Advancing ecological restoration through experimental design on spatial and temporal scales relevant to wildlife

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ABSTRACT

Experimenting with new and unconventional restoration methods and designs is critical to advancing the field of ecological restoration. Conventional methods cannot be considered reliable in a future with climate change-induced shifts in weather conditions, species distributions, and ecosystem processes. It is crucial that researchers and practitioners collaborate to identify the most effective restoration methods, yet there remains a disturbing lack of restoration experiments at the spatial or temporal scales relevant for evaluating wildlife responses. We suspect that willingness to attempt such experiments is hampered by the perceived difficulty of conducting these experiments combined with a fear of failure. However, we argue that failure to experiment with new methods guarantees learning nothing new. Here, we address many of the major challenges of designing an experiment to evaluate wildlife responses to restoration, including (1) distinguishing between the goals and objectives of the restoration project and the key uncertainties the experiment will address, (2) designing the experiment itself, including optimizing plot size and replication, and (3) determining how and when the results will be evaluated. We then illustrate how we designed an experiment to evaluate riparian bird responses to restoration along the lower Cosumnes River in the Central Valley of California, USA. Researchers and practitioners working together from the start of the objectives-setting /process, through experimental design, implementation, and evaluation can proactively address the challenges of conducting a restoration experiment and maximize the chances of successfully identifying effective restoration methods, adding to the practitioners' toolbox, and accelerating the rate of successful habitat restoration.

Keywords: California, Central Valley, Cosumnes River, restoration experiment, riparian birds

Introduction

Experimentation with new and unconventional restoration methods and designs is critical to making advances in the field of ecological restoration (Seavy et al. 2009, Goreau and Trench 2012). Climate change-induced shifts in weather conditions, species distributions, and ecosystem processes signal a future in which conventional methods cannot be considered reliable (Hobbs et al. 2009, Perry et al. 2015). With limited time and resources, researchers and practitioners must collaborate to identify the methods and designs that will be the most effective and resilient to climate change. Yet, advances have been severely limited by the general lack of scientific experimentation, except on relatively small scales and over short time frames (e.g. $< 1m^2$ over < 1 growing season; Kettenring and Adams 2011). Larger-scale and longer-term evaluations of restoration success, let alone experiments, are far more rare (Osenberg et al. 2006, Dickens and Suding 2013), even though they are necessary for evaluating the responses of wildlife, the restoration of ecological functions and services, and the performance of restorations under extreme weather conditions.

In the case of wildlife responses to restoration, many restoration practitioners have focused on restoring habitat structure and composition, assuming that wildlife will recolonize restored areas soon after suitable habitat conditions have been provided (the “Field of Dreams” hypothesis; Palmer et al. 1997). Yet, when wildlife responses to restoration are evaluated, they are not always successful (Shanahan et al. 2011, Cristescu et al. 2013, Calhoun et al. 2014). This is perhaps not surprising since it is usually unrealistic for restoration practitioners to remove human modifications to ecosystems such as dams and levees, reverse the spread of non-native species, or prevent climate change-induced shifts in weather extremes, any of which can impact wildlife populations and the degree to which they benefit from a restoration project.

Consequently, if the goals of a restoration project include benefitting wildlife populations, it is essential to assess wildlife responses to restoration. However, we argue that the field of ecological restoration will benefit the most from efforts to design restoration projects that allow comparing the relative effectiveness of alternative restoration designs and methods.

Several papers have outlined general concepts and theory for developing a restoration experiment to evaluate effects on wildlife, including an array of analytical approaches and a multitude of pitfalls and barriers to successful experiments (Michener 1997, Chapman 1998, Block et al. 2001). Despite this guidance, experiments evaluating wildlife responses to habitat restoration remain rare, and likely have been hampered by financial and logistical constraints combined with fear of failure (Aslan et al. 2013, Dickens and Suding 2013). We suspect that researchers and practitioners fear that an imperfect experiment will result in non-significant *p*-values, squandered resources, and a failure to learn anything new. However, continuing to use conventional restoration methods and designs without experimentation guarantees learning nothing new. Here, we address the major challenges of designing a large-scale restoration experiment, with a focus on evaluating wildlife responses. As a case study, we then describe how we designed an experiment to evaluate the response of riparian birds to three habitat restoration treatments as part of a project enhancing floodplain connectivity along the Cosumnes River in the Central Valley of California.

Addressing the Challenges of Designing Restoration Experiments to Evaluate Wildlife Responses

The challenges of designing large-scale restoration experiments to evaluate wildlife responses begin with a lack of clearly defined goals and objectives for the restoration project itself, including wildlife species and response metrics that either have not been specified, are too numerous, or are too impractical to study. When it comes to the experimental design itself, a major challenge lies in balancing a study area that is both (a) large enough for multiple replicates of each treatment on plots that are large enough to detect a wildlife response and (b) small enough that the replicate plots are relatively similar to each other and that the implementation and evaluation of the experiment is manageable over multiple years. The classical experimental design assumptions of randomly assigned treatments and controls and independence among replicate plots further add to the challenge. Finally, there is considerable uncertainty over how to evaluate the results and draw conclusions, particularly when the experimental design is imperfect. To help facilitate collaborations between researchers and practitioners in designing successful restoration experiments to evaluate wildlife responses, we address each of these challenges sequentially, making recommendations and referring readers to the relevant literature for more information.

1. Define the Goals and Objectives

Defining the goals and objectives is a critical first step to designing successful habitat restoration projects and experiments. We distinguish the goals of a restoration project, which are often broad and visionary statements, from the objectives of a restoration project, which are the specific, measurable outcomes necessary to achieving the goals (CMP 2013). For example, to meet a goal of restoring habitat to benefit migratory birds, objectives should specify which types of migratory birds (e.g., ducks or warblers), what determines whether the birds have benefitted (e.g., changes in abundance, survival, or reproductive success), and the size of the response that will be considered a success (e.g., target population size). The objectives of the restoration experiment will flow directly from the project's goals and objectives (e.g., which of these alternative restoration approaches achieves the project's goals and objectives more quickly?). A conceptual model is useful for illustrating the hypothesized cause-effect relationships linking specific restoration actions to achieving the restoration project's objectives and goals (Figure 1; Michener 1997; Holmes & Miller 2010), as well as for identifying key uncertainties in cause-effect relationships that could be addressed by a restoration experiment. We recommend that researchers and practitioners collaborate on the experimental design from the start, including defining the project's goals and objectives and developing a conceptual model, to ensure that the restoration experiment is achievable, designed to provide the research-based information needed by practitioners, and has the best chances for success.

Identify the species of interest. In many cases, the project's goals will include a broadly-defined group of species (e.g., small mammals), such that we recommend carefully selecting a subset of individual species that can be feasibly monitored. We recommend first considering the type of monitoring required for each species, especially the investment in time and resources required for gathering the appropriate data for the response metrics of interest (discussed in the next section). We also recommend choosing species that are dependent on the type of habitat being restored and are likely to respond soon after the habitat becomes suitable (Carignan and Villard 2002), so that the lack of a response is a clear indication that the restoration was unsuccessful. For example, one should consider the location of existing source populations and likely dispersal distances, which can limit the ability of a species to colonize suitable restored habitat (Golet et al. 2011, Grundel et al. 2014). Similarly, one should consider whether there are broader factors that may limit the ability of the species to respond to a restoration project, such as disease susceptibility or habitat limitation during other parts of a migratory species' annual cycle

(Block et al. 2001, Carignan and Villard 2002). These species may still be important to include in the project's objectives, but the meaning of a lack of response to the restoration is less clear. Finally, we recommend maximizing the diversity of the species chosen, in terms of trophic position, life history, behavior, or even the time of year during which it relies on the type of habitat being restored, so that they each reflect different aspects of habitat or ecosystem condition (Carignan and Villard 2002).

In some cases, the species of interest will already be defined, such as restoration projects designed specifically for the recovery of a threatened species. However, we caution that it can be difficult to measure a response to restoration by very rare species, at least in the short term, because only small numbers of animals are initially available to respond. Thus, the meaning of an apparent lack of response to the restoration may be unclear. Similarly, if the species of interest is a highly mobile species relative to the spatial scale of the restoration project, it may be difficult to detect a measurable response within the restored area. In these cases, it may be useful to select and monitor several additional species that can provide a better indication of immediate changes in local habitat quality (Carignan and Villard 2002). In addition to the criteria for selecting species described in the previous paragraph, we recommend considering species likely to respond in a similar way to the rare or highly mobile species, such as those with similar habitat requirements, life histories, or behavior.

Select response metrics that reflect project goals. There are many wildlife response metrics that could be examined (Johnson 2007), each with its own advantages and disadvantages. For example, differences in the probability of species occurrence between sites or years can be estimated using species presence/absence data (Mackenzie and Royle 2005), which may require as little as a few hours of active effort per plot, including methods such as point counts, camera traps, or acoustical monitoring (Ralph et al. 1995, O'Farrell and Gannon 1999). Similar methods can also be used to estimate changes in abundance or density (Buckland et al. 2001, Rowcliffe et al. 2008), which can indicate an improvement in habitat quality (Bock & Jones 2004; but see Van Horne 1983). As an alternative to species presence or abundance, changes in demographic performance, including reproductive success and survival, can provide a deeper, mechanistic understanding of species responses to restoration, but may require a considerably larger investment of time and resources. For example, locating and monitoring songbird nests can take several hours over several weeks or months for each nest, while mist-netting and banding songbirds to acquire mark-recapture or mark-resight data can take hundreds of net hours over several months or years for each survival estimate (Ralph et al. 1993, White and Burnham 1999). Similarly, measures of body condition or behavior can also indicate habitat quality (Cooke and Suski 2008, Morrison and Lindell 2011), but a considerable investment of time and resources may be required to capture individuals for physiological metrics or to record individual behavior. We recommend selecting wildlife response metrics that most closely reflect the goals of the restoration project and fit the conceptual model linking restoration actions to changes in habitat conditions and subsequent effects on the wildlife response metrics, while also considering the intensity and duration of monitoring effort and the complexity of analysis each metric requires.

Define a successful response to restoration. In addition to identifying the species and response metrics of interest, defining the specific, measurable objectives of a restoration project requires quantifying the magnitude of the wildlife response that will be considered a success (Osenberg et al. 2006). For example, the objectives may include an improvement over the baseline conditions and/or to reach a specific benchmark, such as a desired abundance or survival rate. Setting a specific benchmark can be challenging, but common approaches are to base objectives on historical information or on relatively undisturbed reference sites used for comparison (Rich et al. 2004, Gardali et al. 2006). In many cases, comparable reference sites may not exist and objectives based on historical information may be unrealistic in landscapes that have changed significantly due to factors like urbanization, altered fire regimes, or water diversion (Suding 2011). In these cases, alternative approaches to setting objectives should be considered (Sanderson 2006). Given the rapid pace of climate change, these objectives should be informed by historical conditions, but also be forward-looking and incorporate information about projected future conditions (Chornesky et al. 2015).

Identify the objectives of the experiment. Experiments examining wildlife responses to restoration will commonly include the objectives of identifying which of several restoration treatment options is most effective in achieving the project's wildlife response objectives, and because restoration requires substantial financial investment, which option is most cost-effective or most risky. Given the projected impacts of climate change for a region (e.g., warmer temperatures and increased risk of extreme drought), the objectives of the experiment might also include identifying which treatment option is able to meet the project objectives during extreme weather conditions and has the highest likelihood of long-term persistence.

2. Design the Experiment.

A large-scale restoration experiment is unlikely to meet all of the standard assumptions of classical experimental design, including the randomized assignment of treatments and controls to independent replicated experimental plots (Hurlbert 1984, Gotelli and Ellison 2004). Further, the design of any habitat restoration experiment will be complicated by the real-world logistical constraints and complications of on-the-ground restoration and monitoring that will take place over multiple years. However, imperfect ‘quasi-experiments’ are not doomed to failure and will still provide valuable information (Block et al. 2001), particularly if the alternative is not to attempt any experiment at all. We recommend that researchers and practitioners acknowledge up front that the experiment may not meet classical experimental design rules and work together to maximize the value of the experiment *despite* breaking these rules.

Select restoration treatments and controls that will advance understanding. A critical first step is to define the alternative restoration methods or treatments that will be compared and contrasted, based on the objectives of the experiment defined in the previous section. The simplest experiments would compare restored (treated) and unrestored (control) groups of experimental plots. However, if the objective of the experiment is instead to determine whether a particular restoration technique improved the wildlife response, such as irrigation of planted trees, the experiment would compare plots with irrigated (treated) and unirrigated (control) planted trees. If the size of the study area allows, more than one restoration treatment can be included to examine the relative effectiveness of multiple methods. We recommend selecting the smallest number of restoration treatments necessary to address the objectives of the experiment, allowing for more replicates (plots) of each treatment.

Define the study area and, if necessary, divide it into blocks. We assume the study area for the experiment will fall within the boundaries of a previously defined restoration project, determined by property boundaries, funding, and/or logistical constraints. The study area for the experiment may be identical to the project area or restricted to a subset of that area. For example, consider excluding areas with unusual features and instead focus on areas that are more representative of the landscape to be restored. Within the experiment’s study area, there may still be important heterogeneity representative of a range of conditions in the landscape of interest, such as slope, aspect, elevation, soil moisture, or prior land use. If so, we recommend dividing the study area into a few blocks capturing the major patterns in this heterogeneity and/or identifying important covariates to be measured on each plot (Hurlbert 1984, Gotelli and Ellison 2004). Focus on the primary sources of heterogeneity that are most likely to have a strong interaction with the restoration treatments that will be applied, and therefore a measurable impact on wildlife responses.

Define the minimum plot size. Each restoration treatment will ideally be applied to multiple experimental plots within the study area and at least one per block. Selecting an appropriate size for experimental plots is of the utmost importance, because if the plots are too small, there may not be a measurable response by wildlife (Block et al. 2001), but if they are too large, it will be difficult to replicate each treatment within each block. We recommend first defining the minimum plot size appropriate to the restoration treatment, species, and response metrics of interest. For example, to measure a change in the number of territories on a plot (i.e. species presence or an increase in density), the plots must be large enough to accommodate multiple territories. Information about the typical home range, territory size, or density of the species of interest, or simply the scale of previous successful habitat restoration efforts, can provide guidance. After identifying the minimum plot size required, it is straight-forward to determine the maximum number of plots that can fit within the study area and/or within each block. Ideally, there will be enough space for one plot of each treatment type per block and multiple plots of each treatment within the study area.

Confront complications with compromises. This is the stage in the experimental design process where the ideal experiment is confronted with the realities on the ground. When deciding how to compromise, we recommend revisiting the goals and objectives to ensure that the experiment will still address the key uncertainties of interest. For example, given the species of interest and restoration treatments to be examined, it may not be possible to fit multiple replicates of each treatment within the study area or one of each treatment per block. In this case, either the blocks or study area need to be larger, the total number of treatments examined fewer, or the plots smaller. While the total size of the study area is often limited by outside constraints, the number of the blocks could be reduced. The objectives of the experiment could also be refined to focus on fewer restoration treatments (e.g. one treatment and one control only). On the other hand, if the species of interest require plot sizes so large that it will always be difficult to fit multiple plots within a study area of manageable size, consider selecting different species that will be more likely to respond to restoration on a smaller scale (see previous section). As an alternative, consider accepting that there will not be replicates. For example, in the case of very large-scale, costly, and/or opportunistic restoration treatments that cannot be replicated on multiple plots, it is still possible to compare one treatment and one control plot using the before-after-control-impact (BACI) design (Stewart-Oaten et al. 1992, Osenberg et al. 2006), particularly if the effect of the treatment is expected to be large, and provided pre-treatment data on both plots are available. Further, replication and strength of inference can come from repeating experiments over time and meta-analysis (Oksanen 2001).

Another complication to confront is the potential lack of independence between adjacent plots. Ideally, plots would be spaced far apart to minimize any influence of neighboring plots and the chances that the same individual animal is sampled on multiple plots (Block et al. 2001, Gotelli and Ellison 2004). However, widely dispersed plots can be more difficult and costly to monitor and are also more likely to differ in other ways that can influence the outcome of the experiment (Gotelli and Ellison 2004). Further, wildlife responses to a restoration plot will always be influenced by the surrounding landscape, whether it's another experimental plot or land outside the study area that may be restored or unrestored; no field experiments take place in a vacuum. Thus, we recommend carefully considering how the landscape surrounding each plot might influence wildlife responses, such as by magnifying or minimizing the apparent effect of each treatment. Randomizing the assignment of each plot to a treatment can help by ensuring that treatments and controls are interspersed throughout the study area.

3. Determine How and When the Results Will Be Evaluated.

Perhaps the greatest objection to conducting an experiment such as we have outlined in the previous section is that any statistical analysis of the results will be invalid if any of the classical experimental design assumptions have been violated, and thus the experiment will have been a waste of time and resources. This closed-minded approach is preventing practitioners from attempting new or unconventional restoration methods and designs, in turn hindering advances in the field of ecological restoration, even as the need to develop climate-smart restoration methods continues to grow (Hobbs et al. 2009, Chornesky et al. 2015, Perry et al. 2015). Thus, we recommend practitioners and researchers discuss how and when the results of the experiment will be evaluated, consider the possible outcomes, and plan for the unexpected.

How. A conventional statistical approach would test a null hypothesis of no difference between restoration treatments, such as a simple t-test comparing the wildlife response metrics in treatment and control plots at the same point in time after the restoration. If the classical experimental design assumptions have been violated, such as due to a lack of replication or randomization among plots, the results of any significance test are meaningless (Hurlbert 1984). However, in most cases, null hypothesis testing will be less important than estimating the strength of evidence for an effect and the relative effect size of each restoration treatment (Stewart-Oaten et al. 1992, Fidler et al. 2006, Osenberg et al. 2006). For example, information-theoretic methods provide a way to evaluate the relative strength of support for alternative models with or without a treatment effect and model averaging (Burnham and Anderson 2002). Bayesian methods can be used to directly evaluate the probability of a particular effect size, and have been used to generate a better understanding of the impacts of logging on rainforest mammals (Crome et al. 1996), forest treatments on Spotted Owl productivity (Lee and Irwin 2005), and avian responses to prescribed fire (Russell et al. 2009). Strategies used to assess environmental impacts, which are neither replicated nor randomized, may also be useful, such as accounting for differences in baseline values by comparing the change in each plot before and after restoration (Wiens and Parker 1995).

When. Wildlife responses to restoration treatments may differ in the total magnitude of change, rate of change, persistence of the change over time, or all of the above (Figure 2), such that the results of the experiment may depend on when the results are evaluated. For example, it can take a decade or more for conditions at a restoration site to become suitable for certain species and the full magnitude of the change to be known (Gardali et al. 2006). Similarly, the ability of a site to withstand extreme weather conditions may require waiting for a number of years before those extreme conditions occur. Differences in the rate of change may be a useful initial indicator of relative effectiveness, if a faster response is likely to be correlated with a greater magnitude of change or achieving project goals more quickly, but these differences may not persist over time. Thus, depending on the objectives of the experiment and the time frame available for conducting the experiment, we recommend evaluating the selected wildlife response metrics for as long as possible to examine the trajectory of each plot and the long-term relative effect size of each treatment, and in turn build a more complete understanding of how the system works.

Consider the possible outcomes. With a better understanding of the relative effect size of each treatment and the strength of evidence for a difference between treatments, an important next step is to revisit the conceptual model linking restoration actions to changes in habitat conditions and subsequent wildlife responses (Figure 1). We recommend evaluating whether the sequence of events after restoration and resulting wildlife responses were consistent with the current understanding of how the system works. In a best case scenario, the restoration treatments will have resulted in large and obvious differences in habitat conditions and wildlife responses between plots, even before any analysis is conducted, successfully identifying what worked and what did not. Another successful outcome would be restoration treatments that produced similar habitat conditions and wildlife responses; with no clear winner, such an outcome would suggest that multiple restoration approaches are available to be added to the practitioner's toolbox, perhaps including ones that may be more cost-effective or use fewer resources and should be considered further.

Other more confusing outcomes include treatments that result in highly variable habitat conditions and wildlife responses across plots, suggesting there were other important environmental factors not considered by the experimental design, or outcomes that were entirely unexpected. For example, two different treatments could ultimately result in similar wildlife responses despite creating very different habitat conditions, or two different treatments could create apparently similar habitat conditions but result in very different wildlife responses. In either case, these results would suggest that the species' habitat requirements are not well understood. While these outcomes may be less desirable, at the very least, these outcomes would

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expose previously unrecognized uncertainties in the conceptual model and demonstrate a need to consider alternative restoration designs or methods.

Plan for the unexpected. As with any restoration project or field experiment, unexpected events or environmental variation can interfere. For example, extreme weather, fire, or flood could interfere with the ability to establish new vegetation, setting back the time table for the project. On the other hand, researchers and practitioners could take advantage of the opportunity to see how the different restoration methods fared under extreme conditions. If environmental conditions vary considerably between years, resulting in annual variation in wildlife responses, a comparison of the differences between treatments in each year can provide insight into whether one treatment consistently fares better than the other (Wiens and Parker 1995, Osenberg et al. 2006).

There are many other reasons why the restoration may not proceed as expected. For example, vegetation may not recruit quickly or survive as well as expected, such that the wildlife species of interest have not (yet) responded. In some cases, invasive plant or animal species may begin to recruit instead, with potentially long-lasting negative impacts. We recommend that researchers and practitioners plan for these scenarios, and identify conditions under which the experiment will be allowed to go on longer or trigger points at which the experiment will end to prevent harm. By working together from the start of the experimental design process through the implementation and evaluation phases, restoration practitioners and researchers can address these challenges proactively and creatively to maximize the experiment's chances of success.

Lower Cosumnes River Restoration as a Case Study

As an example of how these guidelines can be applied in the field, we describe our efforts to establish a restoration experiment in the Central Valley of California. Thirty years ago, the Cosumnes River was identified as a conservation and restoration priority in the Central Valley of California, USA, due to the presence of large blocks of remnant riparian forest and grassland in an otherwise agricultural and rapidly developing landscape (Swenson et al. 2003). Since then, nongovernmental conservation organizations and public agencies have worked together to protect and restore riparian forest. First established in 1987, the Cosumnes River Preserve now protects over 18,000 ha.

Riparian forest restoration efforts began with direct planting of native trees and shrubs into fallowed farm fields in an attempt to reconnect blocks of native riparian forests, but this expensive and time-consuming work often had limited success in this highly modified landscape with high levels of pressure from exotic invasive species (Swenson et al. 2012). However, investigation of the landscape, historical records, and photographs revealed instances where unintentional breaches in the river's levees had resulted in the development of diverse, early and late successional riparian forests, presumably due to enhanced floodplain connectivity. This discovery inspired a new era of using the Cosumnes River Preserve as a restoration and research platform to investigate the ecological and human benefits of enhancing hydrological process to restore ecosystem function and diversity.

1. Goals and Objectives

The Lower Cosumnes River Restoration Project, led by the Nature Conservancy (TNC), is enhancing floodplain hydrological processes on approximately 200 ha at the Cosumnes River Preserve, and is the largest levee-breach yet implemented on this river. The goal of this project is to restore riparian ecosystem function and diversity, with multiple benefits including providing habitat for riparian wildlife.

Species of interest. We expect that many species will benefit, but birds are recognized as good indicators of ecosystem condition (Temple and Wiens 1989, Carignan and Villard 2002, Ortega-Álvarez and Lindig-Cisneros 2012), and monitoring techniques are well-established and cost-effective (Ralph et al. 1993). Further, previous studies of riparian vegetation restoration in the Central Valley have documented an immediate increase in the abundance of common bird species and the return of previously absent species once the vegetation was established (Gardali et al. 2006, Dybala et al. 2014), suggesting that riparian birds will respond quickly once the vegetation becomes suitable. Thus, we chose to focus on a subset of riparian breeding bird species that have been identified by the Central Valley Joint Venture (CVJV; www.centralvalleyjointventure.org) as indicators of riparian ecosystem function (Table 1; Dybala et al. in press). These species were selected because they use riparian vegetation as a principal breeding habitat in the Central Valley and represent a range of life histories and specific vegetation associations (Table 1), providing information about different aspects of Central Valley riparian ecosystems.

Response metric that reflects project goals. Because our goal is to provide habitat for riparian wildlife, and we have selected focal species that breed in riparian habitat, our response metric of interest is the breeding density of each focal species. We will measure breeding densities by spot mapping birds that are exhibiting breeding behavior (e.g., singing or carrying nest material or food; Ralph et al. 1993). This method can measure the bird response at smaller scales and with greater precision than the more common point count technique, and allows collecting information about the density and distribution of territories on each plot.

Definition of successful response. We defined success as breeding densities for all 6 riparian focal species increasing from the pre-restoration baseline of 0 breeding territories (Dettling and Seavy 2011) to territory densities that are equivalent to or higher than current average breeding densities in riparian vegetation throughout the region within 10 years of implementation (Table 1; Dybala et al. in press).

Objectives of the experiment. We expect that successfully restoring a diverse riparian vegetation community will in turn support an abundant riparian breeding bird community, meeting the objectives and goals of the project (Figure 1). However, the key uncertainty we identified is whether it is necessary to invest substantial resources in traditional, horticultural restoration (i.e. manually planting native vegetation, irrigation, and weed management) on top of the process-based restoration (i.e. increasing floodplain connectivity and frequency of inundation; Beechie et al. 2010), or whether a reduced effort could be just as effective. Where hydrological processes are limited, intensive horticultural restoration practices may generally be more effective in establishing riparian vegetation and achieving the desired wildlife response, compared to a relatively low effort horticultural restoration that relies more on natural recruitment but may be vulnerable to invasion by exotic species. However, we hypothesized that enhancing hydrological processes would improve the effectiveness of reduced effort horticultural restoration due to sediment deposition, seed dispersal and groundwater recharge (Florsheim & Mount 2003; Opperman 2012).

To test this hypothesis, we designed a restoration experiment with the objective of evaluating the effectiveness of different levels of horticultural restoration effort in increasing riparian breeding bird abundance across a gradient of floodplain connectivity. We predict that where floodplain connectivity is high, reduced effort horticultural restoration will result in an equal (or improved) riparian breeding bird densities yet cost less and require fewer resources (e.g., water for irrigation) than high effort horticultural restoration practices.

2. Experimental Design

Restoration treatments and controls. To examine the bird responses to additional horticultural restoration effort on top of the process-based restoration, we defined 3 experimental groups including 2 scenarios of horticultural restoration effort and control plots with no horticultural restoration effort:

1. High effort, representative of many river restoration projects in North America, including a structurally diverse planting palette and irrigation of native plantings;
2. Reduced effort, including the planting of native trees only; and
3. Control plots, which will go unplanted.

These 3 groups allow us to compare the bird response between high and reduced effort scenarios of horticultural restoration, as well whether either of these groups is different from the control plots.

Study area and blocks. Within the 200 ha project area, we selected 120 ha of former agricultural land along the Cosumnes River as the study area for the experiment (Figure 4). Because we expect the bird response in each type of plot to vary with the degree of floodplain inundation, we took advantage of a natural gradient of topography and floodplain connectivity in the study area and organized the study area into 3 blocks representing the degree of floodplain connectivity.

Minimum plot size. To estimate the minimum plot size necessary for each of the six focal species, we again drew on current regional average densities in riparian vegetation in the Central Valley (Table 1; Dybala et al. in press). Densities ranged from 0.34 to 5.35 birds/ha, and assuming two individuals per territory, we estimated that 10 ha plots could support between 1.70 and 26.75 territories of each focal species. Thus, we chose to aim for 12 plots that were approximately 10 ha in size, with 4 plots in each of the 3 blocks.

Compromises. For convenience, we used existing boundaries (e.g. roads or irrigation ditches) to divide the 120 ha study area into 12 plots (Figure 4), which resulted in some variation in plot size. Initially, all of the plots were over 9 ha, but hydrogeomorphology monitoring close to the streambed ultimately required excluding a portion of the study area, and two plots were reduced to approximately 7 ha. Although we would have preferred larger plots, all plots were above the minimum of 6 ha recommended for Breeding Bird Census plots (15 acres; Hall 1964).

We also recognized that the plots are adjacent to each other, such that neighboring plots could influence an individual bird's habitat selection decisions. As a result, the differences in breeding densities among plots could either be exaggerated if one plot type is consistently preferred over the other adjacent plots (Gotelli and Ellison 2004), or underestimated if birds establishing territories in the preferred plot attract additional birds whose territories spill over into adjacent plots. However, the random assignment of treatments to plots ensures that treatments are interspersed (Figure 4), and we expect that our territory mapping and behavioral observations will allow us to detect if either of these cases is happening. The alternatives would be to: (1) greatly reduce the plot sizes to create space between plots, which would severely limit the number of territories that could be established in each plot and likely still would not ensure independence between plots; (2) attempt to establish widely dispersed and isolated plots, which would likely be more heterogeneous and could still be influenced by the surrounding agricultural matrix; or (3) simply not conduct an experiment and guarantee learning nothing new. We felt that none of these alternatives were acceptable, and that this experiment would still provide valuable insights into the relative effectiveness of the restoration treatments, *despite* the potential lack of independence between plots.

3. Evaluating Results

How. To evaluate the response of each focal species, we will map breeding territories across the study area and quantify the territory density of each focal species in each plot (territories/ha). Using the territory density of each species as a response variable, we can use generalized linear models with an information-theoretic approach to evaluate the weight of evidence for differences among treatments. By quantifying and incorporating the actual number of days each plot is inundated as a covariate, we can also examine the influence of floodplain connectivity.

When. We anticipate that our results will initially vary among species, as well as over time. While we expect an immediate response from several of the focal species that are associated with early successional riparian vegetation (i.e., within 3 years), it will take more time for the area to become suitable for species associated with mature trees (Gardali et al. 2006). Early results may be an important indication of whether or not all treatments are on a desirable trajectory, and thus whether the experiment should continue, while continued monitoring will reveal the full value of each treatment for each species. The analysis will be repeated over time to re-evaluate the total magnitude, rate, and persistence of change in plots of each treatment type, as well as whether the bird response to high and reduced effort treatments are converging.

Possible outcomes. The results of the Cosumnes River experiment will help evaluate how much planting effort is necessary to achieve the desired outcome for riparian bird populations. Based on our understanding of the rate of riparian vegetation growth and riparian bird responses, we expect that 5 years after restoration focal species in the high effort plots will have achieved densities >75% of the regional average densities (Table 1), while focal species in the reduced effort and control plots will reach densities of <50% and <10% of regional average densities, respectively (Figure 3). However, if wildlife responses to the reduced effort treatment are relatively similar to the high effort treatment (e.g., >50% of regional average densities after 5 years and still increasing), this experiment may identify an alternative, more cost-effective option for riparian restoration. If wildlife responses vary with floodplain connectivity, it will illuminate the role of this connectivity and flooding in the success of restoration. Otherwise, it will contribute scientific evidence for the necessity of traditional, high effort planting, even where floodplain connectivity is high.

Conclusions

Nobody likes to fail, and when we consider how easy it is to sling arrows at large-scale restoration experiments, it’s not surprising that relatively few examples exist. Conducting restoration experiments on spatial and temporal scales relevant for wildlife is challenging but not impossible, and these experiments are very likely to generate new insights into effective restoration methods and designs. Identifying effective methods that will persist under climate change is becoming increasingly important, and is likely to require experimenting with new and unconventional methods. By addressing the logistical challenges and fear of failure, we intend for the recommendations and examples presented here to facilitate collaborations between researchers and practitioners and accelerate the rate of relatively large-scale, long-term restoration experimentation. By addressing key uncertainties, such experiments will demonstrate the relative effectiveness of alternative methods, in turn helping restoration practitioners choose the best course of action, accelerating the rate of successful restoration, and advancing the field of ecology restoration.

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Table 1. Riparian bird focal species life history traits, vegetation associations, regional average density estimates, and the resulting expected number of territories per 10 ha plot.

Species	**Migratory status**	**Nest substrate**	**Habitat & vegetation associations**	**Regional average density (individuals/ha)**[a]	**Expected territories per 10 ha plot**
Nuttall's Woodpecker (*Picoides nuttallii*)	Resident	Tree, 1° cavity	Mature riparian woodland	1.34 (1.10-1.64)	6.70 (5.50-8.20)
Ash-throated Flycatcher (*Myiarchus cinerascens*)	Resident	Tree, 2° cavity	Mature, open riparian woodland	2.14 (1.76-2.59)	10.70 (8.80-12.95)
Common Yellowthroat (*Geothlypis trichas*)	Migrant	Herb, Shrub	Dense understory and ground cover, esp. near river edges and wetlands	0.34 (0.24-0.49)	1.70 (1.20-2.45)
Spotted Towhee (*Pipilo maculatus*)	Resident	Ground	Dense understory and ground cover	5.35 (4.56-6.29)	26.75 (22.80-31.45)
Song Sparrow (*Melospiza melodia*)	Resident	Herb, Shrub	Dense understory	3.33 (2.65-4.20)	16.65 (13.25-21.00)
Black-headed Grosbeak (*Pheucticus melanocephalus*)	Migrant	Tree	Complex habitat with large trees and dense understory	0.81 (0.63, 1.04)	4.05 (3.15-5.20)

[a] Average density estimates for the Delta planning region of the Central Valley Joint Venture (Dybala et al. n.d. in press).

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Figure 1. Conceptual model for the lower Cosumnes River restoration project. Boxes represent different phases of vegetation, and arrows represent the ecosystem processes (solid) or management actions (dashed) that facilitate transitions between phases. The levee breach along the Cosumnes River has enhanced floodplain connectivity and the ecosystem processes facilitating the transition from bare ground to diverse riparian vegetation, which is the phase during which riparian bird density is expected to be highest. In the absence of these ecosystem processes, horticultural restoration is essential to establishing diverse riparian vegetation, but in the presence of these ecosystem processes, the effectiveness of investing in additional horticultural restoration is uncertain.

Figure 2. Potential differences in wildlife responses to two alternative restoration treatments. A) Treatments do not differ in rate of response, but in total magnitude of wildlife response. B) Treatments differ in rate but not total magnitude of wildlife response. C) Treatments do not differ in initial rate or magnitude of response, but in persistence and variance of the response over time. In all 3 cases, we assume control plots show no change in wildlife response metric over time.

Figure 3. Hypothesized responses of breeding bird densities to the Lower Cosumnes River restoration experiment: high effort (solid), reduced effort (dashed), and control (dotted), in comparison to regional average densities (horizontal line). After 5 years, we hypothesize that after 5 years, plots in the high treatment will have reached >75% of average densities, while plots in the reduced and control treatment plots will have densities <50% and <10% of regional average densities, respectively.

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Figure 4. Lower Cosumnes River Restoration experimental study area, showing restoration treatments, blocks, and plot sizes (ha). The Cosumnes River flows north to south.

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Figure 1

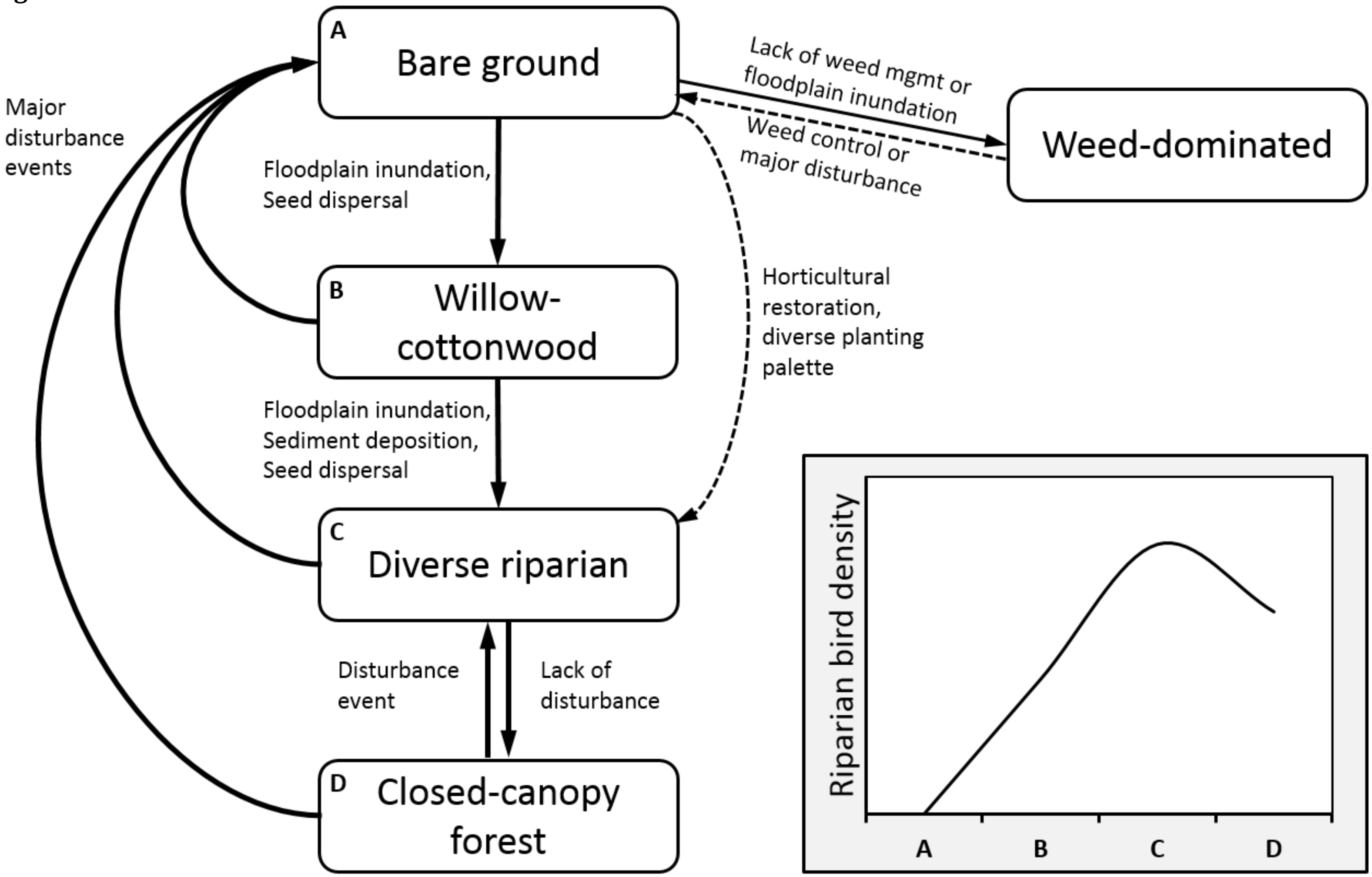

A
Bare ground
Major disturbance events
Floodplain inundation, Seed dispersal
Lack of weed mgmt or floodplain inundation
Weed control or major disturbance
Weed-dominated
B
Willow-cottonwood
Horticultural restoration, diverse planting palette
Floodplain inundation, Sediment deposition, Seed dispersal
C
Diverse riparian
Disturbance event
Lack of disturbance
D
Closed-canopy forest
Riparian bird density
A
B
C
D

Figure 2

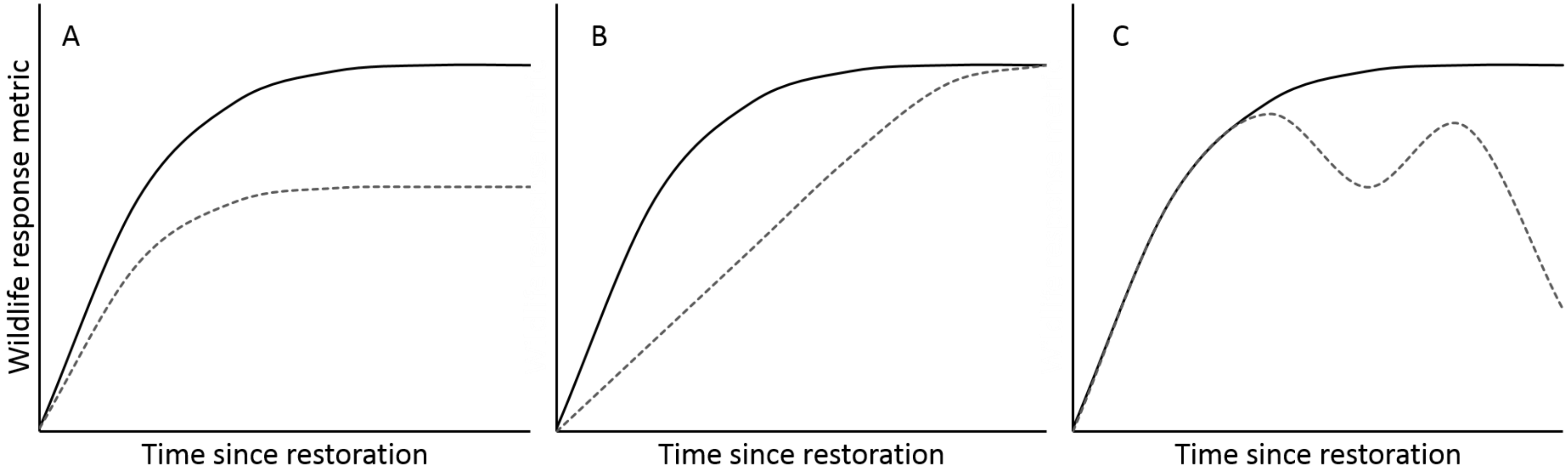
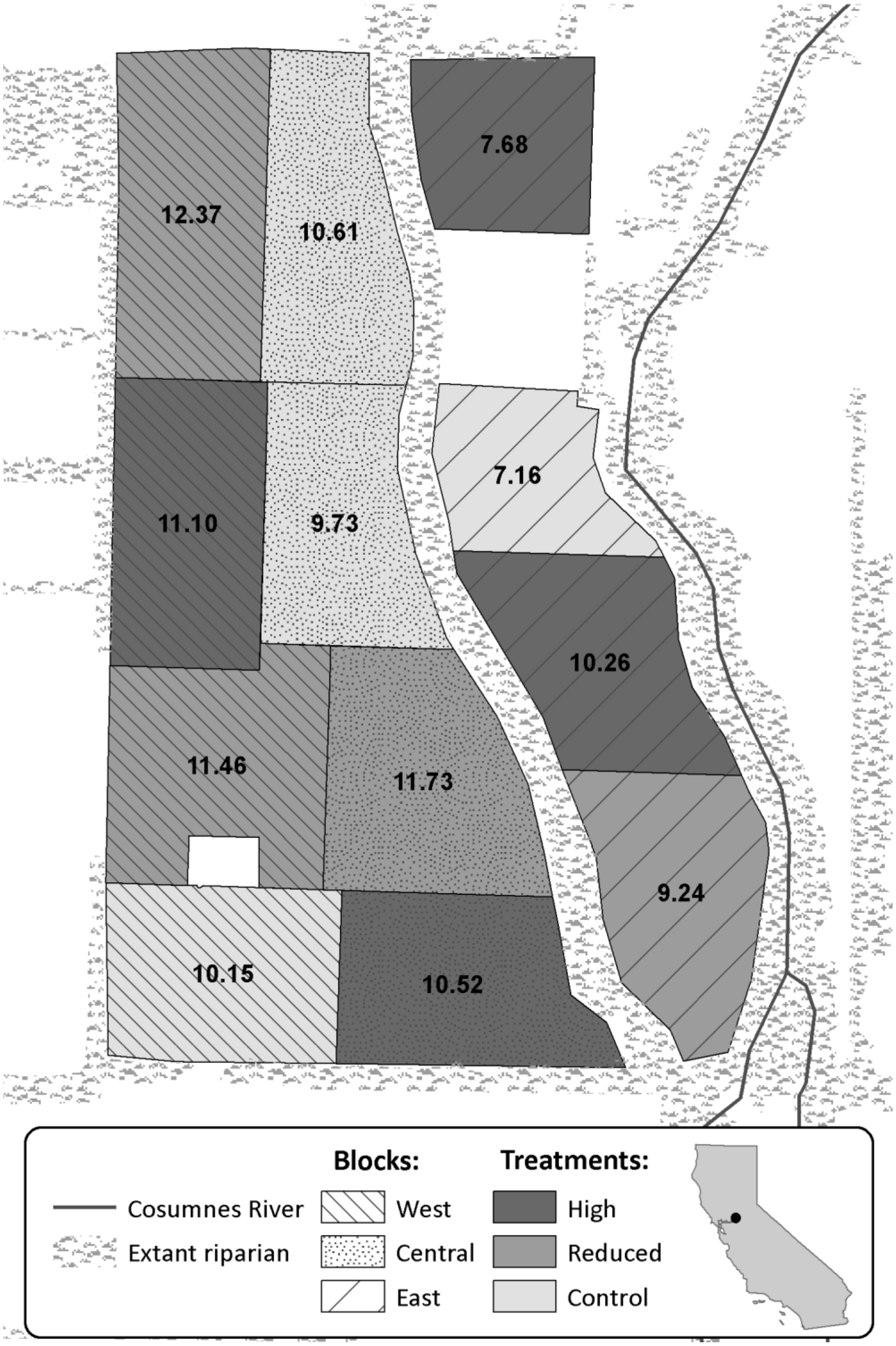

A
B
C
Wildlife response metric
Time since restoration
Time since restoration
Time since restoration

Figure 3

Figure 4


12.37
10.61
7.68
11.10
9.73
7.16
10.26
11.46
11.73
9.24
10.15
10.52
Cosumnes River
Extant riparian
Blocks:
West
Central
East
Treatments:
High
Reduced
Control