Effectiveness of Best Management Practices on Nutrient Reduction in Florida

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Introduction and Background

- Nutrient pollution in surface waters in Florida
  - Majority from Nonpoint sources - agriculture
  - Algae/plant overgrowth, reduction in functionality

- *What is the effectiveness of the FDACS agricultural BMPs for reducing nutrients from agricultural operations to off-site environmental media (groundwater and surface water) in Florida?*


Jackson Blue Springs


Algae overgrowth in Alexander Spring

What are Best Management Practices?

- Techniques for reducing offsite nutrient export
- Structural and nonstructural
- In general:
  - Cow/calf: aimed at keeping cattle away from water
  - Agronomic/vegetable: avoid fertilizer from entering water

Fencing off streams

Drip irrigation

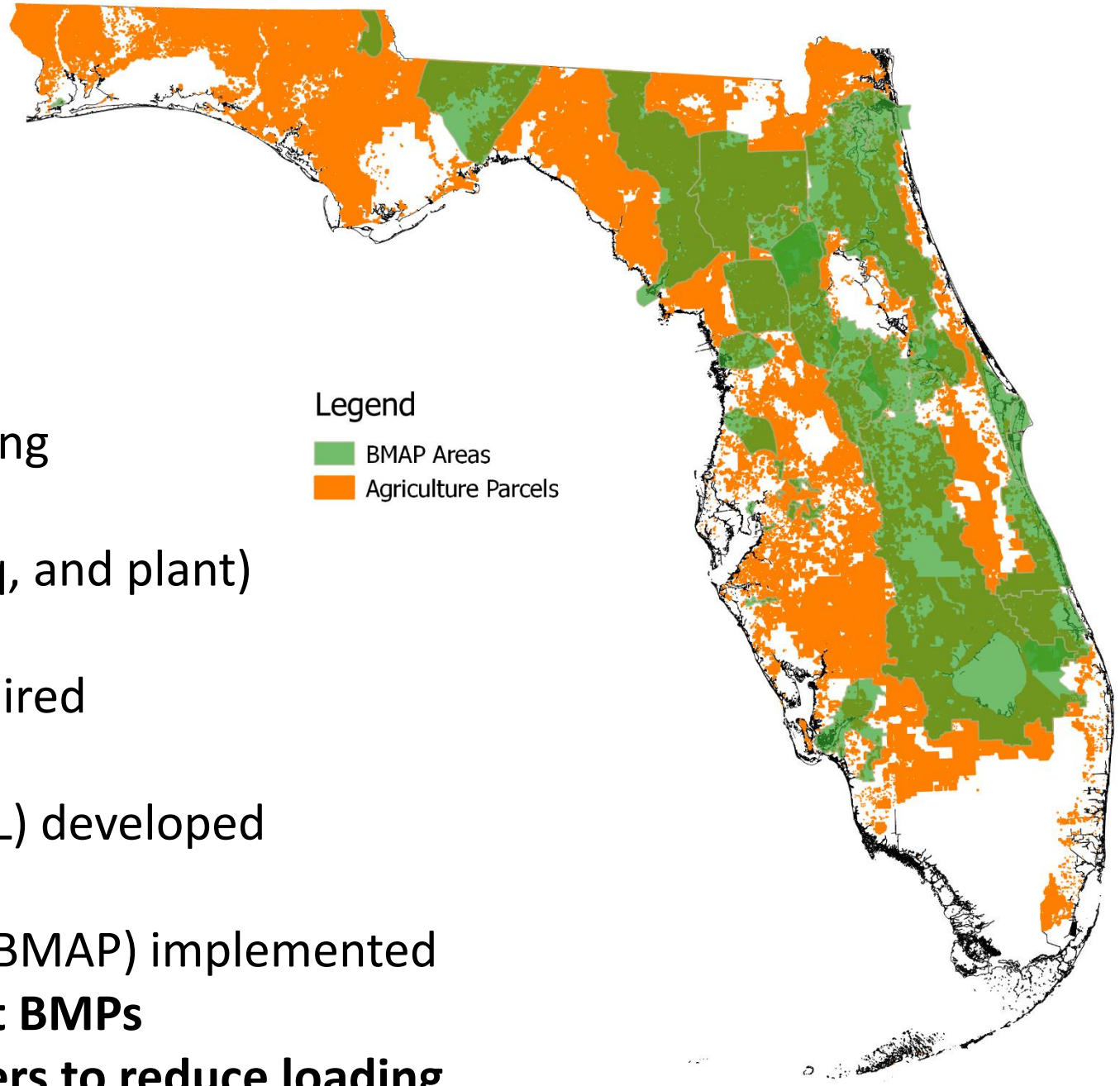
Soil moisture probes

Filter strips

Soil testing

Regulatory overview

1. Water quality sampling/monitoring
2. Nutrient criteria violated (bio, wq, and plant)
3. Waterbody (WBID) listed as impaired
4. Total Maximum Daily Load (TMDL) developed
5. Basin Management Action Plan (BMAP) implemented
   a) **Growers asked to implement BMPs**
   b) **Mandatory for all stakeholders to reduce loading**



Presumption of Compliance

- Implementing and maintaining verified FDACS-adopted BMPs provides a presumption of compliance with state water-quality standards for the pollutants addressed by the BMPs.
- Assumed to be a consistent **30% reduction**
- This presumption not **quantified** or examined

Examining the Presumption

Examined Florida specific Best Management Practices for:

- three crop types:

1. Cow/calf

2. Agronomic - sugarcane, corn, soybeans, cotton, peanuts, hay

3. Vegetable - potato, strawberries, tomatoes, peppers, melons, cucumbers

- Average effect and variability of **nitrogen** and **phosphorus** reduction

Methods – Inclusion Criteria

- Needed to compare one or more BMP to no-BMP
- In Florida on the appropriate crop type
- Measured water quality for N or P
- Needed to contain information to calculate effect size and variability

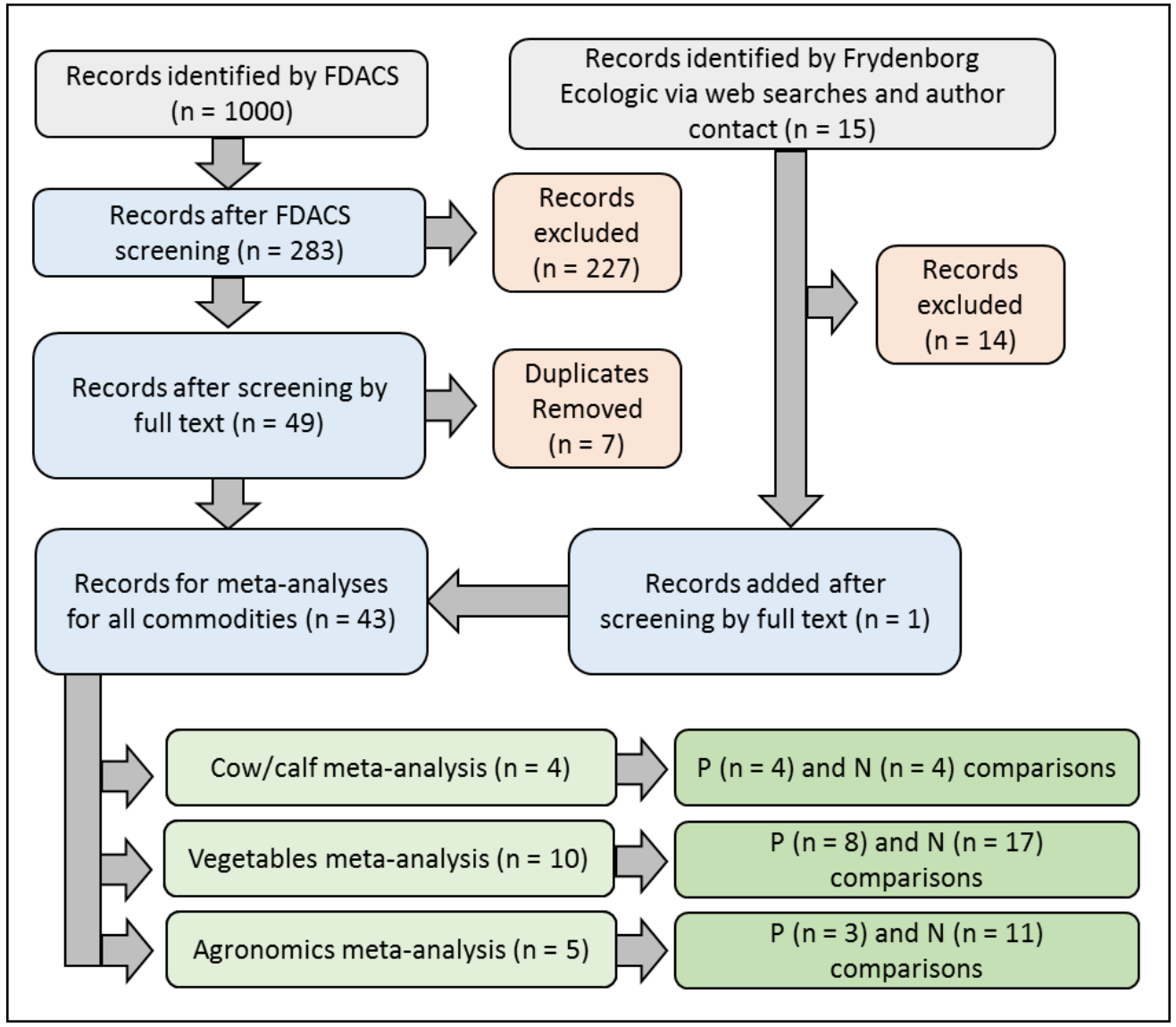
Methods – Statistical Analysis

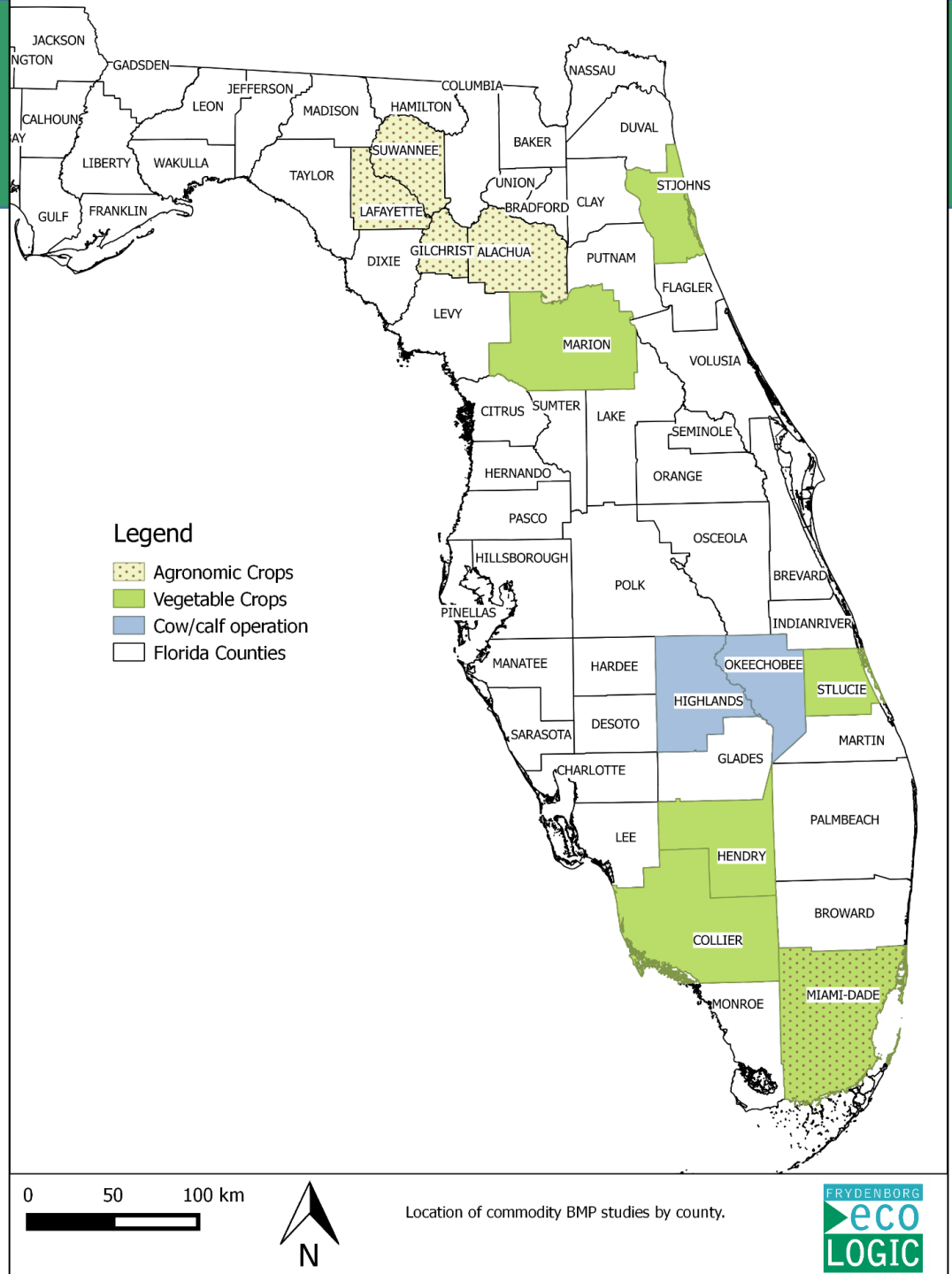
- Effect size for each study calculated using the **ln-transformed ratio of means** (unit-less)
  - Effect sizes within same paper aggregated with **univariate Borenstein, Hedges, Higgins, and Rothstein (BHHR)**
  - Allows for an approximation to normal distribution

- Random Effects meta-analysis - **Restricted Maximum Likelihood** with **inverse-variance weighting**
  - *Allows for variability of effect sizes amongst studies, and treats heterogeneity/variation between studies as random.*

- **Mean estimate** and its confidence interval addresses the question, “what is the average intervention effect”?
  - **Forest plots,** funnel plots, inter-study variation examined, mixed effect model if heterogeneity observed
  - Effect sizes transformed for a **percent reduction**

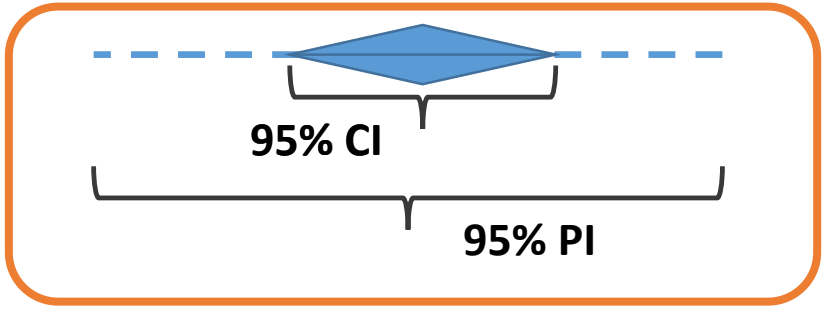
Results - metadata



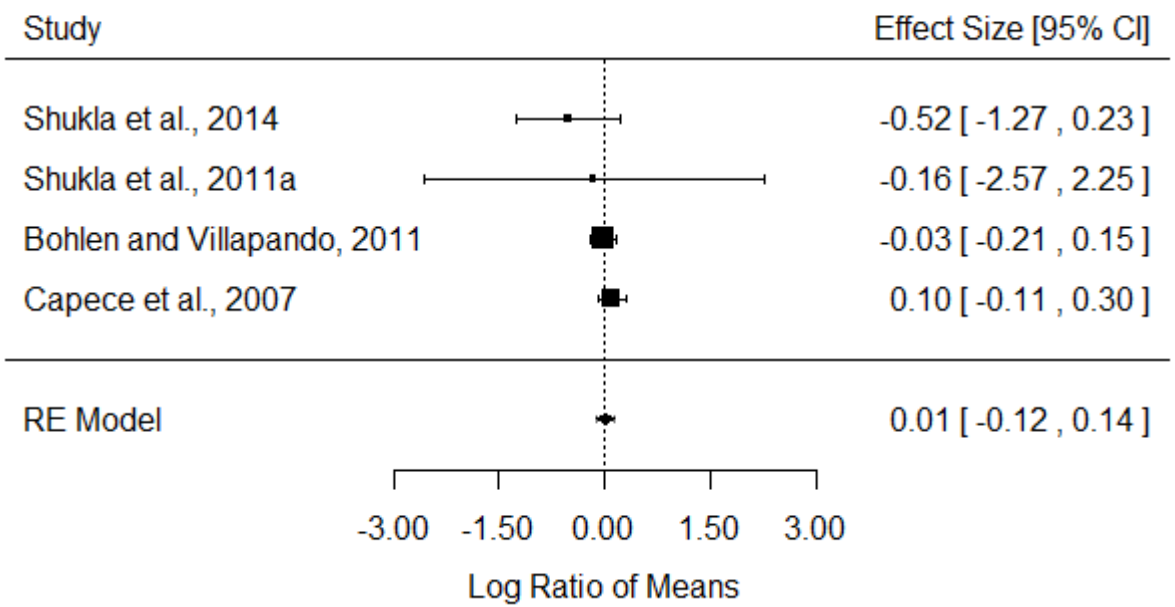


Results – Cow/calf Operations

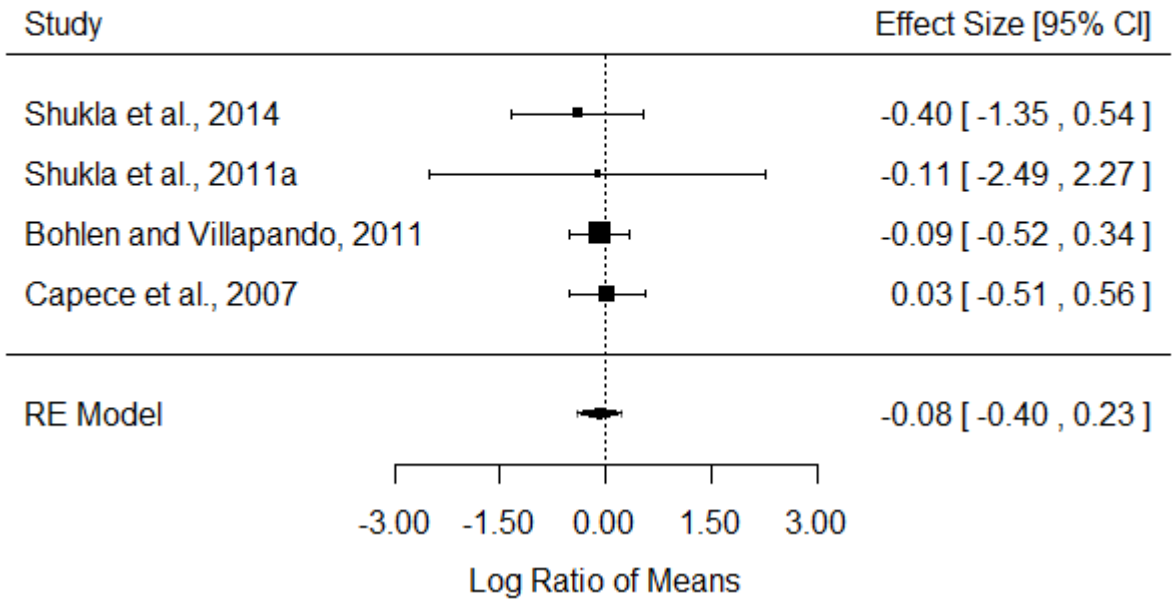
- **No reductions** in nitrogen or phosphorus
- Low number of studies



Cow/calf BMP effects on Nitrogen

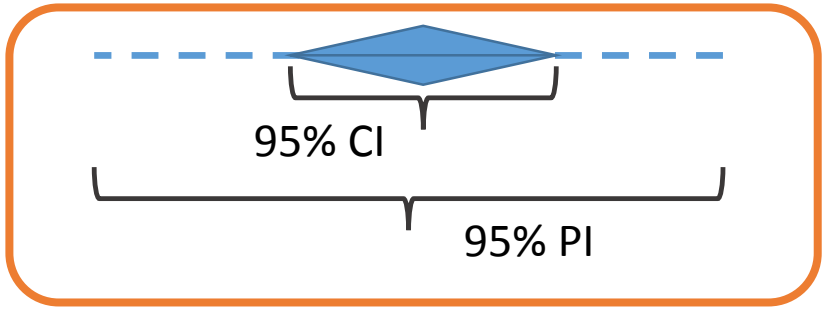


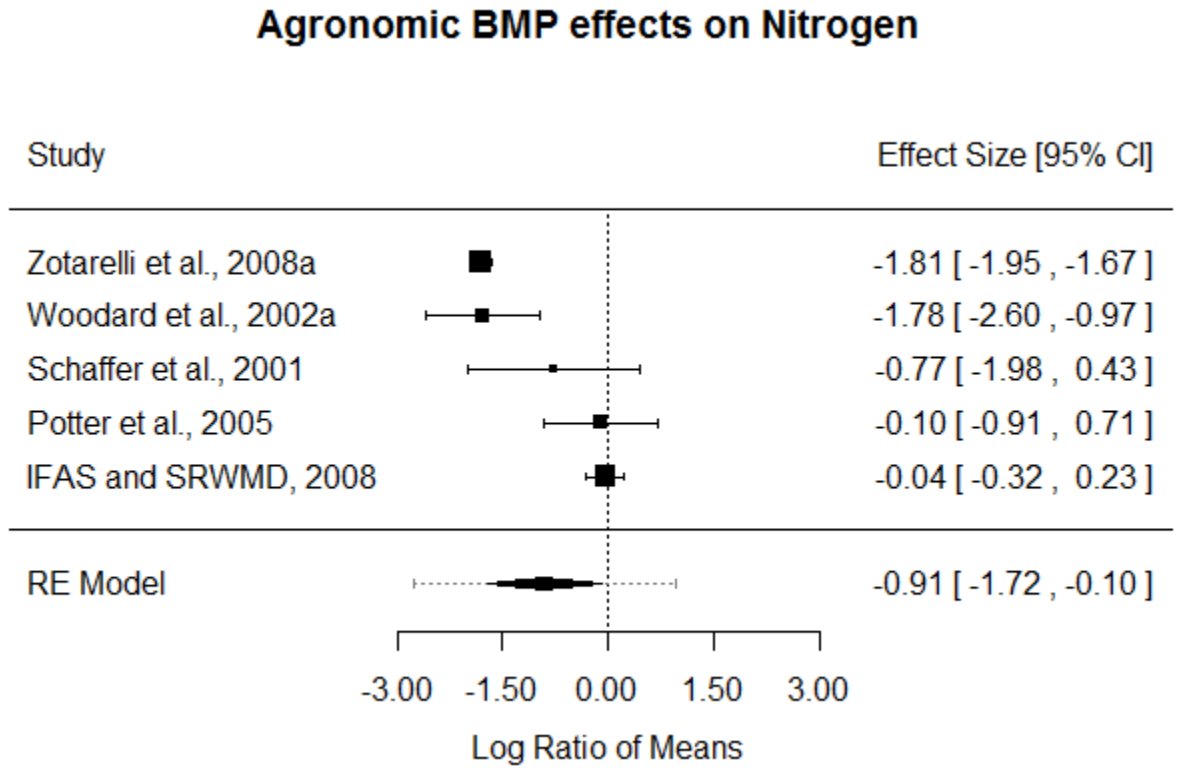
Cow/calf BMP effects on Phosphorus

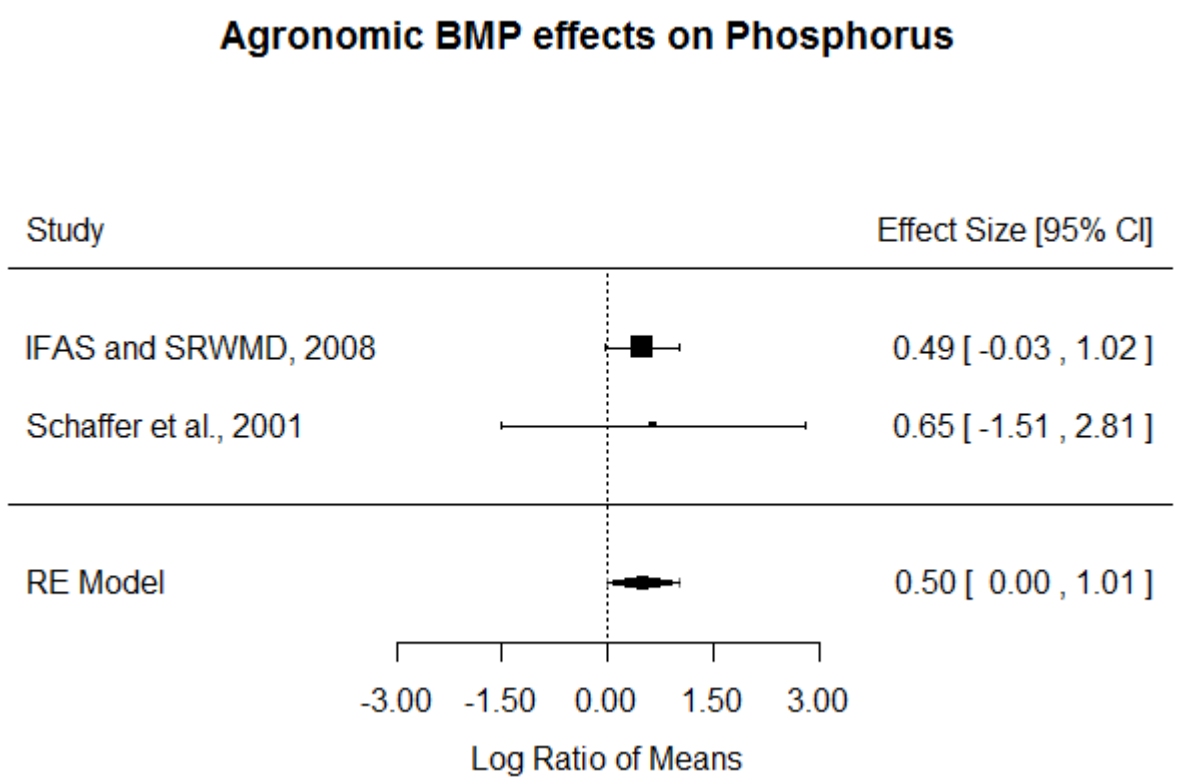


Results – Agronomic Crops

- **60%** average reduction in **nitrogen**
  - Large variability: 9.5% – 82.1% reduction for 95% CI
- **No** reduction in **phosphorus**

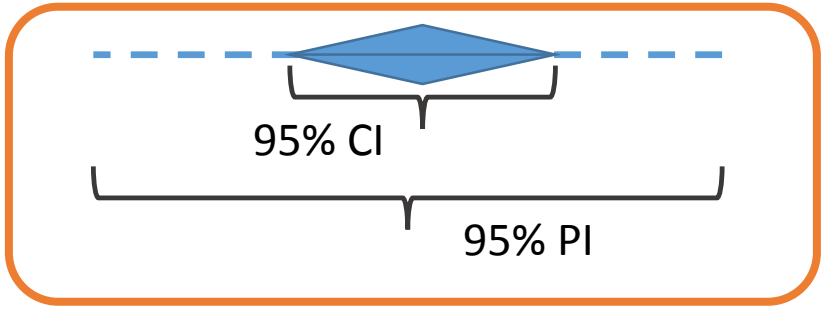




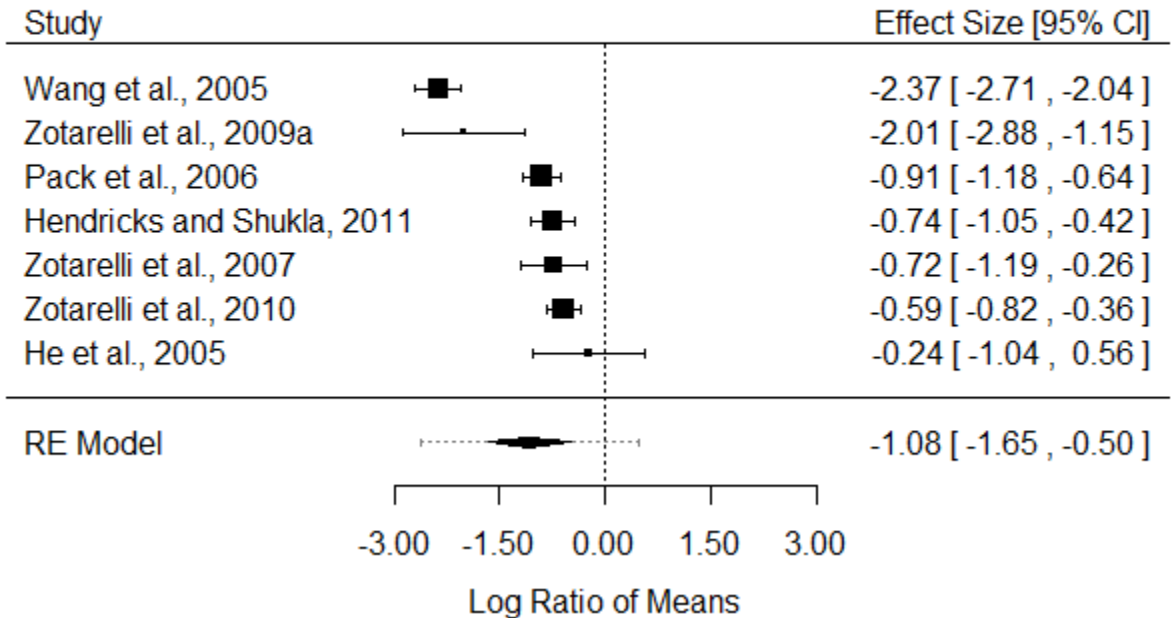


Results – Vegetable Crops

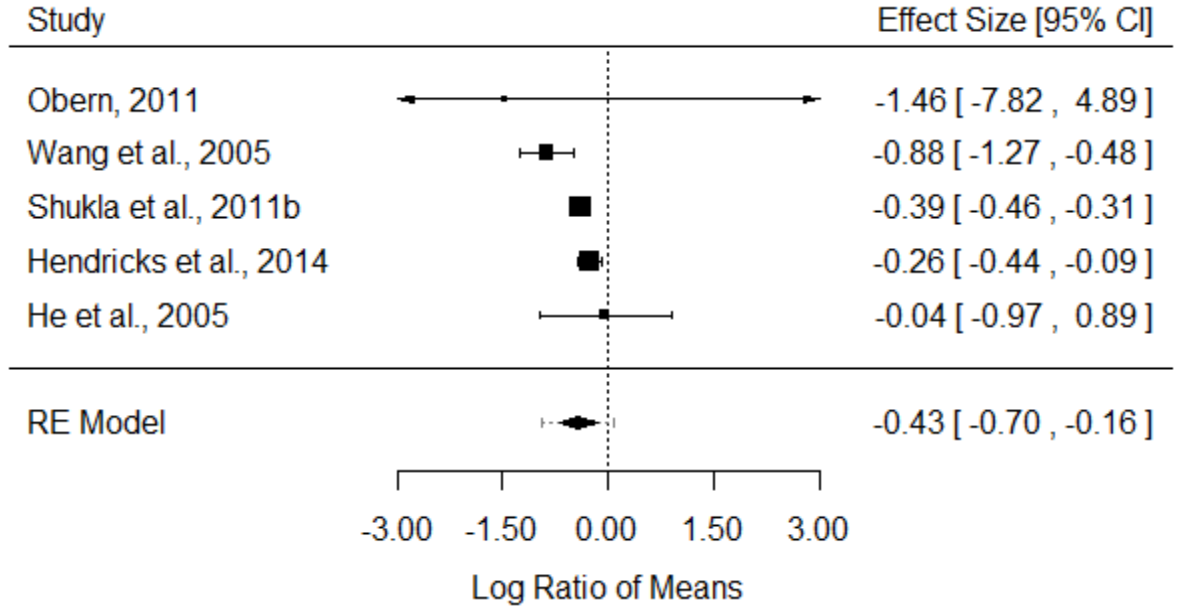
- **66%** average reduction for **nitrogen**
  - 39.3% - 79.8% reductions at 95% CI
- **35%** average reduction for **phosphorus**
  - 14.8% - 50.3% reductions at 95% CI



Vegetable BMP effects on Nitrogen



Vegetable BMP effects on Phosphorus



Conclusions

- Is Presumption of Compliance supported?
  - No reduction for cow/calf
  - Large but variable reduction for row crops

- Takeaways for policy makers
  - **A 66% reduction might still cause imbalances in waterbodies**
  - More site/crop specific approach should be considered
  - Funded studies need to report useful metrics
    - FDACS has implemented this for ongoing/future studies

Acknowledgements

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Questions?

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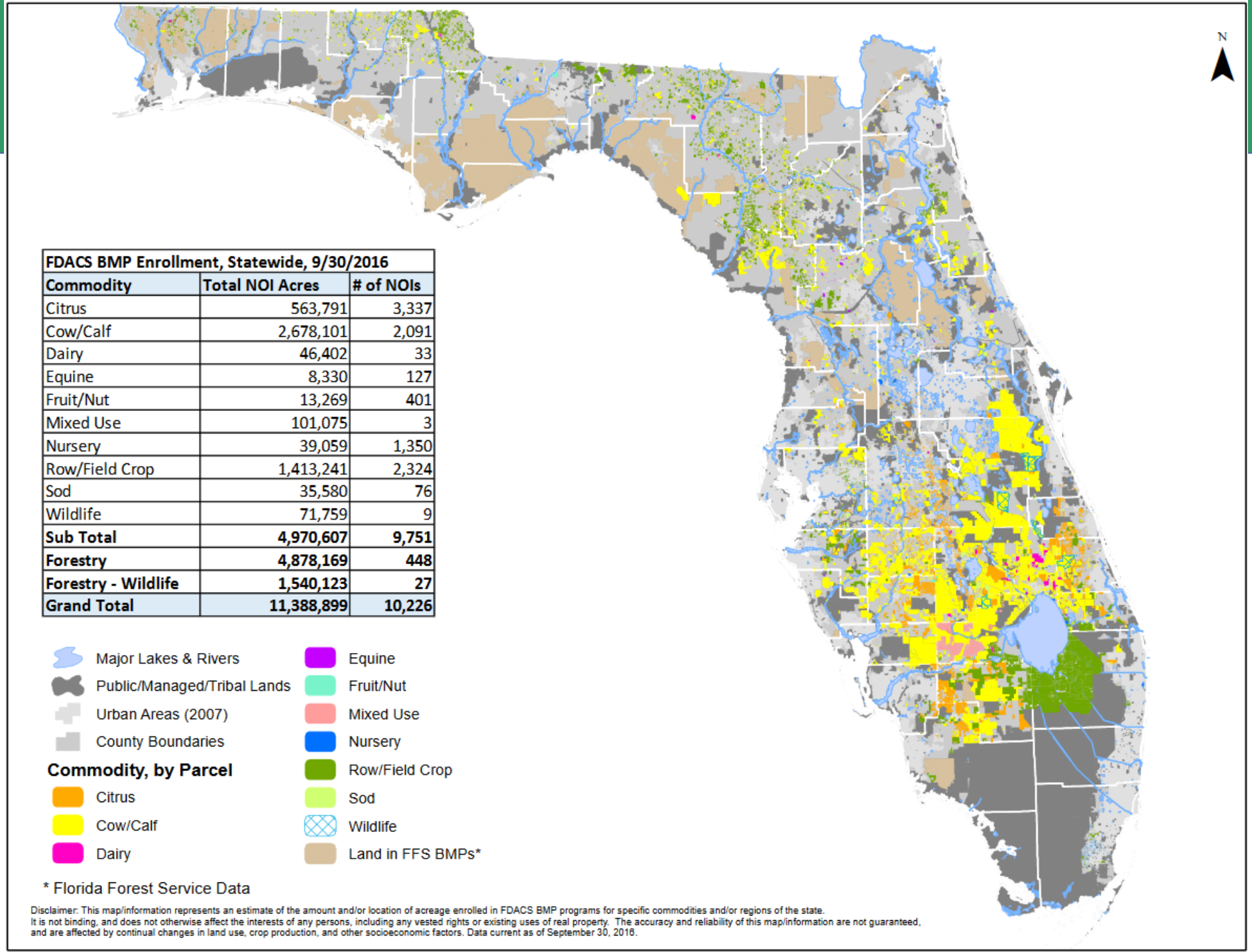
Participating areas in BMPs

FDACS BMP Enrollment, Statewide, 9/30/2016		
Commodity	**Total NOI Acres**	**# of NOIs**
Citrus	563,791	3,337
Cow/Calf	2,678,101	2,091
Dairy	46,402	33
Equine	8,330	127
Fruit/Nut	13,269	401
Mixed Use	101,075	3
Nursery	39,059	1,350
Row/Field Crop	1,413,241	2,324
Sod	35,580	76
Wildlife	71,759	9
Sub Total	**4,970,607**	**9,751**
Forestry	**4,878,169**	**448**
Forestry - Wildlife	**1,540,123**	**27**
Grand Total	**11,388,899**	**10,226**



* Florida Forest Service Data

Disclaimer: This map/information represents an estimate of the amount and/or location of acreage enrolled in FDACS BMP programs for specific commodities and/or regions of the state. It is not binding, and does not otherwise affect the interests of any persons, including any vested rights or existing uses of real property. The accuracy and reliability of this map/information are not guaranteed, and are affected by continual changes in land use, crop production, and other socioeconomic factors. Data current as of September 30, 2016.

Definitions of Acronyms ☹

- BMPs – Best Management Practices.
  - Aim to conserve water and reduce amount of pesticides, fertilizers, and animal waste enter surface and ground water.
- TMDL – total maximum daily load.
  - A determination of tolerable pollutant loading.
- BMAP – Basin management action plan.
  - Florida specific term that implements a TMDL

Detailed Objectives

- **Population**

- Agricultural operations in Florida subject to FDACS regulation and Florida water quality rules. These are often grouped as follows: cow/calf, citrus, agronomic, vegetable, equine, nurseries, specialty fruit and nut crops, and sod operations. At the request of FDACS, this review examined cow/calf, agronomic, and vegetable operations.

- **Interventions**

- The potential interventions included any BMP recommended by FDACS and adopted into rule. These are outlined in documents available from their website (FDACS, Office of Agricultural Water Policy, 2008, 2015). BMPs vary between commodities, but are generally focused on nutrient and irrigation management.

- **Comparator**

- Absence of BMP intervention (*i.e.,* practices conducted by the farmer without BMPs) was compared to operations in which BMPs were included.

- **Outcome**

- Outcome involves the effect on water quality in terms of change to selected forms of N (nitrate, total nitrogen) or P (phosphate, total phosphorus). This was limited to actual environmental measures (*e.g.* no simulated data, no calculations based on crop nutrient content).

Methods – Inclusion Criteria detailed

- *Relevant population(*s): Articles that investigated one or more BMPs aimed at improving water quality in Florida
- *Types of interventions:* Reports measuring any intervention aimed at improving water quality were included
- *Types of comparators:* The absence of a BMP intervention
- *Types of outcomes:* Water quality measured by changes in N and P
- *Types of studies:* Only studies that reported primary research measuring the effect on an intervention were included
- Needed to contain information to calculate effect size and variability

Equations

$$RoM = \frac{mean_{exp}}{mean_{contr}}$$

Equation 2. Variance calculation for the ratio of means effect size. From (Friedrich et al., 2008).

$$Var\left[\ln\left(\frac{mean_{exp}}{mean_{contr}}\right)\right] = Var\left[\ln\left(mean_{exp}\right) - \ln\left(mean_{contr}\right)\right]$$

$$= Var\left[\ln\left(mean_{exp}\right)\right] + Var\left[\ln\left(mean_{contr}\right)\right] \quad \text{[since the groups are independent]}$$

$$= \left(\frac{1}{mean_{exp}}\right)^2 Var\left(mean_{exp}\right) + \left(\frac{1}{mean_{contr}}\right)^2 Var\left(mean_{contr}\right)$$

$$= \frac{1}{n_{exp}}\left(\frac{sd_{exp}}{mean_{exp}}\right)^2 + \frac{1}{n_{contr}}\left(\frac{sd_{contr}}{mean_{contr}}\right)^2$$

$$\left[\text{since for random variable } X,\ Var\left(mean_X\right) = \frac{Var(X)}{n_X} = \frac{sd_X^2}{n_X}\right]$$

Equation 3. The ratio of the means is back transformed to obtain a pooled ratio and associated 95% confidence interval. From (Friedrich et al., 2008).

$$95\%CI = exp\left\{\left[\ln\left(\frac{mean_{exp}}{mean_{contr}}\right)\right] \pm 1.96\sqrt{Var\left[\ln\left(\frac{mean_{exp}}{mean_{contr}}\right)\right]}\right\}$$

Equation 4. Log Ratio of Means Effect size = x. No effect = 0.

$$\text{Percent Reduction} = \frac{e^0 - e^x}{e^0} * 100$$

$$\Theta_{IV(RE)} = \frac{\Sigma_{i=1,k} w_i^* \times \Theta_i}{\Sigma_{i=1,k} w_i^*} \quad \text{with variance } (\Theta_{IV(RE)}) = 1 / \Sigma_{i=1,k} w_i^*$$

In **Equation 5**, $\Theta_{IV(FE)}$ is the **inverse-variance weighted fixed effects** pooled effect estimate. k designates the number of studies, i is the effect measure estimate for study i with a weighting of $w_i = 1/\text{variance}(\Theta_I)$.

BHHR - Borenstein, Hedges, Higgins, and Rothstein

Heterogeneity and publication bias

- Variability between studies in each group was examined using a heterogeneity measure (Q),
  - calculated by weighting the sum of squared differences between individual effects and the pooled effect, which was tested against a chi-square distribution.
- Excessive heterogeneity is problematic for interpreting effect size properly, use of a random-effects model can help overcome the effects of heterogeneity (Eysenck, 1994).
- "Publication bias" was examined through the use of funnel plots, and an inspection of the regression test for funnel plot asymmetry.
- QQ plots were also examined for approximate normality.
  - Several modifiers were examined to determine their influence on any heterogeneity observed in each model, including crop type, BMP type, and response unit (*e.g.,* kg/ha vs. mg/L).

Random effects model

- characteristic of the random effects model is that there is not one single true effect size, but rather a range of possible effects. The random-effects estimate and its confidence interval addresses the question “what is the average intervention effect”? Random effects models are more conservative than fixed effects models, with larger confidence intervals.
- effect sizes resulting from multiple comparisons made in a single study were aggregated to calculate one effect size per study. Aggregation of effect sizes from studies can be accomplished using the univariate procedure of Borenstein, Hedges, Higgins, and Rothstein (BHHR). This type of pre-aggregation step has been found to be the least biased and most precise for meta-analysis (Del Re, 2015).

Study quality guidelines

Category	Score	Hierarchy of evidence
Randomization	1	Yes – randomized
	0	Not randomized
Control type	3	Controlled BACI
	2	Control-Impact
	1	Before-After
	0	No control
Study length	2	Greater than 2 years
	1	Between 1 and 2 years
	0	Less than 1 year
Replication	2	Temporal and spatial replication
	1	Temporal or spatial replication
	0	No replication
Study type	2	Manipulative Study
	1	Correlative Study
	0	Sampling Study

Data extraction example

Citation	Commodity/crop, Type of study, BMP	Control mean	Control St. Dev. Or 95% CI or SE	Con n	Treat-ment mean	Treat-ment St. Dev. Or 95% CI or SE	Response variable and units	Treat n
(Bohlen and Villapando, 2011)	Cow/calf in Lake Okeechobee. Study: Control-Impact, partial BACI. BMP: On-ranch water retention/detention to control nutrient loss. Replication: 4 plots control and 4 with water retention, measured water quality 6 times in 2005-2006 at all sites via grab samples. Collected 6 grab samples during flow events in pastures but don't specify if it was 6 per plot, so assume 6 total. Calculation: averages and se taken directly from report. Limitations: Authors mention that pastures with water control structure had significantly lower average annual TN loads before structures installed. They note that magnitude of reduction increased. BACI analysis did not find significant effect from water retention on TP loads.	0.61	0.11 (SE)	6	0.56	0.07 (SE)	TP concentration (mg/L) exiting plots	6

BMPs employed and study type

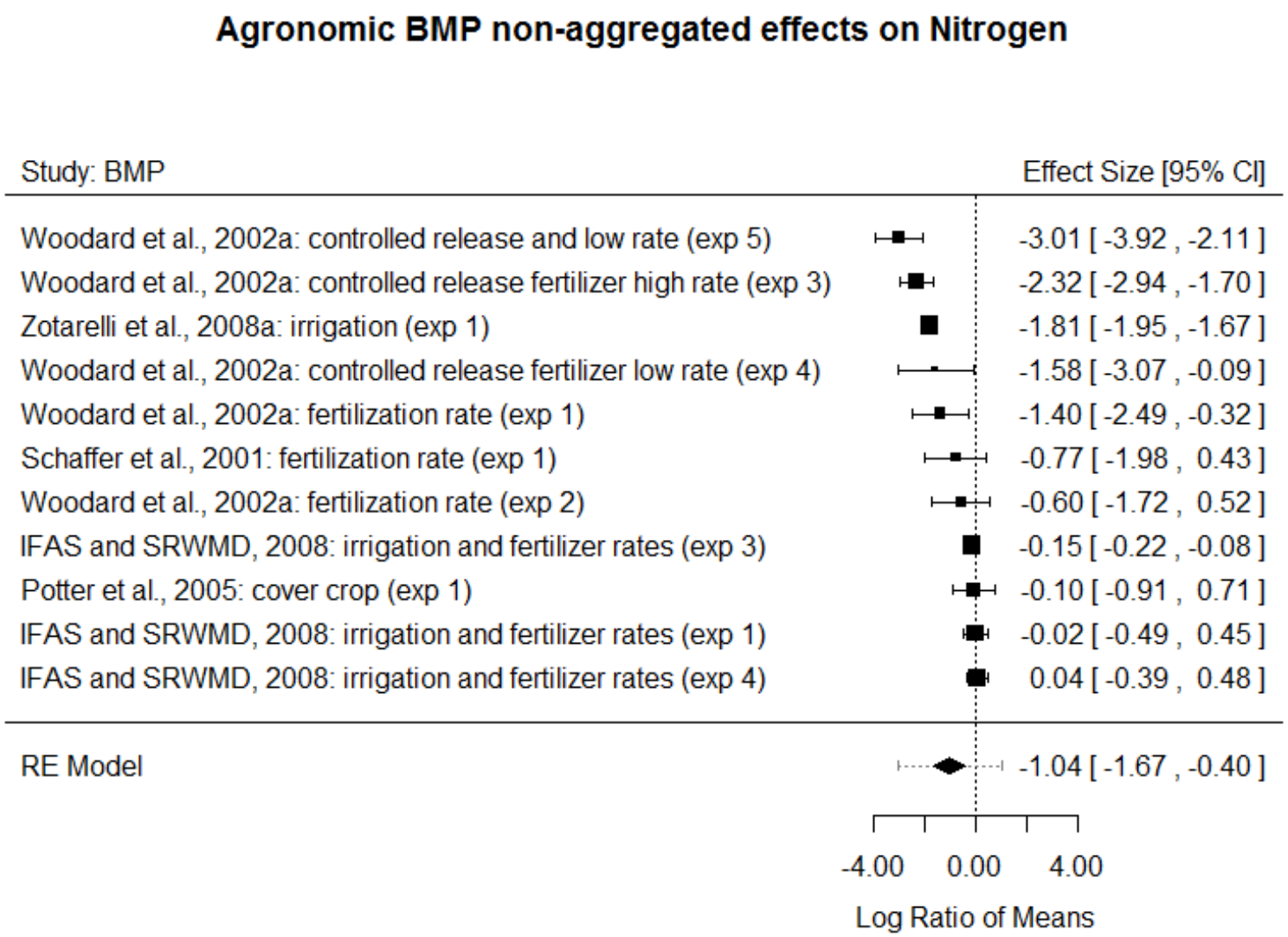
BMP manipulation	commodity	N (# of studies)	P (# of studies)
Water retention/detention	Cow/calf	2	2
Stocking rate (pasture management)	Cow/calf	1	1
Waterway exclusion (culvert crossings and ditch fencing)	Cow/calf	1	1
Cover crop use	Agronomic	1	1
Irrigation BMP	Agronomic	2	1
Organic, slow release fertilizer use	Agronomic	1	0
Efficient fertilizer application	Agronomic	2	2
Irrigation and Efficient fertilizer application BMPs	Agronomic	1	0
Efficient fertigation BMP	Vegetable	1	0
Efficient fertilization and micro-irrigation BMPs	Vegetable	1	0
Tensiometer-controlled irrigation, efficient fertilization BMP	Vegetable	1	0
Surface and subsuface drip irrigation, efficient fertilization	Vegetable	1	1
Cover crop use BMP	Vegetable	1	0
Optimization of wetland treatment	Vegetable	2	2
Controlled release fertilizer use BMP	Vegetable	1	1
Water management BMP	Vegetable	1	0
Efficient fertilization, drip irrigation	Vegetable	2	2
Micro-drip irrigation, efficient fertilization	Vegetable	2	2

Type and number of BMP manipulations studied for reducing N and P.

The number of study designs in each commodity grouping.

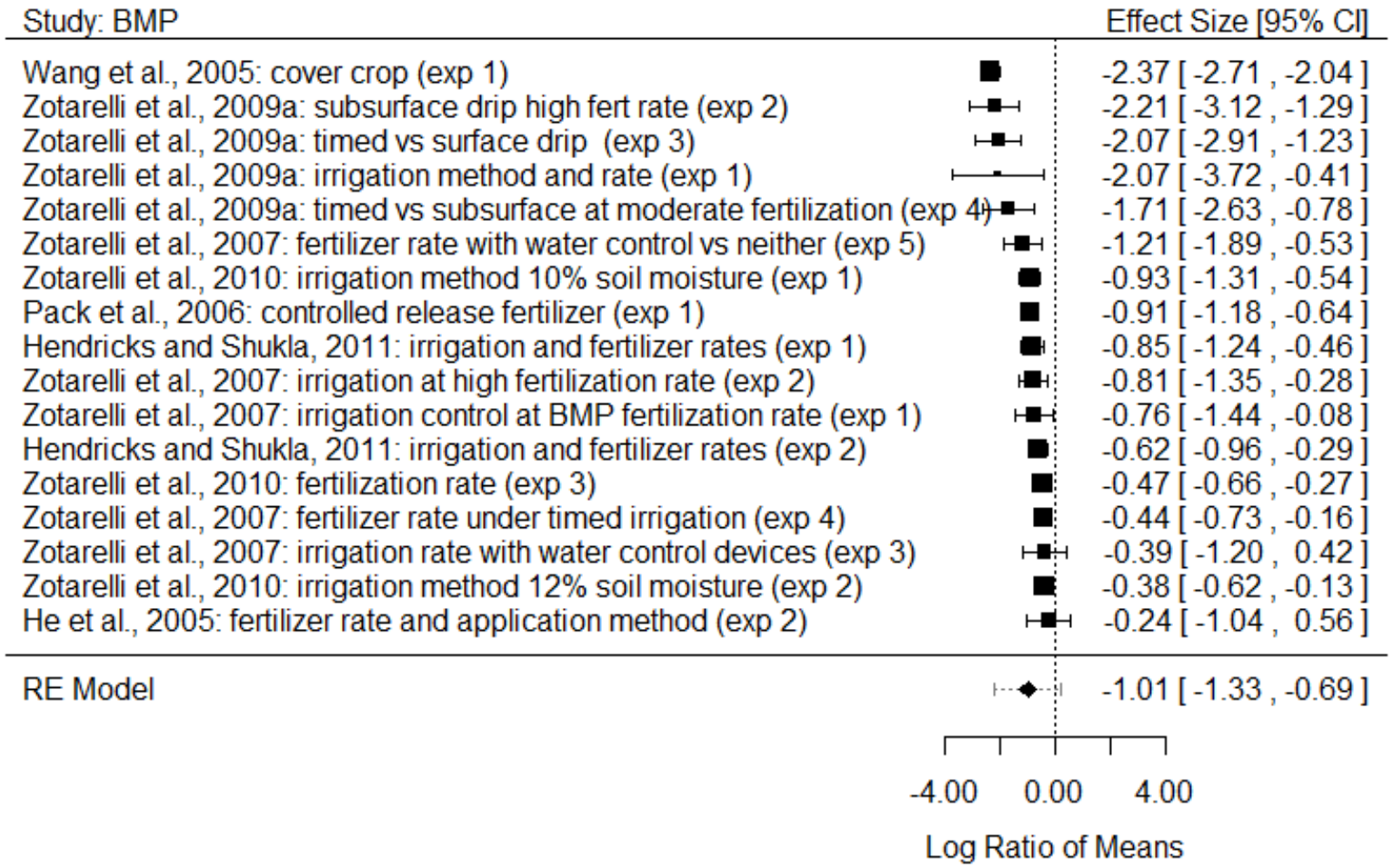
Study Design	Cow/calf (4 total)	Vegetable (10 total)	Agronomic (5 total)
BACI	2	0	0
CI	1	9	5
BA	1	1	0

Agronomic non-aggregated Nitrogen



Vegetable non-aggregated Nitrogen

Vegetable BMP non-aggregated effects on Nitrogen



Vegetable non-aggregated Phosphorus