Evidence Synthesis: Temperate North American Wetland Restoration

# Objective

Restoration is a powerful conservation tool, but it can be difficult to make decisions for a specific ecosystem as data on outcomes are often scarce. We want to gain a greater understanding of wetland restoration practices and outcomes to ultimately improve predictive power for managers deciding what conservation actions to take.

The objective of this work is to generate a review of wetland restoration in temperate North America. This will provide information on a) what restoration interventions are common, b) the length of monitoring following interventions, c) timeframes to ‘recovery’, and d) insight into potential systematic review topics based on data availability. Ideally, the data will be used to identify drivers of successful restoration projects.

# Question

* What are the drivers of restoration success in North American (Canada & USA) wetlands?

Population – wetlands in Canada and USA

Intervention – ecological restoration

Control – wetlands where no intervention takes place

Outcome – Leaving this open-ended to capture what is measured in the literature. Outcomes may include abiotic factors (e.g., nutrients, hydrology, carbon sequestration) or biotic factors (e.g., plants, birds, herptiles, mammals).

# Protocol

## Search Strategy

## Test list (Preliminary, may want to expand this more)

1. Ahn, C. and Dee, S. 2011. Early development of plant community in created mitigation wetland as affected by introduced hydrologic design elements. Ecological Engineering. 10.1016/j.ecoleng.2011.03.019
2. Aronson, MFJ and Galatowitsch, S. 2008. Long-term vegetation development of restored prairie pothole wetlands. Wetlands 28: 883-895
3. Ballantine, K and Schneider, R. 2009. Fifty-five years of soil development in restored freshwater depressional wetlands. Ecological Applications. 10.1890/07-0588.1
4. Baumane, M. et al. 2021. Danish wetlands remained poor with plant species 17-years after restoration. Science of the Total Environment. 10.1016/j.scitotenv.2021.149146
5. Matthews, J.W. and Endress, A.G. 2008. Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. Environmental Management 41: 130-141
6. Moreno-Mateos, D. et al. 2015. Structural and functional loss in restored wetland ecosystems. PLOS Biology <https://doi.org/10.1371/journal.pbio.1001247>
7. Salaria, S. et al. 2019. Incomplete recovery of plant diversity in restored prairie wetlands on agricultural landscapes. Restoration Ecology. 27: 520- 530
8. Zedler, J.B. and Callaway, J.C. 1999. Tracking wetland restoration: Do mitigation sites follow desired trajectories? Restoration Ecology 7: 69 – 73
9. Zhao et al. 2016. A review of methodologies and success indicators for coastal wetland restoration. Ecological Indicators. <http://dx.doi.org/10.1016/j.ecolind.2015.07.003>

## Search terms (preliminary)

|  |  |
| --- | --- |
| **Population** | **Intervention** |
| Wetland$ | Restore$ |
| Marsh | Rewilding |
| Swamp | Rehabilitation |
| Peatland | Remediation |
| Bog |  |
| Fen |  |
| Pothole |  |
| Mire |  |

## Databases

* Web of Science Core Collection
* Grey literature
  + Science.gov
  + Federal databases
  + Proquest Global Theses/Dissertations

## Search string

* (wetland$ OR marsh\* OR swamp$ OR peatland$ OR bog$ OR fen$ OR pothole$ OR mire$) AND (restor\*)
* Did searches with ‘rehabilitation’, ‘remediation’, and ‘rewilding’ and determined they captured no relevant results (See `wetland\_restoration\_scoping.xlsx`)

## Search results

### Primary Literature

Web of Science Core Collection

* All terms were searched in “Topic”
* 11,305 results

*Grey Literature*

**ProQuest:**

Search Date: Feb 1, 2022

Search String Used:

(wetland$ OR marsh\* OR swamp$ OR peatland$ OR bog$ OR fen$ OR pothole$ OR mire$) AND (restor\*)

Date Range: None

Master’s Theses and Dissertations

Number of Results: 1850

All downloaded and uploaded into EPPI to check for duplicates

**Federal Science Library:**

Search Date: Feb 2, 2022

Search String Used: \*Subject Terms\*

(wetland$ OR marsh\* OR swamp$ OR peatland$ OR bog$ OR fen$ OR pothole$ OR mire$) AND (restor\*)

Date Range: Completed 6 separate searches using same string for these dates:

02/02/2020 to 02/01/2022: 376 Results

02/02/2018 to 02/01/2020: 368 Results

02/02/2016 to 02/01/2018: 262 Results

02/02/2014 to 02/01/2016: 174 Results

02/02/2012 to 02/01/2014: 143 Results

02/02/2010 to 02/01/2012: 100 Results

02/02/2008 to 02/01/2010: 83 Results

Everything Prior to 02/01/2008: 355 Results

This database only allows access to 500 articles at a time so multiple searches were completed to keep each search result under this number. All these results were uploaded into EPPI to find duplicates. There were likely many duplicates because some dates only have year listed which would show up in multiple searches. These duplicates were removed in EPPI.

**Science.gov:**

Search Date: Feb 1, 2022

Search String Used:

(wetland$ OR marsh\* OR swamp$ OR peatland$ OR bog$ OR fen$ OR pothole$ OR mire$) AND (restor\*)

Date Range: None

Number of Results: 892

All downloaded and uploaded into EPPI to check for duplicates

**GoogleScholar:**

Search Date: Feb 2, 2022

Search String Used:

(wetland$ OR marsh\* OR swamp$ OR peatland$ OR bog$ OR fen$ OR pothole$ OR mire$) AND (restor\*)

\*Typed direct into GoogleScholar search bar, didn’t used Advanced Search\*

Date Range: None

Number of Results: 644 total

* Used First 250, downloaded and brought into Excel to search for Duplicates
* Only 2 separate duplicates found (Total of 4 Papers)

Ducks Unlimited Canada IWWR Library

* <https://ducks.kohacatalog.com/>
* Search:
  + Keyword: “restoration”
  + Note: the previous search string did not return any results
  + Selected “Electronic library” as per IWWR librarian (Ian Glass) suggestion which resulted in 82 results
    - Read through them and requested articles from librarian.
  + These articles are already screened at title and abstract and will be included with the others after that stage.

# Criteria for “Title and Abstract” screening

* Follow questions during the screening of each abstract
* If “Yes” to **all** questions > **Include**
  + Err on the side of inclusion, it can be excluded at the next stage if necessary
* Any *reviews* that may be relevant > **Include** 
  + We will check references to make sure we are capturing all relevant papers
* If you are uncertain > **Include** 
  + Flag for a second opinion

*Questions*

1. Is this paper written in English?
   1. French may be an option if we get someone on the team who can read and extract information from these papers.

*If yes – go to Q2*

*If no – Exclude*

1. Did this study take place in a wetland?
   1. Includes peatlands (bogs and fens), marshes, swamps, shallow open-water wetlands, estuaries, shallow ponds, flooded riverine wetlands. Lakes ≤ 1 m may be included.
   2. **Exclude** papers that describe wetlands that were created to treat wastewater, contaminants (e.g., pesticides, mine tailings), as stormwater ponds, etc.

*If yes – go to Q3*

*If no – Exclude*

1. Does this study include ecological restoration?
   1. Include papers examining an intervention that assists the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER Primer 2004).
   2. This includes natural/spontaneous recovery. Removing a disturbance and allowing native plants to re-colonize an area is a common restoration approach and should be included.
   3. Studies about contamination remediation are not included.
   4. The wetland restoration does not have to take place within the confines of the study – studies evaluating restored wetlands years after restoration took place, for example, should be included. Comparisons between natural vs restored vs disturbed wetlands (etc.) should be included. We also want to capture long-term trajectories.
   5. Some papers use the word “created” – if the wetland was created in the watershed to replace a disturbed wetland (e.g., a new wetland was created for the purpose of being a natural wetland on the landscape) it should be included.
      1. Wetlands created for the sole purpose of contaminant removal etc. should not be included (see 2b).

*If yes – go to Q4*

*If no – Exclude*

1. *Does this study take place in the USA or Canada?*

*If yes – Q5*

*If no – Exclude*

1. Is this primary literature that reports empirical findings as qualitative and quantitative data?
   1. Include studies that are supported by data.
   2. **Exclude** reports or articles that are purely descriptive or anecdotal, or entirely theoretical modeling.
      1. Papers that simulate data should be coded “modeling”. Most empirical studies will use statistical modeling, but they should be included.
      2. If a paper generates a theoretical model but tests it by collecting field data then it should be included – the field data may provide inside into a useful relationship we are interested in (if it meets the other criteria).
   3. *Relevant reviews* – these are reviews of wetland restoration in temperate climates, multiple projects in an area (if case studies are included this should likely be Include at T&A as they will contain data).
   4. *Commentary/Management* – relevant commentary on wetland restoration in temperate ecosystems.
   5. If an article has a relevant title but no abstract, select “Include” and we will assess at the full text stage.

*If yes – Include at T&A*

*If yes, but theoretical modelling – Include (Modeling)*

*If no, but relevant review – Include (Relevant Review)*

*If no, but relevant commentary – Include (Commentary/Management)*

*If no, Exclude*

# Full-Text Screening Protocol

*If the article is excluded, write why in the Notes section of the excel sheet.*

1. Did this study take place in Canada or northern USA?
   1. Any study in Canada is eligible, and anything in northern USA that is relevant to Canada (e.g., Great Lakes region, Prairie Pothole Region, etc.)
   2. Ecosystems that are not relevant to Canada are not included (e.g., tropical environments, southern states, etc.)
      1. *If no – Exclude (not geographically relevant)*
      2. *If yes – go to next question*
2. Did this study take place in a wetland?
   1. Includes peatlands, marshes, swamps, shallow open-water wetlands, estuaries, flooded riverine wetlands. Lakes ≤ 1 m may be included.
      1. *If no – Exclude (not a wetland)*
      2. *If yes – go to next question*
3. Is the restoration occurring where a wetland historically occurred?
   1. Is the restoration work taking place in an area where there used to be a wetland (e.g., it is not creating a wetland where there wasn’t one previously)
   2. **Exclude** papers that describe wetlands that were created to treat wastewater, contaminants, as a stormwater pond, created as compensation, etc.
      1. *If no – Exclude (not a natural wetland)*
      2. *If yes – go to next question*
4. Is there an ecological restoration intervention?
   1. Ecological restoration is any activity that **assists the recovery of an ecosystem that has been degraded, damaged, or destroyed** (SER Primer 2004).
      1. *If no – Exclude (not restoration)*
      2. *If yes – go to next question*

5a. Is there a reference condition included in the study?

* 1. This would be a ‘pristine’ (e.g., not degraded) wetland study site that is used as a comparator for the restored site, often the restoration target.
  2. The study site should not have been altered by human activities (e.g., not a site where restoration was performed a long time ago compared to more recent restoration)
     1. *If no – go to next question*
     2. *If yes – Include, and go to next question*

5b. Is there a degraded condition included in the study?

* 1. This would be a ‘degraded’ wetland study site that represents the pre-restoration condition of the restored site.
  2. The study site should have the same disturbance as the site that is restored, and is used as a ‘negative comparator’ to show change from the degraded condition.
     1. *If no and 5a was no – Exclude, no appropriate comparator*
     2. *If yes and 5a was no – Include, note only a disturbed and restored treatment*
     3. *If yes and 5a was yes – Include, note the three treatments*
     4. *If no and 5a was yes – Include, note only restored and reference*

*If the article has been Included, then continue to extracting the appropriate information from the excel sheet. Each row in the sheet is a Study, and it will indicate what the study measured as the outcome variable (e.g., plant community composition, greenhouse gas emissions). If more than one taxa are measured (e.g., plants and fish) then there should be two separate rows.*

*Notes for meta-analysis:*

*Time series and non-independence:* Be clear about measurement time, treatment duration, etc. For ease, we could extract only a single data point per measurement time series (e.g., at the end of the treatment or at peak standing biomass) to circumvent non-independence. Results may vary among the time periods of studies (e.g., 4 months vs 5 years). However, this may mean we lose some interesting patterns (e.g., changes over time) – need to decide exactly how to tackle this in data extraction.

**Other potential issues**: single studies reporting data from multiple treatments, species, locations, outcomes, etc.

Determining the correct sample size associated with a reported statistic

**Quality assessment**: will use a qualitative approach (e.g., noting pseudo-replication, inappropriate controls, highly variable sample size across treatment in ‘notes’ field).

* Inclusion standards of a ‘control’ and ‘appropriate replication’ are setting *a priori* quality standards in each review.
* Other pieces of information can then be used to perform a sensitivity analysis (e.g., do short-term studies affect our conclusions about the success of restoration).

*Diagram

Description automatically generated*

*Studies of Interest:*

1. Crouzeilles, R., Curran, M., Ferreira, M.S., Lindenmayer, D.B., Grelle, C.E. and Rey Benayas, J.M., 2016**. A global meta-analysis on the ecological drivers of forest restoration success.** *Nature communications*, *7*(1), pp.1-8.
   1. *Study criteria:* i) conducted in a forest ecosystem, ii) had multiple sampling site to measure biodiversity and/or vegetation structure in reference and restored/degraded systems (replicates for all systems), and iii) used old-growth or less-disturbed forests as a reference/benchmark for the system under study
      1. study year, (ii) country, (iii) geographic region, (iv) latitude and longitude, (v) disturbance type, (vi) the time elapsed since restoration began, (vii) restoration activity, (viii) ecological metric used to assess biodiversity and (ix) quantitative measure of biodiversity response and/or vegetation structure for reference and restored and/or degraded systems
      2. biodiversity into ﬁve broad taxonomic groups (mammals, birds, herpetofauna, invertebrates and plants) and vegetation structure into ﬁve measures related to ecological succession (density, litter, cover, biomass and height).
   2. What are the main ecological drivers of forest restoration success for biodiversity (abundance, richness, diversity/similarity) and structural features of vegetation at the local and landscape scale? 2) does restoration success change across different geographic regions and ecological metrics used to assess biodiversity?
      1. We evaluated a total of eight potential drivers of restoration success at both local and landscape scale. The three drivers of restoration success quantiﬁed for restored systems at the local scale were as follows: (i) disturbance type according to ref. 16 (namely secondary forest and selectively logged forest), (ii) time lapsed since restoration began and (iii) restoration activity (passive regeneration, active management and planting). The ﬁve drivers of restoration success quantiﬁed for all forest patches at the landscape scale were as follows: (iv) percentage of forest cover, (v) mean size of forest patches, (vi) size of largest forest patch, (vii) isolation of forest patches (measured as mean nearest-neighbour distance among patches) and (viii) edge:area ratio of forest patches. In addition, we evaluated two variables potentially inﬂuencing restoration success, namely the geographic region, represented by six biogeographic realms40 (Fig. 1) and (x) the ecological metric used to assess biodiversity.
2. Moreno-Mateos, D., Power, M.E., Comín, F.A. and Yockteng, R., 2012. **Structural and functional loss in restored wetland ecosystems.** *PLoS biology*, *10*(1), p.e1001247.
   1. We compared recovery trajectories of hydrologic, biological, and biogeochemical variables of restored and created wetlands to address three questions: (a) How fast are biological and biogeochemical components of restored ecosystems changing relative to less perturbed reference ecosystems?; (b) Do these changes trend towards or away from the predisturbed ecosystem or parallel control ecosystems?; and (c) Does wetland size or environmental setting (regional climate, hydrologic connectivity) affect recovery?
   2. For each variable we recorded the age of the restored or created wetland, the wetland hydrogeomorphic type, the number of restored or created and reference wetlands considered in a given study, the size (ha) of the restored or created and reference wetlands, the initial condition (restored or created), the geographic location, and the climate.

Table

Description automatically generated

* 1. Methods:
     1. A reference search was done in the scientific database ISI Web of Science – SCI-Expanded. The terms used were “(wetland\* or floodplain\*or peatland\* or marsh\* or mangrove\*) same (restor\* or creat\* or re-creat\* or rehabilit\*).
     2. “We considered restored wetlands to be wetlands recreated on sites where wetlands had formerly existed but been drained or otherwise severely degraded… We selected studies of wetlands under natural hydrological regimes, planted with native species, and in which no allochthonous substrates were imported during the restoration or creation activities.”
     3. We applied the general selection criterion: “Articles must compare measurements of structural components and biogeochemical processes in restored or created and reference wetlands at a known age.” Under this criterion we selected 172 articles. These articles were read, and those in which data were averaged over time intervals larger than 5 y, those in which sizes differing by more than one order of magnitude were averaged, and those lacking reliable measurements or comparable restored and reference conditions were discarded, leaving 124 articles. Reference wetlands were usually adjacent to restored or created wetlands, although in some cases they were separated by several kilometers (maximum distance found was ∼100 km). In all cases, restored or created wetlands were of the same wetland hydrogeomorphic type as reference wetlands with which they were compared
  2. Data extraction:
     1. Measurements of structural components and biogeochemical processes were extracted from the main text, tables, and figures of the articles. When abundance of one species was measured at different life stages, only the adult abundance of each species was selected.
     2. Variables describing hydrological structure, biological structure, element storage and cycling, and organic matter accumulation were classified as structural components or biogeochemical processes according to wetland functions described by Smith et al. [[42]](https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1001247#pbio.1001247-AndersonTeixeira1), and as ecosystem services described in the Millennium Ecosystem Assessment (MEA) (organic matter accumulation was sometimes designated as “soil formation” in the MEA but not in other soil science references).
     3. Element storage and cycling variables measured processes (mineralization or denitrification) and concentration of elements in different pools (total content in soil, organic content in soil, or content in roots), which suggest how nutrients are moving between pools through biotic and abiotic processes ([Tables S1](https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1001247#pbio.1001247.s005) and [S2](https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1001247#pbio.1001247.s006)). The studies presented enough data points to plot recovery of storage of carbon, nitrogen, and phosphorus
  3. Response ratio: To standardize and compare data, we used standard response ratios used in meta-analysis, ln(Xrest+1/Xref+1)

**Identification of studies via other methods**

**Identification of studies via databases and registers**

Records removed *before screening*:

Duplicate records removed (n = 1,933)

Records identified from Web of Science Core Collection, ProQuest, Science.gov, GoogleScholar (first 200 records), and DUC library

n = 14,432

**Identification**

Records screened at Title and Abstract

(n = 8,629)

Records excluded\*

(n = 6,999)\* used EPPI machine learning until plateau

Reports not retrieved

(n = )

Reports sought for retrieval

(n = )

Reports sought for retrieval

(n = 1,630)

Reports not retrieved

(n = ?)

**Screening**

Reports excluded:

Not a wetland (n = 87 )

No restoration activity (n = 232)

No comparator (n = 769)

Wrong outcome variable (n = 81)

Full text not available (n = 50)

Reports assessed for eligibility

(n = )

Reports excluded:

Reason 1 (n = )

Reason 2 (n = )

Reason 3 (n = )

etc.

Reports assessed for eligibility (removal of duplicates)

(n = 1,624)

Articles retained\*

(n = 755)

**Included**

*From:*  Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: <http://www.prisma-statement.org/>

**Flow diagram (Feb 26, 2024)**

14,432 records identified through database searching

12,499 records after duplicate removal

Records excluded\*

(n = 6,999)\* used EPPI machine learning until plateau

8,629 records screened at title/abstract level

1,624 full-text articles assessed for eligibility

869 full-text articles excluded, with reasons

N studies excluded (geographic parameters)

755 full-text articles included

N studies extracted

Handbook on Meta-Analyses in EcoEvo Excerpts:

Meta-analysis: a set of statistical methods for combining the magnitudes of the outcomes (effect sizes) across different data sets addressing the same research question. Meta-analysis is based on expressing the outcome of each study on a common scale. This measure of outcome, an “effect size,” includes information on the sign and magnitude of an effect of interest from each study.

In most cases the key question in ecoevo meta-analyses can be distilled to: What is the mean effect? Does it differ from the null expectation? Can we explain variation (heterogeneity) in the outcome of different studies?

The last question requires that you think about factors (moderators) that differ among studies that might affect the effect size estimate. Our practical tip to get you started is to encode studies based on the population studied, with the most obvious groupings of taxonomy, geography, habitat or ecotype, functional type (e.g., predator/herbivore, tree/shrub), and organism size; the methodology used (e.g., lab or field study, duration of study); how the outcome is measured (e.g., sperm count/ejaculate volume, leaf area/leaf mass); and the population to which a treatment is compared , that is, the baseline level of the measured outcome (e.g., rate of disease in control plants). You should note that in some cases the comparison will simply be to a null value (e.g., r = 0). Remember that moderators of effect sizes can be discrete factors or continuous variables. A final tip is that there is no point having a very large number of moderators, or many levels of a discrete moderator. If the number of papers per group is small you will have very low statistical power. Be prepared to pool groups before conducting your final statistical analyses (e.g., you might code “bird,” “mammal,” “insect,” and “spider,” but end up using the codes “vertebrate” and “invertebrate” instead). You should be keenly aware of confounded moderators, and decide how you want to handle this. For example, if all studies on woody plants are longer than one year and all studies on herbaceous plants are shorter than four months, then one cannot test for study duration without also comparing functional groups and vice versa.

For an excellent basic introduction to complex data structures within a study and the similarities and differences among multiple independent subgroups, multiple outcomes (including time points), and multiple comparisons, we can highly recommend Borenstein et al. (2009, 215–45).

One library file contains citation information and electronic copies of papers (or permanent links to papers) found to not possess the necessary inclusion criteria. The other library file contains citation data and annotated copies of all papers included in the meta-analysis.