Wetland Creation and Restoration: Using Science to Determine Success

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Wetland Succession and Success

- ***Succession*** **is the change in the species present in a community (Morin 1999).**
- ***Success*** **is an anthropogenic term where a created/restored system achieves the intended functions of a natural wetland.**

Theoretical Succession

Study of changes in biological communities and in the chemical and physical parameters that drive the composition of the community (e.g. Study of changes in vegetation communities, soil maturation, increases in salinity)

Applied Succession

Using the data and results developed in theoretical studies to understand anthropogenic changes in wetland ecosystems.

Wetland Succession and Success

Two types:

1) Primary (bare soil, no seed bank present)

Examples: Earthquake scarps, major cyclone damage, volcano eruptions, ice scour, created wetlands

2) Secondary (may have semi-mature soils, seed bank usually present)

Examples: Natural changes over time, minor cyclone damage, timbered (logged) wetlands, restored (aka rehabilitated and enhanced) wetlands

Relationship of Wetland Succession to Success

- In wetland creation/restoration, the purpose is to replace the natural functions of a wetland (e.g. improvement of water quality, erosion and sedimentation control, habitat for wildlife, and nutrient cycling)

- Wetland creation/restoration start at either a primary or early secondary successional stage, therefore, their biotic and environmental parameters should be equal to that of a natural system at that same stage of succession.

- To test the success of a created/restored wetland we should be able to measure specific ecological parameters (e.g. species diversity, nutrient cycling, habitat availability, etc.) in a natural system and compare them to the created/restored data.

Therefore, to measure success you must be able to measure specific ecological similarities.

Setting Goals:

1) Define specific functions served by natural system (e.g. nutrient cycling, habitat, water quality).

2) Identify target functions of created/restored system.

Setting Objectives:

Define data collection methods and statistics needed to identify when each goal is met, e.g.;

- **for nutrient cycling and water quality: NEE and C:N:P ratios, redox (hydrology, hydric soil formation);**

- **for habitat: landscape and edge diversity (including open space/water), FQI and/or IBI, species composition, structure, diversity, and richness.**

Examples of Measuring Success in Created Wetlands

Example 1: Measuring Successes in Created Mid-Atlantic Tidal Salt Marshes

Purpose: to determine if created salt marshes were maturing on a trajectory similar to natural systems.

Goals:

1) Nutrient Cycling and Water Quality

2) Habitat

3) Sediment Control

Objectives:

Nutrient Cycling and Water Quality

1) **Ecosystem carbon flux measured as Net Ecosystem Exchange (NEE) of CO_2, and pore water nutrients and salinity;**

2) **Community hydrology, hydric soil composition (organic content).**

Habitat

1) **Plant standing crop and density, NEE.**

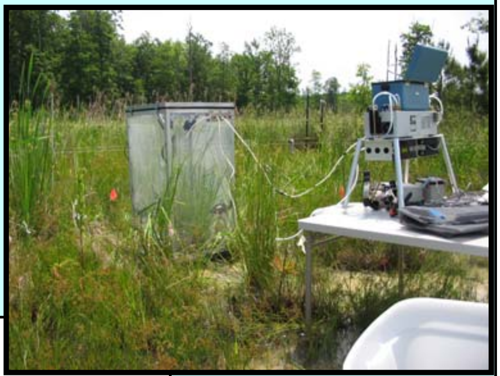
Dominated by one species (*Spartina alternifolia*)

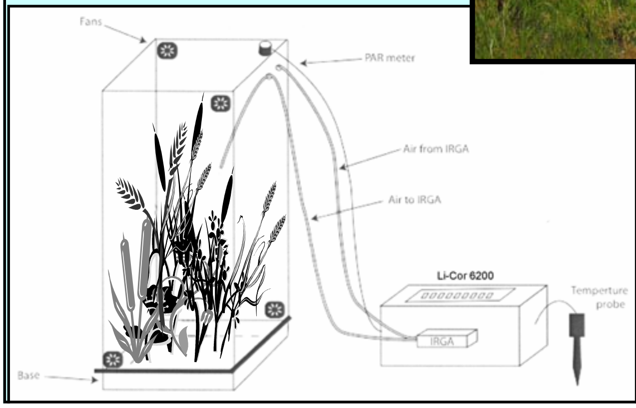
Tidal exchange (1m)

Salinity of 5-15psu

- Plant Community Composition
  - Monthly % Cover
  - Peak Seasonal Biomass

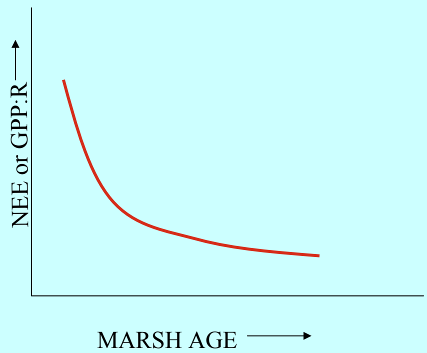
- Net Ecosystem Exchange (NEE)





Gas exchange hypotheses

- NEE will be highest in the youngest marsh and decrease with age



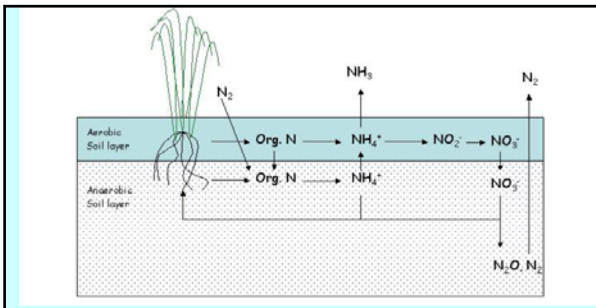


Fig 1. Basic nitrogen cycle in a tidal salt marsh.

Acid Extraction N,P, +
Soil Bulk Density
Organic C w/depth

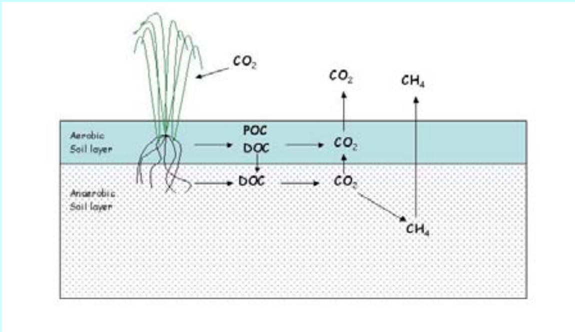
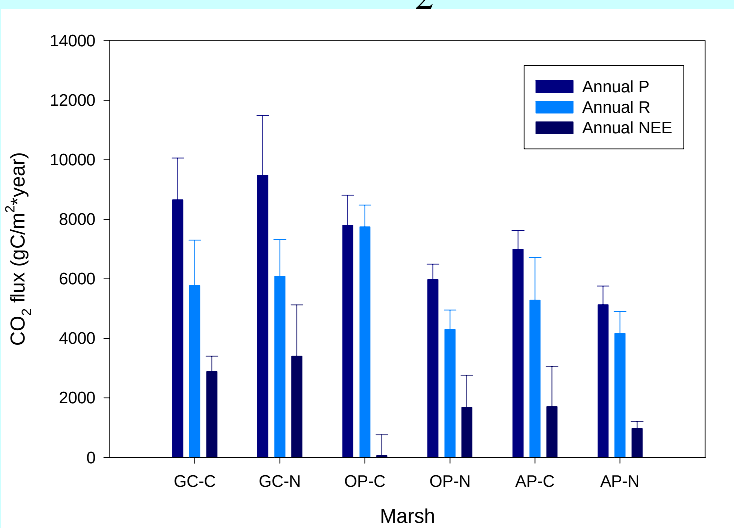


Fig 2. The basic carbon cycle in tidal salt marshes.

Annual CO_2 fluxes



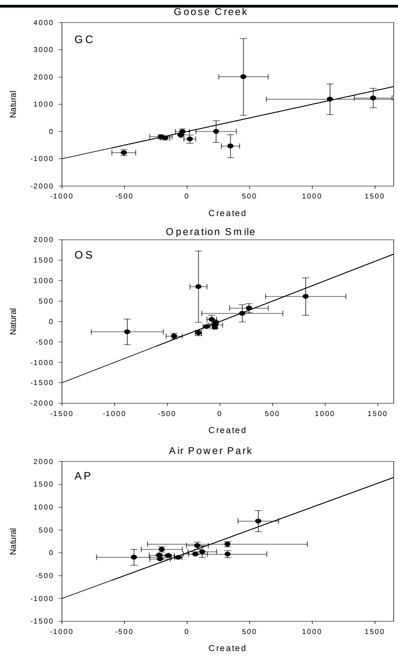
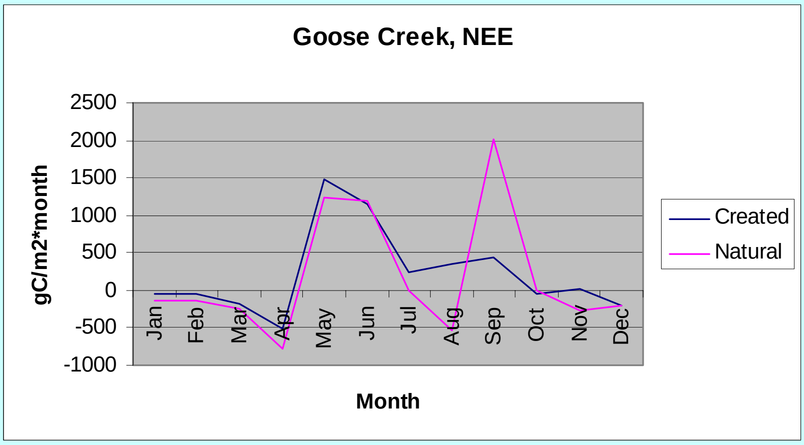


Figure 9. Ratio of NEE in Created and Natural Marshes. Line shows a theoretical 1:1 ratio line. 56

Results of annual CO_2 Flux

- Annual GPP, R, NEE were similar in all marshes
- No pattern of differences in created vs. natural marshes (pore water salinity & nutr., biomass)
- No pattern of differences with increase in marsh age (pore water salinity & nutr., biomass)
- GPP:R ratio highest in young marsh
- Organic buildup projected to equal natural system in 40+ years.



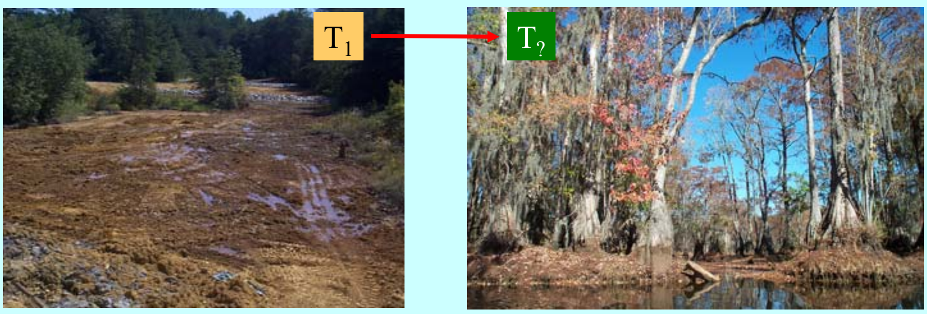
Results of monthly NEE

- Created and adjacent natural marshes tightly coupled throughout most of the year
- Coupling is looser in the late summer and fall months
  - May be due to differences in plant communities or nutrient levels
- Created marshes are net autotrophic in mid-summer while natural are net heterotrophic

Summary of Tidal Marsh Succession

- In GPP, R, and NEE: created marshes seem to be functioning in a similar ecological manner to natural marshes.
  - Caveat 1: On a monthly basis, they may show differences in NEE
  - Caveat 2: Some created marshes have non-target plant species in them
- In soil development: created marshes are following a sequence of development similar to that seen in naturally developing marshes. However, projected time frame may be longer than previous predicted by models.
- Structure and composition in early stages of succession similar.
- Fall autotrophic spike found in mature systems, but not in created wetlands.

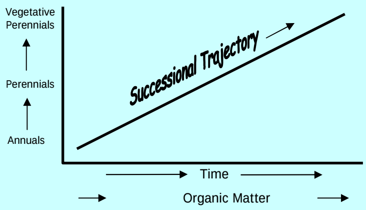
Measuring Success in Non-Tidal Wetlands



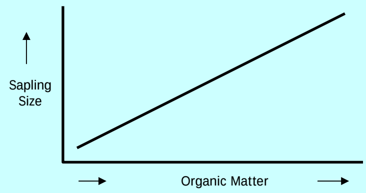
Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164:262-270.

Succession is the change in the species present in a community (Morin 1999).

- Plant Community Composition

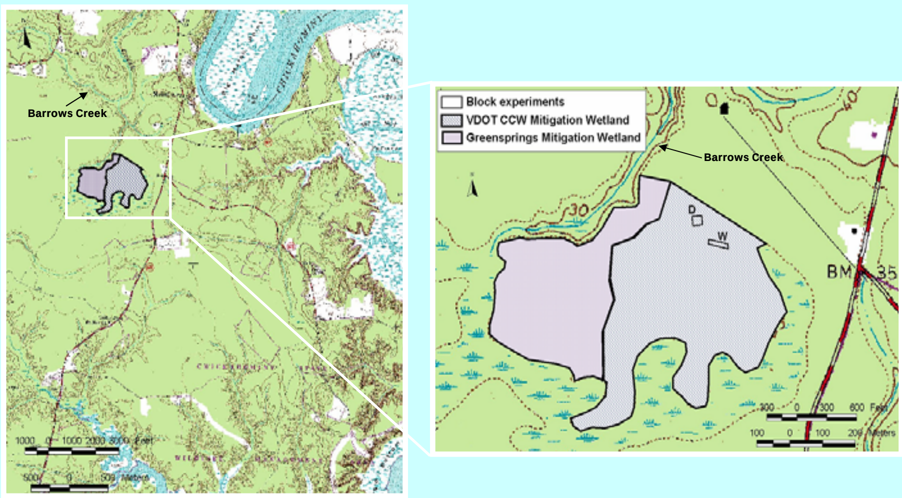


- Woody Vegetation Development



Charles City Wetland Mitigation Site (CCW)

- Goals: Forested wetland to replace water quality and habitat.



Setting Objectives:

Water Quality

1) Ecosystem carbon flux measured as Net Ecosystem Exchange (NEE) of CO_2 and CH_4
2) Community hydrology, hydric soil composition

Habitat

1) Plant community composition and standing crop of herbaceous vegetation
2) Development of planted woody vegetation

Methods

- Plant Community Composition
  - Monthly % Cover
  - Peak Seasonal Biomass

Relative Cover

$$= \frac{\text{Species coverage}}{\text{Sum of coverage values for all species}} \times 100$$

Relative Frequency

$$= \frac{\text{Species frequency}}{\text{Sum of frequency values for all species}} \times 100$$

IV (per species) = relative cover + relative frequency

- Woody Plant Development
  - *Betula nigra* saplings
  - Morphometrics:
    - Total Height
    - Crown Diameter
    - Main Stem Diameter
    - # Stems

Table 5. Pearson Correlation matrix. AW monthly standing crop was correlated (* = significant at p = 0.05) with standing crop of all CW transects with the exception of the most remote (80m) transect. The 80m transect showed no correlation to any of the other CW transects as well. (from DeBerry and Perry 2004)

	AW	**80m CW**	**60m CW**	**40m CW**	**20m CW**
02m CW	r=0.9890 p=*0.0013	0.2637 0.6681	0.9514 *0.0128	0.9173 *0.0282	0.9270 *0.0234
20m CW	0.8909 *0.0426	0.2066 0.7388	0.8785 *0.0499	0.8068 0.0989	
40m CW	0.9640 *0.0081	0.5857 0.3421	0.9854 *0.0021		
60m CW	0.9773 *0.0041	0.5451 0.3421			
80m CW	0.3714 0.5382				

Biomass Similar

Table 2. Sørensen Similarity Index (SI) matrix (2c/a+b). Similarity was calculated between each transect at the close of the sampling period (April to August, 1998). Similarity was low between the AW and all transects within the CW (i.e. SI < 0.50) (from DeBerry and Perry 2004).

	AW	80m	60m	40m	20m
02m	0.4231	0.6729	0.7805	0.8085	0.7727
20m	0.4815	0.6909	0.7907	0.7347	
40m	0.4912	0.7931	0.7826		
60m	0.4313	0.7308			
80m	0.4762				

Composition of species differed significantly.

Table 2. List of dominant vascular plants. Dominants plants were defined as species with % cover greater than 20% of a trap plot (five meter radius of each trap location). Life history of each species was divided into herbaceous (H) or woody (W) (Muehler et al. unpublished data).

SPECIES	LH	C1	C2	N1	N2
Acer rubrum L.	W			X	X
Baccharis halimifolia L.	W		X		
Ilex opaca Ait.	W			X	
Myrica cerifera L.	W			X	
Pinus taeda L.	W			X	
Platanus occidentalis L.	W				X
Salix nigra Marsh	W				X
Taxodium distichum (L.) L.C.Rich.	W			X	
TOTALS:	35	10	17	14	14

Other Problems:

Pore water redox >400mv

OM low (>1%)

Soil temperature too variable due to lack of vegetation cover

Very high bulk density

Remediation:

Regrade elevation to correct level

Addition of woody OM

Replant with native woody species

Low density vehicles, mechanical soil “raking”

Results

- Plant Community Composition

Dominant Plants 4/05 - 6/05
Not including Open and Dead Space

	LR 1	LR 2	LR 3	LR 4	LR 5
Scirpus cyperinus	14.26	12.00	18.84	19.34	27.34
Eleocharis obtusa	11.65	10.15	3.72		
Juncus acuminatus	6.71	9.83	4.47	1.61	
Typha latifolia	4.16	6.57	3.82	1.59	2.69
Juncus effusus	4.02	7.08	8.70	10.20	5.24
Polygonum persicaria	3.67	2.81	2.08		
Betula nigra	3.22		2.29	3.46	3.64
Ludwigia palustris	1.78	3.08	1.72	1.45	
Andropogon virginicus	1.57			4.04	6.61
Ambrosia artemisiifolia			2.13		
Eclipta prostrata			2.07	3.53	
Quercus palustris			1.79	2.17	2.52
Ludwigia alternifolia				1.21	
PIGWEED				1.36	2.28
Setaria parviflora				1.00	

- Woody Plant Development

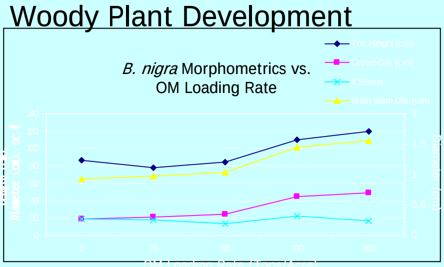
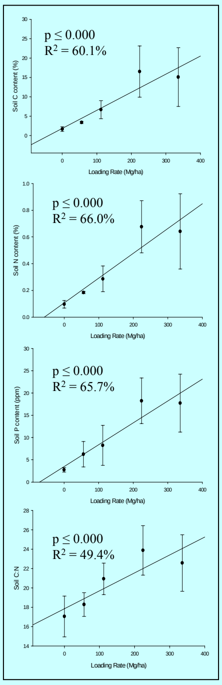


Figure 7. Mean (±1 SD) soil Carbon (C), Nitrogen (N), Phosphorus (P) content and C:N vs. loading rate in CCW, Charles City County, VA, on August 22, 2005. P-values reported indicate significance of the linear regression at the α = 0.05 level. Different letters above the treatment means denote significant differences at the α = 0.05 level based on Wilcoxon Rank Sum Test for C and N and Tukey's family Error Rate for P and C:N.



Adding organic amendments increased available nutrients.

Summary of Non-tidal Wetland Success

1) Herbaceous species structure similar in early stages of primary and secondary succession, but composition statistically different.

2) Addition of OM and decreasing soil bulk density improved the ability of the created/restored system to reach its goals of nutrient cycling, water quality, and habitat.

3) Both structure and composition different in primary and secondary successional forested wetlands, but woody structure similar after 20+ yrs. This was significantly improved w/OM amendments and plantings

4) NEE and nutrient cycling maturing as needed w/OM amendment.

When do we recommend using wetland creation or restoration?

1. To compensate for unavoidable wetland impacts due to development.

As populations expand, intrusion into sensitive habitats will be necessary.

2. To restore the habitat structure of a disturbed wetland ecosystems such as:
   a. A mix of forested-herbaceous-open water converted to open water.

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   b. A mix herbaceous-mud flat-open water to vegetated flats.

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2. To restore structure to disturbed wetland ecosystems such as:
   a. A mix of forested-herbaceous-open water converted to open water.
   b. A mix herbaceous-mud flat-open water to vegetated flats.

Research has shown that a mix of structures leads to a mix of habitats. That in turn increases avian faunal diversity (Erwin et al. 2006) and plant species richness (DeBerry and Perry 2005, plus others).

Why do we feel confident in wetland creation or restoration methods?

1. There are strong scientific methods in place to measure success and to avoid failure;

   a. Rapid assessment techniques can be used to identify early problems if any.

   b. Ecological field methods can be used to identify any specific problem.

   c. Methods for correcting the problems that we have discovered so far have been quickly developed.

   - lime to reduce acidity, ripping to decrease soil bulk density

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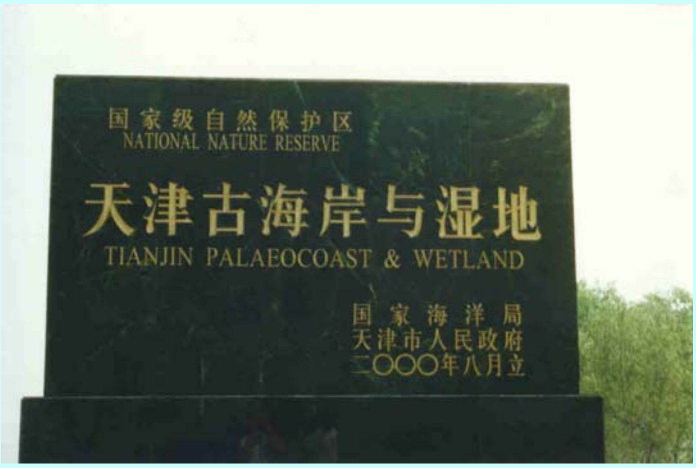
      - lime to reduce acidity, ripping to decrease soil bulk density
      - addition of organic matter to increase soil carbon
      - seeding/sprigging with native species

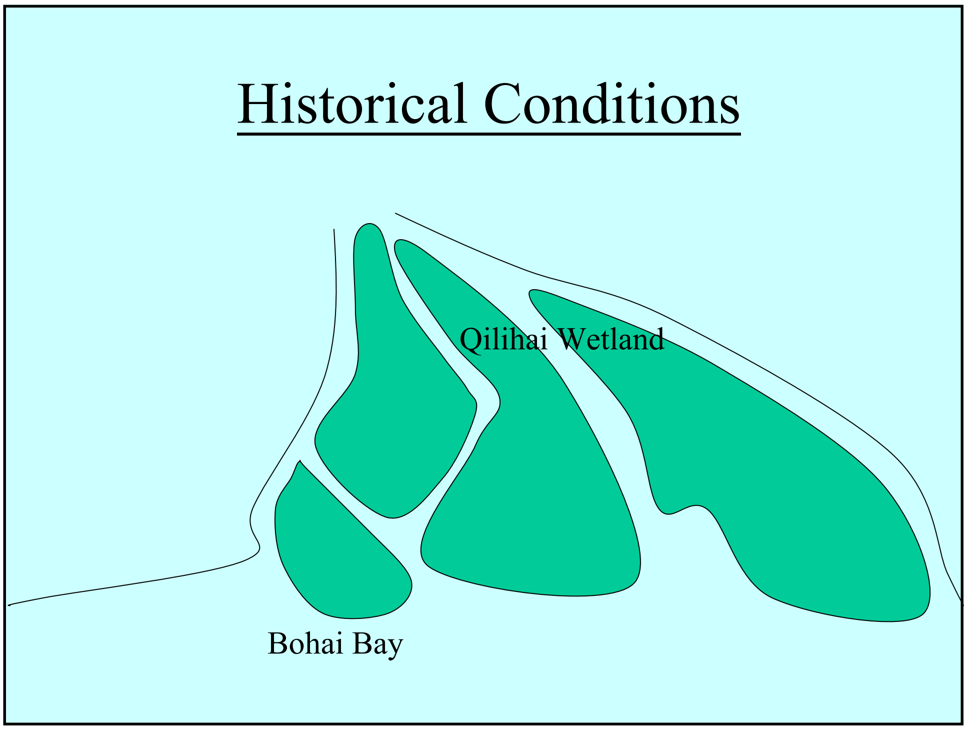
Why do we feel confident in wetland creation or restoration methods?

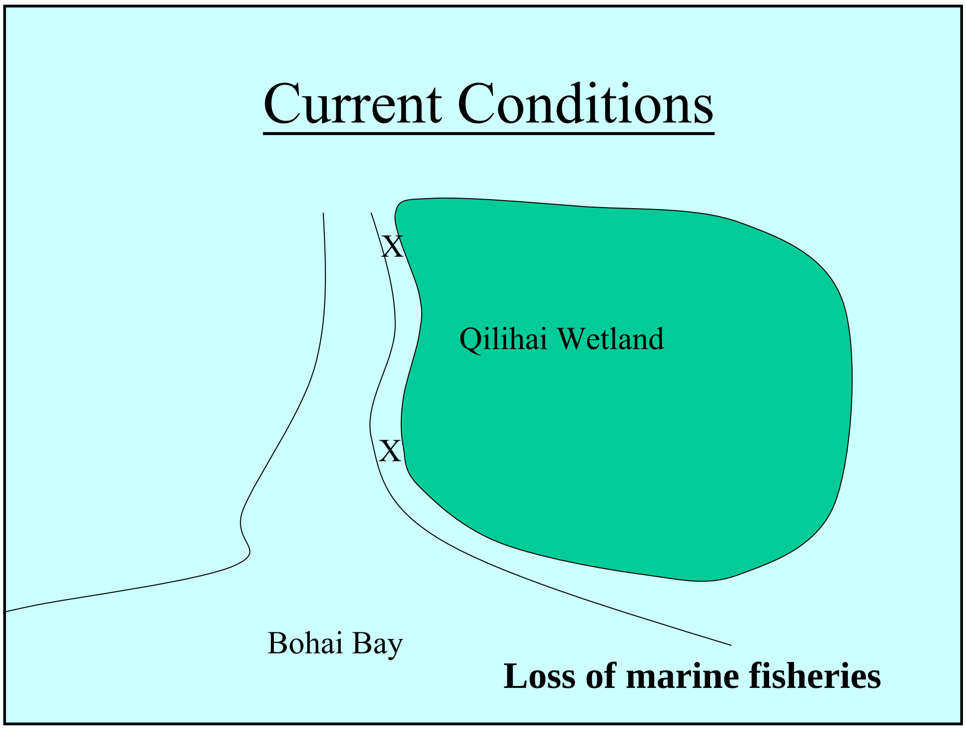
2. Many peer-reviewed publications indicate that with proper planning, design, construction, and monitoring, Creation and Restoration processes can be functionally successful on both large and small scales (Perry et al 2001, Craft et al 2002, DeBerry and Perry 2004, Richardson and Fadhal 2006, plus others).

Acknowledgements: Special thanks to my many students, especially **David Bailey, Doug DeBerry**, **Michel Fox**, **Rose Laird**, **Molly Mitchell**, **Liz Mountz**, **Amanda Mueller**, **John Nichols**, and **David Spencer**, who, without threat of bodily harm from me (I promise) freely walked into the muck and mire of wetland science for little more than the knowledge that they feel that they gained from it. And to **Lee Daniels** and his crew of soil scientist for teaching me how to dig getting down and dirty.

Qilihai Wetlands




Historical Conditions
Qilihai Wetland
Bohai Bay


Current Conditions
X
Qilihai Wetland
X
Bohai Bay
Loss of marine fisheries

Qilihai Wetlands

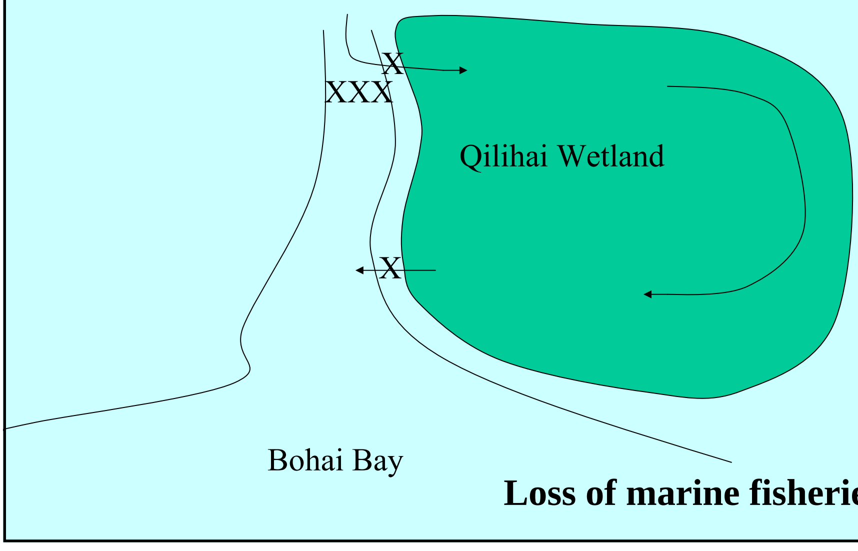
Qilihai Wetlands Goals

1. Conserve existing ecological integrity
2. Restoration of habitat diversity
3. Establishing data base management system
4. Establish management plan in buffer area to enhance ecological goals for core area

Qilihai Wetlands Goals

5. Introduce ecotourism
6. Support education & outreach plan
7. Support sustainable economic use of wetlands (support the socio-economic well being of the local population).
8. Develop rules & regulations for enforcement of goals

Proposed Conditions



Loss of marine fisheries