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ORIGINAL PAPER

Controlling mosquitoes through innovative and collaborative wetland management practices in the Pacific Northwest

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Abstract When developing a plan to restore or modify a wetland within the Pacific Northwest of the United States (PNW), land managers must consider all of the potential ecological impacts, including the unintended production of mosquitoes which can adversely impact the health of people and wildlife in the area. Case studies in this article highlight mitigation activities conducted in cooperation with local mosquito control professionals for water conveyances in the states of Washington and Oregon that effectively minimize production of mosquitoes in managed wetlands. Communicating with mosquito control professionals early in the wetland restoration planning process can save valuable time and resources if the restored wetland becomes an ideal breeding site for pestiferous mosquitoes. By preventing unintentional mosquito production, resources that would be spent controlling mosquitoes and responding to public health concerns post restoration could be redirected towards achieving the overall mission of the wetland restoration. The authors will demonstrate how mosquito control professionals and wetland managers worked cooperatively to achieve mutually-beneficial results, while complying with all local, state, and federal regulations. The following broad steps for a wetland restoration project are recommended: (1) Create a long-term vision for the project; (2) Build a team of collaborators and gather stakeholders; (3) Outline the regulatory guidelines; (4) Prepare required planning documents/acquire permits; (5) Conduct project, while monitoring (target and non-target) impacts including mosquitoes; and (6) Periodically review environmental impacts.

Keywords Wetland restoration · Wetland regulation · Habitat conservation · Mosquito control · Water control structure

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Introduction/Background

The rapid loss of wetlands to agriculture and urban development is depleting the potential ecosystem services that they provide (Ramos 2018). Ditching of

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wetlands and coastal marshes, primarily to control mosquitoes, has been practiced on Atlantic coastal salt marshes since the early 1900s (Rozsa 1995; Sebold 1992). Up to 95% of Atlantic coastal salt marshes were ditched in the first half of the twentieth century (Clarke et al. 1984; Crain et al. 2009), causing permanent habitat alterations, the effects of which are still being remediated in the landscape today. Historically, ditching to control mosquito populations sought to drain the marsh of pooled waters where mosquito larvae develop and allowed foraging fish to feed on mosquito larvae during high tides (Stearns and MacCreary 1936). However, excessive ditching has negative impacts on the salt marsh ecosystems due to lower water tables, altering the natural vegetation communities, and decreasing fish use and other wildlife on the marsh (Bourn and Cottam 1950; Clarke et al. 1984; Wolfe 1996). By the late 1960s in these Atlantic coastal marshes, land managers began implementing Open Marsh Water Management (OMWM) plans to restore salt marshes (Ferrigno and Jobbins 1968) to more natural conditions. OMWM plans are advantageous because they consist of alterations to the marsh that allow for increased tidal flow and water retention in the existing mosquito ditches or create new pools and ponds that promote suitable habitat for wildlife and safe harborage for larvivorous fishes (Meredith et al. 1985; Wolfe 1996). These approaches, now broadly used in restoration projects on the east coast, are rarely seen in western marsh management programs.

The data gaps between wetland management and mosquito control were documented in the review conducted by P. E. R. Dale (2008), yet there is still a need for best management practices for mosquito control. The need for improved public health infrastructure and data modernization in the United States is a primary goal for public health organizations (TFAH 2019). As the United States works to improve the National Public Health Framework for the Prevention and Control of Vector-Borne Diseases in Humans, the resources referenced in this paper are currently available (CDC 2020).

Most mosquito control programs in the United States are funded by local property taxes or assessments, with 68% of them reporting that they "need improvement" (Gridley-Smith 2017). Also, many areas of the United States do not have any organized mosquito control districts. In the absence of sustained funding for mosquito surveillance and control, local health jurisdictions and land managers are not aware of the many mosquito species present in their area or their threats to public health. Consequently, the vector control education provided to the public can often lack local reference. While public education is a key component of Integrated Mosquito Management (Barker et al. 2017), the concept that mosquito-borne diseases can be controlled simply by encouraging the public to empty standing water on their property overlooks the fact that many disease-carrying mosquitoes can develop in large areas of standing water, such as wetlands, often publicly owned. Source reduction campaigns may be impactful in controlling *Aedes aegypti*, the primary vector of yellow fever and dengue because it is an urban, container-breeding mosquito (Barker et al. 2017); however, *Culex* species mosquitoes that transmit West Nile virus can be found in large bodies of water adjacent to neighborhoods and therefore require organized larviciding efforts to achieve adequate control. Correspondingly, there are many species, e.g., *Aedes dorsalis*, which can emerge from salt marshes and other wetlands in numbers so great that personal protection measures and avoidance are not a feasible option for surrounding communities. Where the need is identified, organized mosquito control programs provide essential public health infrastructure between disease epidemics (Connelly et al. 2020), and can work with local land managers to ensure local wetlands do not produce these immense numbers of mosquitoes.

Approach

The authors conducted a search for wetland restoration projects in the PNW that involved cooperative agreements with mosquito control professionals. The states selected for study are in Legacy Region 1 of the United States Fish and Wildlife Service (USFWS) Refuge System (*States/Territories:* Hawaii, Idaho, Oregon, Washington, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, and the Pacific Trust Territories). Based on previous unpublished work conducted by the primary author, mosquito control in the U.S. territories is fractured with limited control efforts and collaboration, but the states of Idaho, Oregon, and Washington have a reliable infrastructure of mosquito control programs and professional associations. All mosquito control programs work with a variety of land owners (private, local government, state, tribal and federal), but the scope of the paper was further narrowed to locations that had completed a voluntary wetland restoration project in the last 10 years, with mosquito monitoring data from before and after the completion of the projects. The authors then conducted a series of telephone, teleconference, in-person and email conversations with land managers, project engineers, and regulators. In order to create a comparison of the case studies, the authors compiled a set of questions related to site history, restoration mission, planning, regulatory compliance, results, and lessons learned. The next step included data collection and analysis for trends in mosquito surveillance. Finally, the authors compiled regulatory guidance and resources to support land managers and mosquito control professionals in project planning.

Case study 1—The Ni-les'tun Unit of Bandon Marsh National Wildlife Refuge in Coos County, Oregon

Bandon Marsh National Wildlife Refuge in Coos County, Oregon was established in 1983 to protect the last of the naturally occurring tidal marsh in the Coquille River estuary. In 2000, the Ni-les'tun Unit of the refuge was established to restore and protect intertidal marsh, freshwater marsh, and riparian areas to provide a diversity of habitats for migratory birds including waterfowl, shorebirds, wading birds, and songbirds, and to restore the intertidal marsh habitat for anadromous fish, such as Chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*) salmon, steelhead (*Oncorhynchus mykiss*), coastal cutthroat trout (*Oncorhynchus clarki clarki*), and the threatened coho salmon (*Oncorhynchus kisutch*) (USFWS 2013). Over a century ago, the Ni-les'tun Unit, totaling 418 acres, was diked, ditched, fenced, and tide gated during conversion for agricultural purposes (Bridgeland et al. 2017). In 2010, after a decade of planning, land acquisition, scientific study, and extensive engineering design, USFWS, along with many partners, embarked on a mission to conduct the largest tidal wetland restoration project the PNW had ever seen.

The project was a success in many ways. Seeing wildlife return to the marsh and flourish brought jubilation to wetland managers and members of the Coquille Indian Tribe (Oregon Coast National Wildlife Refuge Complex Staff 2011). However, there was a side effect. During the restoration process, shallow straight line drainage ditches on the property were disced or filled to obliterate their function and appearance. While the discing served to remove the ditches from the landscape, it created a series of small, disconnected depressions that filled with tidewater on unusually high tides and were not capable of draining naturally to the primary channels (Bridgeland et al. 2017). Within two years, it became apparent that this disruption in the drainage of the restoration area created an ideal habitat for *Aedes dorsalis*, commonly known as the salt marsh mosquito. Beginning in 2012, the year prior to the completion of the restoration project, calls from neighboring property owners began to come in complaining about an increase in adult mosquitoes in the area. By the next summer, the salt marsh mosquito population flourished, with surveys finding significantly high numbers of mosquitoes, triggering a health advisory to the local community from the Coos County Public Health Director (Bridgeland et al. 2017). In addition, during August 2013, the City of Bandon issued Resolution 13–21 demanding that the USFWS address the problem that the restoration caused. Experts from multiple agencies, organizations, and universities were brought to the refuge to assess the situation. Sampling revealed very high numbers of larval mosquitoes in the undrained pools throughout the restoration area and on neighboring properties. A well-managed marsh may have some mosquito larvae production, but ideally a 4-oz water sample should contain no more than 0–50 larvae and the marsh would not be contributing significantly to adult mosquito populations in the surrounding area (pers. comm., Dr. Daniel Markowski 2020). In 2013, 4-oz water samples at Bandon Marsh National Wildlife Refuge contained larval densities so dense that individual larvae could not be visually counted in the sample cup, indicating hundreds of larvae in each sample and contributing greatly to an unacceptable level of adult mosquitoes in the area. In fact, it was readily apparent that larval mosquito production on the Refuge far exceeded densities that might be considered tolerable (Leisnham and Sandoval-Mohapatra 2011; James-Pirri et al. 2009). Even at relatively low population thresholds the predominant species present, *Ae. dorsalis*, can be a severe nuisance pest and, if left unchecked, mosquito populations resultant from salt marshes can become involved in local arboviral transmission cycles (Rochlin et al. 2009).

Mosquito management activities on national wildlife refuges are generally accomplished by local or county mosquito abatement programs or vector control districts through Special Use Permits. However, there was no mosquito or vector control district in Coos County where the Refuge is located. The community surrounding the Refuge, the City of Bandon, a popular tourist destination known for its highly-acclaimed golf courses, was inundated with voracious adult mosquitoes. USFWS received numerous calls, emails, and letters concerning unprecedented levels of biting mosquitoes and associated health impacts. This public outcry resulted in the August 22, 2013, Coos County Public Health Advisory and the subsequent refuge-based Emergency Declaration, due to excessive numbers of mosquitoes being produced on the Refuge and impacting the health and well-being of local residents. These emergency actions allowed the Refuge to work with Coos County Public Health (CCPH) in an effort to protect the public by reducing mosquito production on the Ni-les'tun Unit (USFWS 2014d).

In 2014, the Refuge along with CCPH, began its mosquito abatement and management program, employing a variety of techniques to resolve the issue with the goal of maintaining a healthy wetland while implementing low-risk mosquito management strategies deemed safe for fish and wildlife utilizing the restored marsh as well as to humans visiting the Refuge. It is important to note the need for flexibility while designing mosquito management plans for environmentally sensitive areas, such as the Ni-les'tun Unit. Although the number of adult mosquitoes had reached unbearable levels, the use of broad spectrum adulticide applications was not a feasible alternative. Hence, a program consisting of intensive site monitoring was initiated to identify all areas producing larval mosquitoes. CCPH contracted the services of Vector Disease Control International (VDCI) to monitor and control larvae breeding on the marsh with the larvicide *Bacillus thuringiensis* subspecies *israelensis* (Bti). These ground applications of Bti were implemented to prevent future broods from developing while USFWS, simultaneously, used the surveillance data to install 20 miles of new channels designed to connect these breeding sites to the previously-restored primary channels. These secondary channels effectively drained the mosquito development pools without hindering the overall goals of the restoration project. The strategies adopted were labor-intensive and required patience by the public and restoration officials; however, the long-term benefits have proven worthwhile.

After assisting with monitoring and managing the mosquito issues on the marsh for two years while the additional channels were created, VDCI and USFWS deemed the mosquito issue resolved after the 2016 season. A Mosquito Action Plan was developed in 2017 (USFWS 2017); this plan was sustainable within the Refuge budget, and ensured that mosquito monitoring would continue in perpetuity and that control interventions be employed as necessary by the current and future Refuge Managers. Since 2017, Refuge staff has monitored larval mosquito populations and channel integrity on the property to ensure the restoration activities remain successful and are not producing excessive mosquito populations. As a part of their plan, they periodically contract with VDCI for an independent perspective. In 2020, standard larval mosquito dip procedures were used to collect mosquito samples by VDCI at 120 test sites on the refuge, of which 81 sites had no presence of larvae while only six sites had more than fifty per dip (USFWS 2021a; VDCI 2020).

In addition to the response to the mosquito issue, the marsh restoration was carefully studied from beginning to end including intensive biological monitoring of the site beginning 2 years prior and wrapping up four years post-restoration. This included studying the presence of wildlife, primarily fish, birds, and herps, vegetation and soil surveys as well as water quality testing and saltmarsh elevation measurements. All ecological parameters measured on the site before and after the restoration were measured on comparable areas of the Bandon Marsh Unit, which provided a reference crucial for evaluating how different the site was before the restoration, as well as the degree to which the restored site functioned as a natural tidal marsh (Bridgeland et al. 2017). In 2020, the restoration effectiveness monitoring continued through a project led by researchers associated with Oregon State University, the Confederated Tribes of the Siletz Indians, and the Institute for Applied Ecology and funded by the Oregon Watershed Enhancement Board. Despite this intensive biological monitoring, the mosquito issue was not anticipated prior to restoration.

This was an immense oversight and proves as a warning for future restoration works of this kind. Currently, the refuge complex is planning smaller restoration projects in other areas of the Oregon Coast National Wildlife Refuge Complex and mosquito monitoring has become a required component of the pre- and post-restoration monitoring.

The regulatory approval process for mosquito control on the refuge included ongoing coordination with CCPH and incorporated appropriate USFWS policy related to addressing mosquito issues on National Wildlife Refuges (USFWS 2014b). The USFWS did not have a national mosquito policy at the time of the project, but has since released a Handbook for Mosquito Management on National Wildlife Refuges in 2018, which was developed with input from mosquito control professionals (USFWS 2018).

The planning process is documented in the Environmental Assessment for unit restoration (USFWS 2009), the Draft Plan and Environmental Assessment for Mosquito Control for Bandon Marsh National Wildlife Refuge, and the lessons learned document (Bridgeland et al. 2017). No final Environmental Assessment was issued for mosquito control due to a Finding of No Significant Impact (USFWS 2014a, 2014c).

The total cost of the restoration, including the ancillary infrastructure projects, efficacy monitoring, and mosquito management was $11,794,158 procured from a variety of sources. Of this, the restoration construction and monitoring cost $3,467,155 and developing and implementing the mosquito plan cost $1,035,456 (Bridgeland et al. 2017). In most years since the issue was deemed resolved in 2016, the mosquitoes on the marsh have been monitored by Refuge staff and interns at the cost of their salary for approximately 40 h a summer. In 2020, the contract with VDCI was implemented to provide an unbiased and professional assessment of the mosquito production of the marsh and totaled only $3950. The Refuge Manager, Kate Iaquinto, has become a resource for regional land managers, instructing them on how to monitor for mosquito infestations and sharing lessons learned.

Though it is not possible to quantify the economic effect of the mosquito infestations between 2012 and 2015, it had a serious impact on the community. The mayor of Bandon, Mary Schermerhorn commented to a local newspaper regarding summer residents, "They've basically been held hostage this summer and kept in their homes. It's a huge problem." In the same article, it was reported that Bandon Dunes Golf Resort applied insecticide to their golf courses for the first time in 14 years. Refuge staff, working on-site in 2013 recalled visible clouds of adult mosquitoes flushing out of the lawn near the Refuge office on nice days in summer and reported it was unbearable to spend time outside. Given that the maximum flight distance of *Aedes dorsalis* is estimated at 20 miles (VDCI 2020), the economic, political, and biological impacts to the surrounding area left an impression that is still observable in the community today despite the current low mosquito production on Bandon Marsh.

The lesson learned from the Ni-les'tun Unit restoration project was to avoid creating tide pools at elevations above the average weekly high tide mark and below the monthly high tides. In these areas, the pools were periodically flooded and then abandoned by daily or sometimes weekly tidal exchange. Generally, if there is any aspect of the site or the implementation of the restoration plan that results in features not previously found in the system that is the target of the restoration, make the effort to involve relevant experts outside of the design team for review and commentary on the plan details, including experts in local mosquito species bionomics. As a further step, mosquito monitoring should be included in the plans for any wetland restoration project, so ecological impacts can be forecasted and alleviated prior to excessive mosquito production (Bridgeland et al. 2017).

Case study 2—The Barker Ranch in Benton County, Washington

Purchased in 1994, the Barker Ranch (TBR) is a 2000-acre duck hunting club in the process of a multi-year restoration project to enhance wetland and upland areas for ducks, geese, cranes, upland birds, and other wildlife species. It is situated along the Yakima River near West Richland, Washington, and is within the Benton County Mosquito Control District (BCMCD). The land that is now TBR has been farmed and ranched since the late 1880's. When purchased, it consisted of antiquated irrigation ditches and water control structures. A succession of four perpetual

Wetland Reserve Program (WRP) easements have been established on parts of the Barker Ranch which led to extensive long-term management planning and restoration work with the United States Department of Agriculture's Natural Resources Conservation Service (NRCS).

Beginning in 2003, a series of restoration projects have greatly improved water delivery and use on TBR. This work was funded by TBR, along with partners such as NRCS, Ducks Unlimited, Washington Department of Ecology, Washington State Conservation Commission, Benton Conservation District, and others. All restoration project work has been either designed and/or approved by NRCS engineers to gain much-improved irrigation efficiencies through new water control structures, culverts, cleaning out and regaining the proper slope and grade on irrigation ditches, etc. To date, there have been approximately 150 water control structures replaced or installed, over three miles of open ditches converted to underground pipe, and over 10 miles of irrigation ditches cleaned, sloped, and graded to achieve better irrigation efficiency and/or water control.

Updated water control structures and irrigation ditches greatly enhance the ability to flood moist soil units more efficiently, as well as remove the water more efficiently to the next unit. Being able to drain the standing water in moist soil units, yet still achieve the moisture level in the soil, is critical to achieving habitat goals and minimizing the production of mosquitoes.

The project to replace over three miles of antiquated open ditch with an automated closed-pipe system was a means of converting a leaky, more-than-a-century-old irrigation ditch that was terribly inefficient into a state-of-the-art, fully-efficient automated water delivery pipeline for TBR. In addition to the piping project, an automation system was concurrently installed. This automation system interconnected all of the water delivery gates that feed water from the Yakima River to TBR and allowed the gates to auto-adjust and maintain a predetermined target flow of water. These automated gates allow land managers to divert a precise amount of water that was needed at any given time. Furthermore, the water levels can be changed at any time from a cell phone or a computer. It has alarms if gates are plugged or if other problems are detected.

The success of the habitat restoration and management is evident by the large numbers of waterfowl, cranes, and other wildlife that occupy TBR each year. What is undetermined, yet anecdotally known to the residents of the community surrounding TBR and to the BCMCD, is that the longstanding coordination between TBR and the BCMCD has significantly reduced mosquito production. "The key to making this work is communication between TBR staff and BCMCD field staff,'' Michael Crowder, land manager of TBR, said. Talking on a regular basis about problem areas of mosquito breeding helped TBR staff, but also letting the BCMCD staff know plans on upcoming irrigation cycles helped them do their job more effectively. It is a night and day difference from a decade ago in the number of mosquitos. Certainly, there are times of mosquitoes, but nowhere near what they used to be before we had better water control and better communication between mosquito control staff.

Prior to the wetland enhancement project on the TBR, large areas of moist soil units, pastureland, and waterfowl habitat had to be treated with larvicides before the larvae metamorphosed into the adult life stage. Since the dramatic improvements in water control have been installed and irrigation water can be applied and removed much more precisely, mosquito control staff communicate directly with TBR staff to keep them informed regarding mosquito production. If ponds producing mosquito larvae are identified, adjustment can be made to irrigation cycles or water flows. In most cases, this collaboration is successful in eliminating the mosquito habitat. If not eliminated, the site can be dramatically reduced in size, so the area that necessitates larviciding is minimized. The combination of the piping project and automated delivery system and the updated water control structures on TBR has reduced the number of days water is allowed to stand in some locations by as much as three days. The mosquito control program is now able to use products that continue to provide control through wet/dry cycles. These products are more expensive, but they require less labor due to fewer treatments and inspections.

Since 2009, BCMCD has been able to reduce the number of full-time, seasonal mosquito control staff assigned to monitor TBR from four to two. By communicating with the land manager, mosquito control knows where the water will persist long enough to produce adult mosquitoes, and can target these areas. This efficient larviciding and water management has reduced the need to conduct wide-area adult mosquito control on TBR. This is significant because modern larviciding treatments are associated with fewer ecological risks than adult control methods.

The BCMCD has been monitoring mosquito production on TBR lands since the District's inception. The level of monitoring and methods of data entry have varied over the years, making it difficult to demonstrate pre- and post-project mosquito population fluctuations.

High numbers of mosquitoes can develop in standing water as a result of flood irrigation (Pratt and Moore 1993), as referenced in Washington State Department of Ecology's Best Management Practices for Mosquito Control (DOE 2004), recommended the following actions to eliminate mosquito breeding sites by using physical controls, which TBR has effectively implemented:

(1) Minimize standing water in fields so that it does not stand stagnant for more than four days by improving drainage channels and grading.
(2) Tailwaters should not be allowed to accumulate for more than four days at the end of the field.
(3) Keep excessive overgrown vegetation out of ditches to promote more rapid drainage, but retain ground cover to prevent soil loss.
(4) Have ditches repaired to reduce seepage to the extent practicable (elevated water tables can produce unintended standing water in fields). Modification or repairs to a ditch should not reduce the carrying capacity.
(5) Minimize flood and rill irrigation practices to the extent practicable.
(6) Avoid over-watering.

Results

Although they are vastly different wetland types there are many similarities between the two case studies. Prior to restoration efforts, both Bandon Marsh and TBR used primitive tide gates to control water and provide flood irrigation for agriculture. Both restorations utilized innovative methods of water conveyances to conserve resources and provide habitat for waterfowl and fish. Each wetland has a federal nexus and a positive impact on federally-listed threatened and/or endangered species of salmonids. Both created *Aedes* species mosquito habitat within close proximity to human population centers. With additional planning, time, and resources they were able to minimize mosquito production while still providing high-quality habitat for multiple aquatic organisms while also minimizing adverse impacts to non-target organisms. Post-project mosquito monitoring indicates that the level of mosquito development on the wetlands is minimal. Complete pre- and post-project mosquito monitoring data would be required to provide an accurate statistical analysis. Unfortunately, in these wetlands, the mosquito monitoring was primarily conducted to make operational pesticide treatment decisions, not to measure changes in mosquito production directly related to the water management techniques applied.

Neither the USFWS nor the owners of TBR were required to cooperate with local mosquito control offices in these cases. Monitoring for mosquito larvae and reducing the number of days that open water is allowed to stagnate on the wetlands takes time and resources. However, these wetland managers recognized the importance of being good neighbors and preventing public health threats caused by large numbers of mosquitoes.

Wetlands serve an important function in the PNW. Land managers working in unison with mosquito control programs can create thriving wetlands without increasing the risk of mosquito-borne illness or adverse impacts for wildlife and surrounding human populations resulting from intense nuisance biting mosquitoes. There are differing regulations for each state depending upon the scope and purpose of the work, owner of the land, how the project is funded, and who is conducting the work. Some regulatory hurdles may deter land managers from initiating a project, but if done correctly, a well-planned water conveyance project will save time and resources in the future, while creating habitat for beneficial organisms. The subsequent procedures are recommended: (1) Create a long-term plan; (2) Build a team of collaborators & gather stakeholders; (3) Outline the regulatory guidelines; (4) Prepare required planning documents/acquire permits; (5) Conduct project, while monitoring (target and non-target) impacts; and (6) Periodically review environmental impacts.

Create a long-term vision

Create a 20-year plan; have small projects "shovel-ready" in case a grant or other funding becomes available. Wetland restoration projects are a long-term commitment. Ducks Unlimited and the NRCS can provide resources to assist in the planning, funding, and regulatory compliance of your project.

Build a team of collaborators

The project manager should consider all potential stakeholders and have an open and transparent planning process. If the project may create mosquito habitat resulting in a public health concern, the American Mosquito Control Association can provide technical advice and contact information for local experts and resources to help determine if a project will promote mosquito production.

Outline the regulations

There must be an understanding of the rules and regulations over the proposed activities. Navigating the regulations can be cumbersome to those new to the process, but an understanding of these rules is critical to limiting legal liability and unintended impacts on a non-target species.

Regulatory considerations for mosquito control professionals working on wetlands:

1. Is the worksite a regulated wetland?
   The Oregon Department of State Lands Fact Sheet on Wetlands provides a checklist on how to identify wetlands (DSL 2015). The United States Geological Service National Wetlands Inventory Wetlands Mapper is a tool that can be used to identify the characteristics, extent, and status of the Nation's wetlands (USFWS 2021b). When in doubt, work with a wetland consultant, or contact the regulatory authority for the area (identified in regulatory consideration #4). An experienced consultant can facilitate the wetland permit process with minimal delays (DSL 2015).
2. Is the land managed by local, state, or federal agencies?
   If the land is privately or locally managed, the process of securing permits for the project will be relatively quick and inexpensive. State lands will require additional environmental compliance measures, a cultural resources investigation, and the project must adhere to the states' plans and mission for the property. When working on federal land, expect a lengthy permitting process. Voluntary wetland restoration is a growing area of collaboration across federal agencies. Different agencies have a variety of authorities and responsibilities. Federal agencies with key roles include the Environmental Protection Agency, United States Army Corps of Engineers, National Oceanic and Atmospheric Administration, United States Fish and Wildlife Service, United States Department of Agriculture, United States Department of Defense, Department of the Interior, United States Forestry Service and the United States Department of Transportation (EPA 2018).
3. Are there threatened and/or endangered species present?
   Generally speaking, the United States Fish and Wildlife Service is responsible for protecting terrestrial species, whereas the National Marine Fisheries Service is responsible for the protection of aquatic species. However, states may have additional species listed for protection. If there are listed species present and the project has any federal nexus, the project will require a consultation under Sect. 7 of the Endangered Species Act (USA, 1989). This can be costly and take years to complete. Another helpful resource for pesticide usage restrictions in sensitive habitat is the EPA's Bulletins Live! Two (EPA 2017). This page was developed to provide county level data to pesticide users to avoid non-target impacts.
4. Who are the primary agencies for wetland modification information and corresponding regulations?
   The Environmental Law Institute (ELI) Study of State Wetland Programs is designed to inform and advance state wetland protection by providing information on state program regulatory and non-regulatory tools and activities to state, tribal, and federal agencies, nongovernmental conservation organizations, and the public (ELI 2008).
5. What are the rules and regulations guiding mosquito control operations?
   Mosquito control authority is outlined in the Association of State and Territorial Health Officials' (ASTHO) Analysis of Express Legal

Authorities for Mosquito Control in the United States, Washington, D.C., and Puerto Rico. By understanding and adhering to the expressed authority in each state, mosquito control agencies and wetland managers can limit liability and undue costs (ASTHO 2018).

Prepare the documents

The authors recommend that all mosquito control programs sign up for notifications through their county planning department, specifically for critical areas ordinances and new developments. The county planning process involves a public notification period. For land managers who do not have a relationship with their local mosquito control program, this could be a solution for reaching those organizations without any additional effort.

Conduct the project, while monitoring (target and non-target) ecological impacts

Project managers are encouraged to conduct a baseline survey of the area's flora and fauna before beginning a project. If mosquitoes are being produced, the authors suggest establishing thresholds for mosquito control interventions and having an open line of communication with the public.

Periodically review environmental impacts

If the ecological balance of habitat creation, mosquito development, and natural predators has been disrupted by the wetland restoration project, it may not be evident immediately or even in the first year following completion. Pre- and post-project mosquito monitoring and timely interventions can prevent excessive production of adult mosquitoes before it becomes a public health concern. Integrated Mosquito Management plans such as ASTHO's "Public Health Confronts the Mosquito" and the American Mosquito Control Association's "Best Practices for Integrated Mosquito Management: A Focused Update" are tools created in response to the spread of the Zika virus, and are designed to provide step-by-step guidance on mosquito control practices that are effective on any budget (ASTHO 2019; Barker et al. 2017).

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