaquín Delta Conservancy	Converting farmland to peatland via levee alteration	3,500	24 million	Ongoing (4 years expected)	To reverse pervasive land subsidence in this region, farmland is being reconverted into peatland. Altering levees will allow for the peatland to be reincorporated into the larger floodplain mosaic.	Flooding	The managed water table, warm weather, and long periods of plant growth have resulted in large amounts of methane emissions. This means it will take longer for the peatland to return to a carbon sink.

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Big Meadows Restoration Project	Rocky Mountain National Park, CO	**National Park Service,** Colorado State University	Blocking ditch entrance with galvanized sheet metal	156	Not provided	1	Completely backfilling the ditch was deemed impractical as the nearest road was more than 2 mi away. Instead, galvanized sheet metal was placed over the outflow point of the ditch.	Drought	The hydrological regime is highly dependent on snowmelt. This results in the fen occasionally drying out in summers with little precipitation post-restoration.
Seney Peatlands Restoration Project	Seney National Wildlife Refuge, MI	**USFWS**	Ditch plugging, plastic piling, and installation of water control structures	3,460	Not provided	2 years	Nine earthen ditch plugs were installed to block the Walsh Ditch, which had drained the peatland. Plastic piling was also used to reinforce the ditch plugs.	Wildfire	In spring, when extra water needs to be discharged from the peatland, water control structures were installed to divert the water back into the natural watershed.
Great Dismal Swamp Restoration Project	Dismal Swamp State Park, NC	**USFWS,** US Army Corps of Engineers, North Carolina Department of Natural and Cultural Resources, North Carolina State University	Water control structures with flashboard risers	1,927	Not provided	1	Drainage ditches and canals were dug to drain peatlands. Water control structures were installed to help the peatland retain water. In addition to stopping water from entering the canals, the project also reduced loss of groundwater.	Wildfire	Water control structures allowed for the project to control the peatland hydrology while only blocking the canal in select places.

Bolding indicates DOI affiliates.

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