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ORIGINAL PAPER

Mosquito control opportunities amid regulations within the tidal marshes of the San Francisco Bay Area

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Abstract The San Francisco Bay Area is a leader in environmental stewardship and home to numerous wetland restoration projects including the largest tidal wetland restoration project on the American West Coast. As tidal marsh wetlands are restored throughout the Bay Area many opportunities remain to reaffirm the importance of water management that reduces mosquito production and protects public health. Unlike the early 1900s when long term saltmarsh mosquito control was achieved with large scale surface water management projects, regulatory restrictions produce new hurdles that impact mosquito control and restoration projects alike. Work done in the wetlands surrounding the San Francisco Bay must comply with existing management plans, permit requirements, and government regulations. The same is true for emerging technologies. While unmanned airsystems employed for mosquito control improves efficiency and accuracy, regulations in this arena limit their broad use in wetlands that abut the San Francisco Bay. Mosquito abatement districts collect substantial scientific data that inform land management and mosquito control operations. This information is useful for evaluating wetland restoration progress in the Bay Area and fostering partnerships that keep a public health perspective at the forefront.

Keywords Mosquito · Legislation · Wetlands · Unmanned airsystem · Drone

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Introduction

The San Francisco Bay Area is historically rich in habitat and species diversity. As such it is one of 28 estuaries designated as an Estuary of National Significance [Title 33 of the U.S. Code Section 1330 (33 U.S.C. § 1330)] by the U.S. Environmental Protection Agency (USEPA). This place-based program is designed to protect and restore the water quality and ecological integrity of estuaries (San Francisco Estuary Partnership 2016). The high population density of the Bay Area, impacts of climate change, and sea level rise further confound achieving program goals. Studies tracking these effects found that mean sea level in the Bay Area has risen continuously, extreme tides have become more frequent and larger over the last few decades, and annual maximum tide levels are rising faster than the rise in average sea level (Mak et al. 2016). These changes have influences beyond the water levels in the Bay. Shoreline restoration projects in tidal wetlands have performed or evolved in ways that were unforeseen when they were planned (Williams and Faber 2001). Likewise, high variation in the

response of tidal ecosystems to sea level rise and sediment concentration produce high variability in tidal marsh bird populations (Veloz et al. 2013), an indicator of other wildlife populations. Solutions to the impacts of climate change and sea level rise are focused on utilizing natural processes in the Bay that proactively integrate nature-based adaptation measures, often employing a combination of methods, into restoration projects. Nature-based approaches (e.g., nearshore reefs, polder management, ecotone levees) have several advantages over grey infrastructure such as riprap levees as they may perform better, cost less over time, and provide co-benefits such as new recreational opportunities and habitat for native species (San Francisco Estuary Institute 2019). One commonly used approach incorporates adjacent uplands with shallow slopes into tidal marsh restoration projects to provide the land needed for future wetland migration if the wetland cannot keep pace with sea-level rise (Callway et al. 2011). This also supports redistributed dredged sediment to raise land elevations and focused restoration efforts in sediment-rich areas to minimize marsh loss (Stralberg et al. 2011). Nature-based adaptation measures, particularly exchanging a traditional levee (grey infrastructure) for a gradual vegetated slope with an expanded horizontal footprint that break the waves (horizontal or ecotone levee) are in the planning stages for sites throughout the shoreline surrounding the Bay. A pilot project at the Oro Loma Sanitary District in San Lorenzo, CA studies how horizontal levees can remove wastewater-derived contaminants, while providing other benefits, such as high-quality habitat, and increased shoreline that are resilience to sea-level rise (Cecchetti et al. 2020).

Projects like the Oro Loma horizontal levee, the South Bay Salt Pond Restoration Project, and Measure AA are motivating Bay Area mosquito abatement districts (MAD) to reaffirm the importance of water management that reduces the potential for mosquito production. Over the next few decades thousands of acres of wetlands along the shoreline will be redesigned and restored based on the science and funding from these projects. Under the California Health and Safety Code Sections 2000–2093 (H.S.C. § 2000–2093) MAD have a responsibility to protect the public health by reducing mosquito populations. To fulfill this mission, MAD rely on a combination of water management and insecticide applications. Water management is generally a more effective and longer-term solution as it prevents immature stage mosquitoes from developing to biting and disease-spreading adult mosquitoes (Resh and Balling 1983; Medlock and Vaux 2011). Chemical control of mosquitoes becomes increasingly important if water management strategies are ineffective or are not properly maintained. Although insecticide applications can quickly reduce mosquito abundance, their impacts are short-lived and must be repeated frequently to ensure low mosquito abundance (Rey et al. 2012). Small unoccupied or unmanned airsystems (UAS), commonly known as aerial drones, have been utilized by many MAD to improve the efficacy of insecticide applications and for rapid landscape surveys to identify sites that produce mosquitoes. The use of UAS by MAD is constrained by regulations, some of which currently prohibit their use at sites that are otherwise ideally suited (e.g. wetlands situated in federal lands).

The regulatory environment in the San Francisco Bay Area is a complex web. Between the multitude of management plans that shape and guide the vision for the shoreline and the state and federal permits that regulate it, MAD must coordinate with many agencies to continue their mosquito control work in tidal wetland habitats. This requires engaging with stakeholders as management plans are updated to include mosquito control public health considerations at the forefront, obtaining the permits necessary to facilitate water circulation in tidal marsh habitats, and weaving through the regulations necessary to implement new technologies like UAS that increase the efficiency of mosquito control efforts. While the need for regulations to protect the Bay's ecosystem are indisputable, much work can be done to eliminate duplicative regulations and expand the advancements of technology while providing the same ecological protections.

Wetlands management plans

By the early 1990's work was well underway in the San Francisco Bay Area to restore wetlands that had been lost to development over the last century and a half. The Bay's most historically abundant habitat, tidal marsh, had been reduced from 190,000 acres that included 6000 miles of channels to 40,000 acres with 1000 miles of channels remaining; a five- and sixfold reduction in wetland habitat, respectively (Goals Project 1999). Restoration efforts started as early as

1961 when Save the Bay (formerly Save the San Francisco Bay Association) was formed by Sylvia McLaughlin, Kay Kerr, and Esther Gulick to mobilize residents and challenge companies, landowners, and politicians in the Bay Area to stop filling in the Bay and assist in its preservation. Their dedicated work paved the way for several plans that guided restoration of the Bay. Early involvement by MAD ensured mosquito control efforts were considered in several of the most impactful plans: the Estuary Blueprint, the Baylands Ecosystem Habitat Goals Project, the San Francisco Bay Joint Venture Implementation Plan (Restoring the Estuary), and the Design Guidelines for Tidal Wetland Restoration in San Francisco Bay (Table 1). Together these plans provide goals for protection, restoration, habitat creation, and climate change adaptation for the shoreline of the San Francisco Bay. While they do not create regulations regarding the use of the shoreline, they define the types of restoration projects that are championed throughout the Bay.

Estuary Blueprint

The Estuary Blueprint is the Comprehensive Conservation and Management Plan (CCMP) for the San Francisco Estuary Partnership, a requirement for estuaries of national significance under Section 320 of the 1987 Clean Water Act (CWA) Amendments. The first plan was completed in 1993 with updates in 2007 and 2016. The Estuary Blueprint focuses on managing the Bay and the San Francisco Bay Delta as one estuary and it was the first plan to do so. The 1993 CCMP brought together science and regional partnerships to tackle the natural resource conflicts involved with repairing damaged habitats and restoring native species throughout the Estuary. The document motivated Bay Area MAD to evaluate the feasibility of using indigenous minnows instead of *Gambusia affinis* in appropriate aquatic sites for larval mosquito control, adopting management practices that promote listed species recovery, providing guidelines for wetland managers that enhance seasonal wetlands that concomitantly reduce mosquito abundance, and managing operations to maximize wildlife and wetland habitats (San Francisco Estuary Project 1993). Another conservation recommendation of the plan involving MAD was to investigate the development of a Habitat Conservation Plan or Natural Communities Conservation Plan that promote the recovery of species and address incidental wildlife loss. While Bay Area MAD have an obligation to act in a manner that is consistent with local conservation efforts and adhere to the federal Endangered Species Act (16 U.S.C. § 1531) and the California Endangered Species Act (Fish and Game Code (F.G.C.) § 2050–2068), their core mission

Table 1 Wetland management plans for the San Francisco Bay Area that incorporate mosquito control measures

Management plan	Year completed (Revised)	Purpose	Mosquito control considerations
Estuary Blueprint	1993 (2007 and 2016)	Highlight natural resource conflicts involved in repairing damaged habitats and species composition of the Estuary	Consult with MAD to limit the production of mosquitoes and highlight MAD practices that may impact other species
Baylands Ecosystem Habitat Goals Project	1999	Set comprehensive restoration goals for the San Francisco Bay Estuary	Design guidance, buffers between wetlands and residential areas, access for mosquito surveillance and control, communication with MAD, and budget for mosquito control
Restoring the Estuary	2001 (2021)	Develop acreage goals and strategies for acquisition, restoration, and enhancement by habitat and region	Partner with MAD to ensure enhancement and restoration designs minimize mosquito production and flooding
Design Guidelines for Tidal Wetland Restoration in San Francisco Bay	2004	Establish objectives and constraints for wetland restoration projects	Provide unimpeded tidal drainage and consulting with local MAD on design elements

is to protect public health, not species recovery or habitat restoration. Importantly, the Estuary Blueprint calls on other agencies to consult with MAD to prevent the growth of mosquitoes while preserving, generating, designing, restoring, and managing wetland sites (San Francisco Estuary Project 1993). The most recent revision of the Estuary Blueprint in 2016 incorporates many of the original CCMP goals but adds a new focus on adaptions to climate change. It examines several science-based indicators of health for five Estuary attributes: water, living resources, habitats, ecological processes, and people (San Francisco Estuary Partnership 2016). The 2016 revision also unveiled a new structure focused upon priority actions to be carried out over five years that are linked to 35-year goals and objectives that are adaptable to uncertain environmental conditions.

Baylands Ecosystem Habitat Goals Project

From 1995 to 1998 the San Francisco Bay Area Wetlands Ecosystem Goals Project convened to develop habitat goals per the recommendation of the 1993 Estuary Blueprint. The project brought together over 100 participants from local, state, and federal agencies, organizations, private firms, individuals, and MAD. The purpose of the project was to map and document the changes that had occurred in the Bay's wetlands over the prior two centuries and to develop a direction for future restoration based on the best available science. The 1999 Baylands Ecosystem Habitat Goals Project (Goals Project) report identified the types, amounts, and distribution of wetlands and related habitats needed to sustain diverse and healthy communities of fish and wildlife. It also provided a guide for regional wetland planning processes to preserve, enhance, and restore the ecological integrity of wetland communities in the San Francisco Bay Area. It called to reestablish 100,000 acres of tidal wetlands along the shoreline (Goals Project 1999) and laid the foundation for many large-scale tidal marsh restoration projects that took place during the early 2000's. Project design recommendations that reduce mosquito abundance included unrestricted tidal exchange, permanently flooded areas and areas of deeper water depths to maintain mosquito predator and fish populations, and open water with little or no vegetation to promote wave action (Goals Project 1999). Additional recommendations included wide buffers between wetlands and residential areas, access points for mosquito surveillance and control, communication with MAD regarding water levels, predator abundance, and observations of mosquito larvae or adults, and funds budgeted for mosquito control (Goals Project 1999). The 2015 Science Update did not change the habitat acreage goals but built upon the original report by incorporating new scientific data to address the challenges resulting from the then current understanding of climate change (Goals Project 2015). Consistent with mosquito prevention strategies, the update promoted the preservation or creation of high channel complexity in tidal marshes, or the restoration of the processes that allow complex channels to develop naturally so that valuable habitat is produced and high water quality is maintained through natural water circulation (Goals Project 2015).

Restoring the Estuary

The San Francisco Bay Joint Venture (SFBJV) was formed per the North American Waterfowl Management Plan to address the need for waterfowl and wetland conservation and to implement the 1993 Estuary Blueprint goal to increase the acreage of wetlands permanently protected in the San Francisco Estuary. In alignment with the Estuary Blueprint, the SFBJV expanded its focus beyond waterfowl and wetlands to include other fish and wildlife populations along with riparian and adjacent uplands habitats. Restoring the Estuary, the SFBJV's Implementation Plan, was completed in 2001 to help the SFBJV's partners accomplish the wetlands acreage objectives laid out in the Goals Project. Restoring the Estuary directs wetland restoration by developing acreage goals and strategies for acquisition, restoration, and enhancement within each of the geographic sub regions: North Bay, Suisun, Central Bay, South Bay, and the San Francisco/San Mateo Coast. The plan addresses goals for the Bay habitats (tidal flats, tidal marshes, beaches, lagoons, and salt ponds), seasonal wetlands, creeks (including riparian zones), and lakes (San Francisco Bay Joint Venture 2001). Utilizing a collaborative non-regulatory approach, Restoring the Estuary promotes a partnership with MAD for tidal restoration projects to ensure that enhancement and restoration designs minimize risks of mosquito production, flooding, and other threats to public health and safety (San Francisco Bay Joint Venture 2001).

The implementation plan provided a 20-year timeline for accomplishing its goals; a revised plan for the next 20 years is expected to be released by the end of 2021.

Design Guidelines for Tidal Wetland Restoration in San Francisco Bay

The Design Guidelines for Tidal Wetland Restoration in San Francisco Bay was the next step in the natural progression for wetland restoration. The guidelines aim to assist planning for the restoration of tidal wetlands as healthy ecosystems by establishing the objectives and constraints for wetland restoration projects within the Bay. The framework for design decisions was based on: (1) allowing for the natural production of biologically rich and diverse tidal wetland habitats; (2) promoting the development of a complex tidal drainage system that supports invertebrates, fish, and birds; (3) maximizing the contribution of the marsh to the estuarine ecosystem; (4) establishing transitional wetland-upland habitat along the upland fringe; (5) providing appropriate habitat to support endangered species; (6) providing and enhancing public access; and (7) reducing flood hazards. These objectives, however, are constrained by: (1) potential impacts of offsite flood hazards and drainage; (2) the presence of public access and utility corridors; (3) preventing colonization and intrusion of invasive species; (4) the requirements for mosquito control; and (5) mitigation for conversion of seasonal wetland habitat to tidal wetlands (Philip Williams and Associates and Faber 2004). The guide recognizes the habitat needs of marsh inhabiting mosquitoes in Bay ecosystems and the importance of understanding the life cycles. Agreed upon steps that minimize mosquito habitat include providing unimpeded tidal drainage and consulting with local MAD on design elements.

The overview herein is not an all-inclusive list of the plans guiding restoration along the shoreline of the Bay. However, each plan proactively addressed mosquito control concerns and were foundational in guiding the development of other plans. As plans are produced or updated to incorporate new scientific discoveries, they should continue to promote measures that ensure public health is protected. The connection between people and the wetlands surrounding the Bay is undeniable, and it is not only tied to recreation activities and the impacts of flooding, but also to mosquitoes. MAD should always be included when developing and implementing wetland management plans. Wetlands have the potential to create large mosquito populations (Jensen et al. 1993) and those impacts must also be at the forefront of wetland management for the safety and wellbeing of wildlife and people.

Source reduction permits

The early years of mosquito control in the Bay Area relied heavily on physical modifications of the environment to reduce breeding habitat. The first district managers of the Alameda County MAD (California, USA), Harold F. Gray (1930–1955) and E. Chester Robinson (1955–1971) were engineers by trade and their focus was on major ditching projects that improved water circulation in the tidal marshes. Over the years, ditching projects have proven to successfully reduce mosquito populations in the Bay Area (Resh and Balling 1983; Kramer et al. 1995; Gray 1952) and have also been utilized by Contra Costa County Mosquito and Vector Control District, Marin Sonoma Mosquito and Vector Control District, Napa County Mosquito Abatement District, San Mateo County Mosquito and Vector Control District, and Solano County Mosquito Abatement District. Despite their success, changes in the perception and management of the Bay (as outlined in the plans above) and increases in federal and state regulations have limited the construction of new circulation ditches in tidal marsh areas. Now source reduction projects carried out by Bay Area MAD are focused upon maintaining existing water circulation ditches. Ditch maintenance permits are sponsored by the California Department of Public Health Vector-Borne Disease Section and currently cover Alameda, Marin, Napa, San Mateo, Solano, and Sonoma counties. Bay Area MAD maintained approximately 115,000 linear feet of ditches under a U.S. Army Corps of Engineers (USACE) Regional General Permit from 2007 to 2011 (USACE Public Notice Number 2007-400304S). Ditch modifications that change the character, scope, or size of the original ditch are not allowed (USACE permit 2016).

All projects in wetland areas that surround the Bay require approval from numerous agencies. To comply with federal laws and regulations (Table 2) work needs to be authorized by the USACE, the U.S. Fish and Wildlife Service (USFWS), the National Marine

Table 2 Federal and California regulations governing the issuance of mosquito source reduction permits in the San Francisco Bay Area

Regulation	Protection provided	Responsible agency(ies)	Permit|issuing agency
Federal*			
Clean Water Act Section 401	Requires water quality certification for any federally licensed or permitted project that may result in a discharge into waters of the United States	USEPA	Fulfilled by waste discharge requirements|Water Quality Control Board (state or regional)
Clean Water Act Section 404	Regulates the discharge of dredged and fill material into waters of the United States, including wetlands	USEPA, USACE, USFWS, NMFS	Individual or general permit|USACE
Coastal Zone Management Act	Encourages coastal states and territories to develop and implement programs to manage the nation's coastal resources	BCDC	Consistency determinations or certifications|BCDC
Endangered Species Act Section 7	Conserves threatened and endangered plants and animals and their habitats	USFWS, NMFS	Letter of concurrence or biological opinion|USFWS, NMFS
Rivers and Harbors Act Section 10	Regulates activities affecting navigable waters of the United States, including wetlands	USACE	Authorized through individual or general 404 permit|USACE
California			
California Environmental Quality Act (CEQA)	Requires all state and local agencies to give major consideration to environmental protection and not approve projects that have feasible and environmentally superior alternatives	CDFW	CEQA compliance document (Notice of Exemption, Negative Declaration, or Environmental Impact Report)|CDFW
California Fish and Game Code Section 1602	Regulates the diversion or obstruction of the natural flow, the use of any material from, or deposit of any material to the bed, channel, or bank of any river, stream, or lake	CDFW	Lake and Streambed Alteration Agreement or documentation it's unnecessary|CDFW
McAteer-Petris Act	Preserves the San Francisco Bay from indiscriminate filling	BCDC	Major, administrative, or regionwide permits|BCDC
Porter-Cologne Water Quality Control Act	Covers all discharges that could affect the quality of waters of the State	Water Quality Control Board (state or regional)	Waste discharge requirements|Water Quality Control board (state or regional)
San Francisco Bay Plan	Protects the Bay as a natural resource and guides development of the Bay and its shoreline to their highest potential with a minimum of Bay filling	BCDC	Major, administrative (minor), or regionwide permits|BCDC

BCDC = San Francisco Bay Conservation and Development Commission, *CDFW* = California Department of Fish and Wildlife, *NMFS* = National Marine Fisheries Service, *USACE* = United States Army Corps of Engineers, *USEPA* = United States Environmental Protection Agency, *USFWS* = United States Fish and Wildlife Service

*Federal regulations reviewed but determined to not be applicable are the Magnuson-Stevens Fishery Conservation and Management Act, the Marine Protection, Research, and Sanctuaries Act, the National Environmental Policy Act, and the National Historic Preservation Act

Fisheries Service (NMFS), and the State or Regional Water Quality Control Board. Additional laws and regulations in California (Table 2) require work to be authorized by the San Francisco Bay Regional Water Quality Control Board (Water Board), the San Francisco Bay Conservation and Development Commission (BCDC), and the California Department of Fish and Wildlife Service (CDFW). More complex

wetlands projects may also require permits from the USEPA, the California State Lands Commission, and local authorization from cities or counties. The applications to obtain each permit provide much of the same detailed information to the various permitting agencies, repackaged each time into agency-specific formats. Described next are the three most significant issuers of permits for wetlands management projects in the San Francisco Bay Estuary: the United States Army Corps of Engineers, the San Francisco Bay Conservation and Development Commission, and the California Department of Fish and Wildlife Service.

United States Army Corps of Engineers

The United States Army Corps of Engineers regulates discharges into the San Francisco Bay to protect Bay Area wetlands. Permits issued by the USACE to discharge dredged or fill materials in the waters directly surrounding the Bay must comply with Sections 404 (33 U.S.C. § 1344) and 401 (33 U.S.C. § 1341) of the CWA for waters of the U.S.(Title 33 of the Code of Federal Regulations (33 C.F.R.) Part 328) and Sections 10 of the Rivers and Harbors Act (33 U.S.C. § 403) for navigable waters of the U.S. (33 C.F.R. Part 329). Ditch maintenance by Bay Area MAD is authorized under a USACE Regional General Permit (RGP) sponsored by the California Department of Public Health which certifies compliance with Section 10 of the Rivers and Harbors Act and Section 404 of the CWA. RGPs are valid for five years and are issued by USACE for classes of activities in a region that are similar in nature and cause minimal individual or cumulative environmental impacts (33 U.S.C. § 1344(e)). RGPs allow for the grouping of similar individual projects but are inflexible because project changes must be reassessed by USACE. CWA Sections 401 requires federal permit applicants with activities that may result in discharges to waters of the U.S. to provide certification from the state that the discharge meets the applicable water quality standards of the federal CWA (33 U.S.C. § 1341). In California, the Porter-Cologne Water Quality Control Act (Water Code, § 13000) regulates discharges of dredged or fill material to waters of the State. This is done through the issuance of waste discharge requirements (Water Code, § 13263) for the project. The Water Board can issue waste discharge requirements concurrently with 401 Certification.

The initiation of a federal permit also triggers consultation under Section 7 of the Endangered Species Act (16 U.S.C. § 1536) with USFWS and NMFS (depending on the listed species) to ensure that the proposed actions do not jeopardize the continued existence of listed or proposed species or adversely modify or destroy critical habitat (50 C.F.R. Part 402). To accomplish this, USACE must determine whether any listed species may be present in the action area and whether that area overlaps with critical habitat. If no species or their critical habitat are present or affected, no consultation is required but all findings must be documented. Consultation with USFWS and NMFS is required if a "no effect" determination is not reached. To consult with USFWS and NMFS, USACE must submit a biological assessment (16 U.S.C. § 1536(c)), that provides information regarding the action's impact on listed species or critical habitat. A "may affect but not likely to adversely affect" determination is made when effects on listed species are expected to be discountable, insignificant, or completely beneficial. This requires written concurrence from USFWS and NMFS, but formal consultation is not required. A "may adversely affect" determination is made if any adverse effect to listed species may occur as a direct or indirect result of the proposed action or its interrelated or interdependent actions. This includes overall beneficial but some adverse effects to wildlife or critical habitat. This determination requires formal consultation and preparation of a biological opinion by USFWS or NMFS. The biological opinion evaluates whether the "may adversely affect" action is likely to jeopardize the continued existence of the listed species or destroy or adversely modify critical habitat. If a jeopardy or adverse modification determination is made, the biological opinion must identify any reasonable and prudent alternatives for the proposed action to allow its continuance or a statement why there are no alternatives. The issuance of a biological opinion is a lengthy process composed of a 90-day consultation period and a 45-day report preparation period. This timeline may even be extended 60 days or longer if additional data is needed.

Several threatened and endangered species that may be disturbed by ditch maintenance activities reside in Bay Area tidal wetlands. This means that it is not possible to have a "no effect" determination for all

species and a biological assessment for ditch maintenance must be prepared. Fortunately, the species that "may be adversely affected" are limited to land so approval for the issuance of the USACE RGP only requires a letter of concurrence from NMFS. However, approval from the USFWS requires a biological opinion. Formal consultation for the 2016 RGP was initiated on June 15, 2015. After a prolonged consultation process the biological opinion from USFWS was received on August 29, 2016.

San Francisco Bay Conservation and Development Commission

Work done in the tidal marshes surrounding the San Francisco Bay to limit habitats that support mosquito production also requires a permit from the San Francisco Bay Conservation and Development Commission (BCDC). BCDC was permanently established in 1969 to carry out the recommendations within the San Francisco Bay Plan, a mandate of the McAteer-Petris Act (Title 14 of the California Code of Regulations (14 C.C.R.) § 10131) which California Governor Ronald Reagan signed into law during 1965. BCDC was the nation's first coastal zone agency. It regulates all areas that are subject to tidal action in the Bay and certain waterways, the salt ponds, managed wetlands, and the band of land extending inland for 100 feet from the shoreline (California Government Code (C.G.C.) § 66610(a)). A project must apply for a BCDC permit if it proposes to fill, extract, or develop within the aforementioned areas within the San Francisco Bay Estuary. All maintenance dredging projects that are completed within a period of 10 years constitute "minor repairs or improvements" that may be authorized by an administrative permit. Permits from BCDC require consistency with the McAteer-Petris Act (14 C.C.R. § 10131), the San Francisco Bay Plan, the Coastal Zone Management Act (16 U.S.C. § 1451), and the California Environmental Quality Act (CEQA). BCDC must receive a copy of a certified environmental document issued under CEQA to verify that the project is in compliance with California environmental quality standards. Acquiring CEQA documentation is an extensive process as it requires assessing 18 environmental factors for potential impacts and several public notices. Approval for a BCDC permit must also be obtained from many of the same agencies as a USACE permit (the Water Board, USFWS, and NMFS) and from the California Department of Fish and Wildlife (CDFW).

California Department of Fish and Wildlife

CDFW has jurisdictional authority over wetland resources associated with rivers, streams, and lakes through the California Department of Fish and Game Code Sections 1600–1616 (F.G.C. § 1600–1616). CDFW regulates work that will substantially divert, obstruct, or change the natural flow of a river, stream, or lake, or will use material from a streambed through a Lake and Streambed Alteration Agreement (LSAA) to ensure fish and wildlife resources are protected. While maintenance of water circulation ditches done by MAD occurs in the tidal wetlands that surround the Bay and not in a river, stream, or lake, CDFW must be consulted to verify that there is not a significant connection between the wetland and a river or stream. An LSAA application also requires the completion of a CEQA document (14 CCR § 15000). Once an application is submitted, CDFW has 30 days to review the project and determine whether an LSAA is required. If CDFW determines it has jurisdiction an LSAA will also be issued for the applicable sites of the project. If an LSAA is not needed, the notification stating there is no jurisdiction verifies CDFWs review of the project.

While only two or three permits are required for ditch maintenance, the need to obtain multiple authorizations for doing so can quickly complicate the process. Most importantly, much of these reviews are duplicative. The USACE requires a biological assessment to consult with USFWS and NMFS and CDFW requires a CEQA document to complete a LSAA application. Both of these documents assess the impacts on endangered species and critical habitats and make impact determinations. Unfortunately, federal and state definitions aren't identical and different formats are used to report very similar if not identical information. The same comparison is true for the USACE permit application, the BCDC permit application, and the LSAA application. While the jurisdiction for each agency may be different, the information they request for projects is very similar. We support better coordination between state and federal agencies and suggest the development of a universal application that addresses the information needed by each agency.

This would greatly streamline the process while still providing agencies with needed information.

Unmanned airsystems regulations

Organized mosquito control efforts were initially led by academic institutions across the nation, with notable contributions starting in 1900 by investigators at the New Jersey Agricultural Experiment Station (now associated with Rutgers University) and in 1904 by faculty at the University of California (now University of California, Berkeley) (Howards 1901; Headlee 1945, MVCAC 2020). These early efforts utilized heavy machinery to modify the wetlands landscape so that water circulation was improved and mosquito growth limited (Patterson 2009; Rey et al. 2012). As chemical control technologies improved, the focus broadened to include the application of larvicide in wetlands (Margalit 1990). The registration of larvicide products that contain *Bacillus thuringiensis* subsp. *israelensis* (*Bti*) by the USEPA (US Environmental Protection Agency 1998) afforded MAD a new approach for mosquito control. These *Bti*-based and other mosquito control products have been applied since the mid-1990s using manned aircraft or all-terrain vehicles (ATV), both of which are effective at depositing insecticide in wetlands, but have limitations. Although hundreds of acres can be treated using manned aircraft in a single day, they cost hundreds of thousands or millions of dollars to purchase and thousands of dollars annually to maintain, which is beyond the fiscal resources of all but a few MAD. The alternative of hiring commercial aircraft operators to apply insecticides remains costly with fees for a 1-h application hovering upwards of $10,000 USD. Purchasing and maintaining ATV to apply larvicide is less costly, but obstacles on the ground limit uniform larvicide deposition, only dozens of acres can be treated by an operator each day, and the footprint of ATV impacts on the landscape is appreciable. Blending the advantages of aerial applications with the low cost and simplicity brought by applications via ATV would improve mosquito control efforts in wetland habitats.

UAS have been widely used for recreation (Dormehl 2018) with first responders being early adopters of UAS. There is great enthusiasm by MAD to utilize UAS in wetlands (Buettner 2018); however, technological and regulatory hurdles have limited widespread pesticide applications by UAS. Pesticide applications via UAS became feasible with the development of the Yamaha RMAX, a gas-powered helicopter costing upwards of $120,000USD (Giles 2015), the DJI AGRAS MG and Precision Vision UAS. By 2016, UAS that apply pesticide became more broadly available in the US at a cost close to that of a small ATV. Regulatory barriers placed by local, state, and federal agencies currently limit the launching of UAS for mosquito control in many wetland sites.

Federal regulations and rules

Federal regulations have the broadest reach and help guide how other agencies craft their laws and policies. The U.S. Federal Aviation Administration (FAA) regulates the physical specifications of UAS and how they may be operated in national airspace. FAA see pilots and the UAS they fly through two distinct lenses: those that fly for recreation and commercial pilots. The latter include those receiving any compensation for piloting the UAS. Recreational pilots must register with the FAA any UAS that weigh more than 250 g and adhere to some common sense rules while flying (e.g. fly at or below 400 feet in controlled airspace, yield to manned aircraft, and maintain visual line of sight (VLOS) with the UAS (FAA 2021).

Non-recreational commercial pilots that operate UAS under 55 lbs., which includes many pesticide applicators with MAD, are bound by additional regulations related to aircraft operation that are commonly known as Part 107 UAS Rules (14 C.F.R Part 107). Such pilots must register their UAS with the FAA and obtain a Remote Pilot Certificate from the FAA to demonstrate knowledge of safe UAS operation practices and regulations. The Remote Pilot Certificate must be renewed every two years by retaking the knowledge test and the UAS re-registered every three years. Among the most impactful of Part 107 Rules on MAD operations include a maximum weight limit of 55 lbs. for the UAS, requirement for the pilot to maintain VLOS, and restriction on dropping objects from the UAS (which includes insecticides). Government agencies, which include most MAD, can seek relief from some Part 107 Rules by obtaining a Certificate of Authorization (COA) from the FAA. When the COA review system was still new (e.g., during 2017–2018), the application review period exceeded four months, whereas now 1–3 weeks is

more typical. Recipients of COA must demonstrate they are a government agency and assume liability for all aspects of the UAS flights. COA are reviewed and written on a case-by-case basis and can offer exemption from many restrictions in Part 107. COA are evaluated by regional FAA Service Areas and air traffic controllers if controlled airspace exists within the COA boundaries, but waivers may not be granted with uniformity across the nation. The aforementioned regulations likely apply only to UAS that were designed for "free flight"; those that were constructed for tethered operation may meet the FAA definition of a kite (14 C.F.R. § 101.11) and may not be bound by Part 107 regulations. Alternative paths for pilots to use UAS for mosquito control include obtaining a pilots license for manned aircraft or to self-certify operation of the UAS using a COA.

While a 55 lb. UAS may seem gargantuan, the empty weight of UAS that apply pesticides often exceed 30 lbs., allowing for at most around 20 lbs. of pesticide to be carried by the UAS. The application rate for granular larvicides that are used in wetlands to control mosquitoes is typically 5–10 lbs./acre (e.g., Vectobac G, Valent Biosciences). Battery constraints on flight duration notwithstanding, 2–4 acres of wetland could be treated before refilling the UAS with larvicide. In contrast, an ATV can carry 80 lbs. or more of granular larvicide and fuel for use over an entire day. Notably, approximately 95% of the formulated larvicide is comprised of inactive ingredients (e.g., corn cob, sand, or water). Consequently, much of the formulated insecticide that is carried by UAS, ATV, or people may be considered unneeded excess weight that could be shed. The efficacy of UAS used by MAD could be enhanced substantially if FAA permitted increased UAS weights and if manufacturers offered low mass pesticides that are formulated with higher concentrations of active ingredients that are approved by Departments of Pesticide Regulation for use in UAS.

Maintaining VLOS of an UAS while aloft is required by FAA to reduce chances of injury or property damage, and is always prudent. However, it can be impractical when using UAS to apply larvicide in wetlands. While such UAS are large and easy to see when nearby, they are piloted at low altitudes when applying larvicides (20–90 feet above the ground) and quickly become difficult for a pilot to visualize as they blend into the landscape whilst sinking in the horizon. Forward-facing field of view camera systems and automatic obstacle avoidance sensors built into the vast majority of UAS bring a great deal of visual awareness to the pilot and safety that reduces the likelihood of a collision. Recent technological advances in pre-programed autonomous flights add another layer of awareness and safety. The potential for injury from a UAS flown over wetlands is low because the only people typically nearby when insecticide is being applied are the pilot and support team, all of whom would be watching the UAS at work. There is limited opportunity for a UAS to damage physical structures, property, or infrastructure as they are typically sparse or absent in wetlands. Thus, MAD pilots should be able to safely operate UAS in wetland habitats without maintaining VLOS if onboard cameras and autonomous flight plans are utilized.

Insecticides targeting adult flying mosquitoes that may be infected with arboviruses are typically applied by MAD during twilight or nighttime hours when environmental conditions are favorable for efficient insecticide deposition and the mosquitoes are aloft (Elnaiem et al. 2008). Part 107 Rules prior to 2021 prohibited UAS operation during nighttime when UAS were most needed by MAD to control mosquitoes that transmit life-threatening pathogens to people and domestic animals. UAS may now be operated during nighttime if there are lighted flashing anti-collision lighting on the UAS visible for at least three statute miles (86 FR 4314). UAS with attached thermal cameras enable pilots to see people and structures during nighttime flights (e.g. Zenmuse H20T camera, DJI Technology Co., Ltd., Shenzhen, China) and could be utilized by MAD to improve safety during nighttime flights.

MAD not wishing to seek a COA to apply insecticide using UAS may instead obtain an Agricultural Aircraft Operator Certificate (AAOC) under Title 14 of the Code of Federal Regulations (14 C.F.R) Part 91 and Part 137. Doing so allows pilots to obtain exemptions from some FAA rules related to piloting the UAS and dispensing insecticides. For an UAS pilot to apply for an AAOC, they first obtain from FAA a valid US Pilot Certificate for manned aircraft (i.e., pilot's license) and a Remote Pilot Certificate. Many hours of training and approximately $10,000 USD for education and fees are needed to obtain a Private Pilot Certificate. FAA prefers that UAS pilots with an

AAOC provide public notice of pesticide applications at least 48 h in advance (14 C.F.R. § 137.51(b) (2)). However, once MAD detect virus-infected mosquitoes, they typically act that or the subsequent day. Waiting two or more days to provide notice may limit the efficacy of MAD in controlling mosquitoes that are spreading pathogens in the community.

Use of most commercially available UAS on U.S. federal lands was constrained with a memo from the U.S. Secretary of the Interior on October 6, 2020. Until the order is rescinded, only UAS from a government-approved list of UAS that are manufactured solely with U.S.-made components, called Blue sUAS, may be used by U.S. government staff or on U.S. federal lands. Because the program is focused on UAS with visual systems, there are no Blue sUAS available that can apply insecticides. Consequently, UAS may not be used to control mosquitoes on any federal lands where MAD typically work, including those that are managed by USFWS, U.S. National Park Service, and the U.S. Bureau of Land Management. MAD use of UAS in wetland habitats can be more effective if the FAA increases flexibility in regulations by (1) updating the UAS weight limitations so that a greater quantity of mosquito control products can be carried by UAS, (2) eliminating the recommendation of 48-h notice prior to applying pesticide via UAS, and (3) permitting flights without maintaining VLOS if the region is sparsely populated, devoid of infrastructure that a UAS could damage, and if camera systems coupled to pre-programed autonomous flight plans are utilized to enhance safety.

FAA regulations apply to UAS during flight, but other agencies manage or regulate the ground from which UAS are launched. It is ideal for MAD to launch UAS near to or within wetlands. The contiguous 48 U.S. has approximately 111 million acres of wetland habitat (U.S. Department of Agriculture 2013) with 18.3 million acres of land in the National Wildlife Refuge System that is managed by USFWS (U.S. Fish and Wildlife Service 2015). Although much of the nation's wetlands are in wilderness or sparsely populated areas, some are within rural communities that are often underserved whilst a few abut urban centers (e.g., Don Edwards San Francisco Bay National Wildlife Refuge). Managers of USFWS lands are guided by federal rules and regulations, yet they have substantial leeway in determining how the fundamental principles of the USFWS are met in each refuge (U.S. Fish and Wildlife Service 2013). Inconsistent rules for the use of UAS on USFWS properties challenge MAD in budgeting for resources used in mosquito control. We encourage the USFWS to consider the scientific literature on the impacts of UAS on wildlife, species composition in the proposed flight region, commission additional studies if warranted so that rules can be established that enable MAD to use UAS for controlling mosquitoes in wetlands of all USFWS lands.

State regulations

Each state in the U.S. establishes laws and rules that guide pesticide application for mosquito control. We focus herein on California as it has greater restrictions relative to other states. The California Department of Pesticide Regulations (CDPR) is responsible for pesticide regulation in the state and is regarded internationally as an authority in this arena. The type and quantity of pesticide used by each MAD is reported monthly to the California Department of Food and Agriculture. Pesticide labels contain information on how the formulated product can be applied, which MAD are legally obligated to follow; it's often said that "the label is the law." MAD in California have a limited stable of pesticides available for mosquito control, none of which are labeled specifically for application via UAS (aerial application is allowed for many). This is due to pesticide manufacturers having not yet sought revision to labels on existing pesticide formulations from CDPR. As noted above, products that are better suited for use with UAS will likely need to be produced by manufacturers. If composition of such products does not differ substantially from those that are currently registered, we encourage CDPR and USEPA to quickly approve their use by MAD. However, insecticides for use in UAS may have a higher active ingredient concentration and thus may require elevated precautionary statements on the pesticide label that affect the marketing and purchase of such products.

State health departments themselves apply pesticide to control vectors or engage with MAD to provide oversight and guidance. CDPH has additional responsibilities in certifying the competence of MAD staff to apply insecticides for vector control. Those that successfully pass the knowledge tests offered by CDPH for qualification as a Public Health Vector

Control Certified Technician are authorized to apply pesticide by hand or terrestrial vehicles (California Health and Safety Code, Section 106925, Article 4). To apply pesticide via UAS in California, each pilot must also earn an Unmanned Pest Control Aircraft Pilot Certification from DPR (AB 527, Caballero. Pest control aircraft pilot's certificate: unmanned aircraft) or operate the UAS under Part 91 and 137 regulations for manned aircraft (14 C.F.R. § 91; 14 C.F.R. § 137). Thus, a pilot in California may need to hold valid certifications from FAA, CDPH, and DPR to apply insecticide using a UAS.

Notably, Section 2063 of California Health and Safety Code provides MAD the authority to enter property without permission from the owner or manager to control vectors, including mosquitoes. However, COA may require pilots to obtain permission from property owners or managers before flying UAS over their property. Thus, it is currently not possible for MAD to fully exercise their legal authority to control mosquitoes using UAS.

Local ordinances and rules

Unlike complying with federal and state regulations, local limits on the use of UAS may be simpler to navigate by establishing personal relations with the property owner or manager. Doing so can motivate exemptions or the recrafting of existing rules that allow UAS to be used on their properties. Partnering with or knowing of other agencies with interests in using UAS can motivate property owners to provide broadened access. For example, Alameda County MAD (California, USA) must control mosquitoes in wetlands that are managed by East Bay Regional Park District (EBRPD). Since 2015, EBRPD has banned all UAS on their properties (East Bay Regional Park District 2015,2019). Because Alameda County MAD had a decades-long and collegial history with EBRPD staff, they obtained permits with exemptions from the prohibitions that would have otherwise prevented them from inspecting those wetland habitats for mosquito breeding sites and applying insecticide via UAS.

Regulations and rules often established by governmental and private institutions in general to keep people and the environment safe. Initial concerns of UAS collisions with people or property due to lost communication links between the UAS and controller are being replaced with the realization that most crashes result from piloting errors. MAD pilots that apply public health pesticides are highly trained as they must hold certificates from FAA, CDPH, and DPR to fly using a COA or a CDPH certificate and a manned pilots license with an additional UAS certificate from FAA to fly with an AAOC (i.e., using 14 C.F.R. Part 137). As UAS technologies improve that increase safety (e.g., autonomous avoidance and piloting systems), we encourage regulators to reconsider regulations that impede MAD, particularly when flights are in wetland settings where risk of injury or property damage are low.

Future opportunities

MAD are not the only agencies that face challenges with the permitting and regulatory processes. Permitting for all projects and technologies utilized within tidal marshes in the San Francisco Bay Area is a time consuming, expensive, and complex process. Many laws and regulations apply to projects in tidal marshes, depending upon the location and specific circumstances, including but not limited to the California Environmental Quality Act, Porter Cologne Water Quality Control Act, California Endangered Species Act, California Native Plant Protection Act, Natural Community Conservation Planning Act, California Fish and Game Code, McAteer-Petris Act, Clean Water Act, National Environmental Policy Act (42 U.S.C. § 4321 et seq), Federal Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. § 1801), Marine Mammal Protection Act (16 U.S.C. § 1361 et seq), and the Coastal Zone Management Act. As a result, coordination between the project sponsors and the multiple agencies administering these laws and regulations can be challenging (WRMP 2020). Two newly implemented programs in the Bay Area, the Wetlands Regional Monitoring Program and the San Francisco Bay Restoration Regulatory Integration Team, aim to address parts of the regulatory and permitting process and hopefully streamline them in the future.

Wetlands Regional Monitoring Program

The development of the Wetlands Regional Monitoring Program (WRMP) is a priority action of the 2016 Estuary Blueprint. The purpose of the WRMP is to

establish an implementable program to monitor mature and restored tidal marsh habitats with improved efficiency for permitting tidal wetland restoration projects and evaluating the condition of the tidal marsh ecosystem at a regional scale. As a newly formed program the WRMP intends to grow in scope and scale over time, while implementing near-term science priorities over the next five to ten years. The science priorities of the program include assessing and monitoring the interactions between people with wetlands so that public safety and wetland health is maintained. Integrating flood protection and mosquito control into project planning and assessment was recognized as crucial for success (WRMP 2020). MAD should support and be an active part of the decision-making processes that can benefit public health as well as restoration activities. MAD utilize scientific data (adult and larval mosquito abundance, disease testing, and UAS imagery) in real-time to make land management and mosquito control decisions. This information is critical for the design of future tidal marsh restoration projects and effective adaptive management strategies for current projects to reduce mosquito production while still implementing new restoration techniques that address climate change. Coordinating this information with the agencies performing and permitting restoration projects will decrease the need for MAD to ditch or apply insecticides in or near restored tidal wetlands.

San Francisco Bay Restoration Regulatory Integration Team

The San Francisco Bay Restoration Regulatory Integration Team (BRRIT) was established in 2018 with funds from Measure AA and the State Coastal Conservancy, Santa Clara Valley Water District, Bay Area Toll Authority, and East Bay Regional Park District. The BRRIT aims to reduce permitting delays for projects meeting Measure AA criteria through early consultation with the regulatory agencies. The BRRIT consists of staff from the six state and federal regulatory agencies with jurisdiction over habitat restoration projects in the San Francisco Bay, including USACE, USFW, NMFS, the Water Board, CDFW, BCDC, and the USEPA who participates on an ad hoc basis. Additionally, the BRRIT has a Policy and Management Committee made up of agency managers to coordinate with the BRRIT and resolve policy issues that may otherwise delay permit decisions. This is the first attempt to bring representatives from all Bay Area permitting agencies together to guide project applicants through the permitting process. While the BRRIT is narrowly focused on projects that are eligible for Measure AA funds, any reforms that may be made to agency's permitting applications and processes will benefit all applicants, including MAD.

Conclusion

Numerous activists, agencies, and regulators in the San Francisco Bay Area have put substantial effort into restoring the health and beauty of the Bay. Part of that effort has led to increased regulatory hurdles. While the need for statutory protection is undeniable, there should be coordination among regulations so that progress is not delayed. Plans that guide restoration must incorporate a public health focus which includes limiting habitat that supports mosquitoes. Federal and state permits that regulate actions in wetlands need a universal application and coordinated environmental compliance certification to reduce duplication. UAS use by certified pilots in areas where there is little risk of property damage or injury to people and wildlife need greater regulatory flexibility. Present regulations have substantially limited mosquito control activities; however due to the scientific nature of mosquito control, expertise as well as field data may be effectively used during the planning and permitting processes. Regulations should be able to protect the health and safety of the public and the critical habitat of endangered species while benefiting wetland restoration and MAD alike.

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