CHAPTER 25

Wetlands of the Central Valley of California and Klamath Basin

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The Central Valley of California (CVCA) and Upper Klamath Basin (KLBA) in southern Oregon and northeastern California contain some of the most important wetland habitats in North America (see area maps in Fig. 25.1). Wetlands in these regions are habitat for a large variety of fauna and flora and provide other important ecosystem functions, such as sediment and nutrient reduction, floodwater storage, and groundwater recharge (Novitzki et al. 1996). Wetlands in these regions are especially critical for migratory birds, with KLBA providing spring and fall migration staging habitats for many of the 10–12 million waterfowl and hundreds of thousands of other migratory waterbirds that winter in or pass through the CVCA annually (Fig. 25.2a–f; Gilmer et al. 1982, 2004; Warnock et al. 1998; Fleskes and Yee 2007). Waterfowl and other waterbirds also breed in both regions in large numbers (Baldassarre and Bolen 1994), which was a major reason that Lower Klamath National Wildlife Refuge (NWR) was established by President Theodore Roosevelt in 1908 as the first waterfowl refuge in the United States. The wetlands in these regions are of international importance, as evidenced by their designation as Ramsar Convention of International Importance sites, Western Hemisphere Shorebird Reserve Network sites, Audubon Important Birds Areas, and North American Waterfowl Management Plan Priority Conservation areas (North American Waterfowl Management Plan Committee 1986). The KLBA and surrounding region is recognized as a global center of biodiversity and is one of the seven North American International Union for Conservation of Nature Areas of Global Botanical Significance. The KLBA and surrounding region is also proposed as a World Heritage Site and United Nations Educational, Scientific and Cultural Organization Biosphere Reserve (Vance-Borland et al. 1995). The CVCA and KLBA have both become the focus of large-scale, multipartner, public-private conservation efforts (e.g., Central Valley Joint Venture [CVJV], Intermountain West Joint Venture) that have been the main forces for wetland habitat conservation in these regions since 1988. Despite these efforts, the large and diverse plant and wetland-dependent wildlife communities in both regions face immense challenges. While KLBA is sparsely populated, CVCA is inhabited by one of the most rapidly increasing human populations in the United States (American Farmland Trust 1995). Irrigated agriculture dominates the landscape in both regions, and along with urban areas, put high demands on land and water resources (Hathaway and Welch 2002). The unfortunate outcome is that many plants and animals in these regions are in peril (e.g., 44 plant and 47 animal species in CVCA are threatened or endangered; www.library.ca.gov/crb/97/09/index.html#Heading37).

Hydrogeology

Central Valley

Totaling about 52,000 km^2, CVCA spans 640 km from Red Bluff in the north to the Tehachapi Mountains in the south, and is 48–112 km wide between the foothills of the Sierra Nevada and the Pacific Coastal Ranges (Gilmer et al. 1982). CVCA is composed of three regions: the Sacramento Valley in the north, the San Joaquin Valley in the south, and the Sacramento–San Joaquin River Delta (hereafter the Delta) in between (Fig. 25.1). The Sacramento Valley drains into the south-flowing Sacramento River. The San Joaquin River runs north and drains the northern third of San Joaquin Valley, including, in exceptionally wet years, the Tulare Lake Bed. However, in most years, Tulare Lake serves as the terminus sink for the Kings, Kern, and Tule Rivers. The Sacramento and San Joaquin Rivers meet in the Delta, with the conjoined waters flowing through Suisun Marsh into San Francisco Bay and out to the Pacific Ocean.

The CVCA is a structural trough filled with Jurassic- to Holocene-aged sediments to a depth of nearly 10 km. Groundwater–surface water interaction is primarily through gaining and losing sections of streambeds, with water percolating into the ground as streams flow into CVCA. Water discharges through evapotranspiration of marsh vegetation, and historically directly into the Tulare Lake; aquifer pumping is now another major source of groundwater outflow (Mullen and Nady 1985; Williamson et al. 1989). Soils are diverse, with many in San Joaquin Valley poorly drained and high in salts, alkalinity, and trace elements, which make management of water quality difficult (Heitmeyer et al. 1989; http://soils.usda

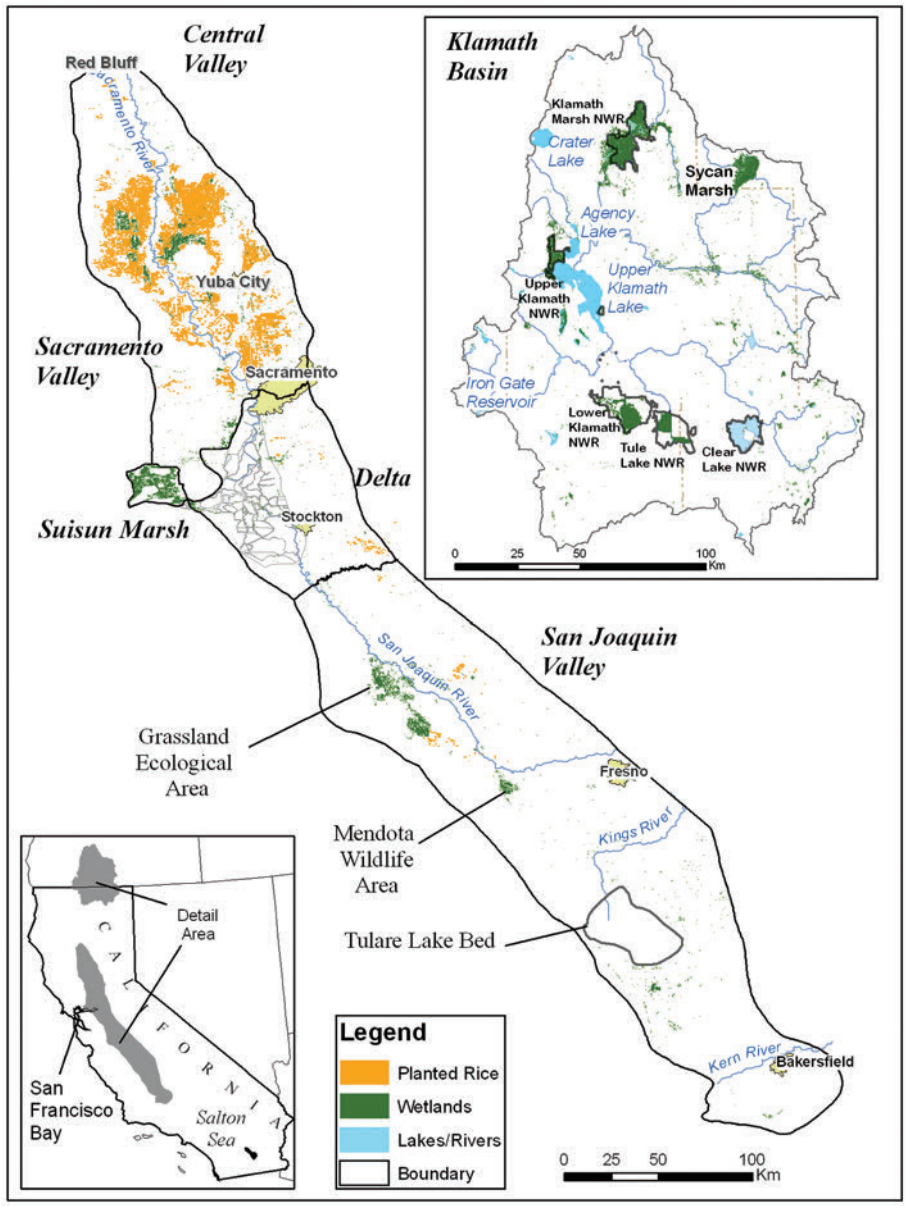

FIG. 25.1. The Central Valley of California and the Klamath Basin of northeastern California and southern Oregon.

.gov/survey/online_surveys/). Climate is Mediterranean, with dry, warm summers and wet, mild winters; > 97% of the precipitation falls October–May (www.wrcc.dri.edu). Evapotranspiration greatly exceeds summer precipitation, especially in the San Joaquin Valley (Faunt 2009), where wetland evapotranspiration is as high as 1.5 cm per day (Heitmeyer et al. 1989) and summer rain rare (e.g., Bakersfield: June–Aug. avg. precipitation = 0.004 cm per day).

Prior to the construction of dams, rivers meandered and flooded widely over the valley most winters. However, hydrology has been greatly altered since European settlement to facilitate agriculture, mining, flood protection, and urbanization. About 70% of the wetland area was modified from 1850 to the 1920s by local drainage, levee, and water diversion (Harding 1960; McGowan 1961), followed by large-scale federal and state projects (Shelton 1987; Frayer et al. 1989). Today, a system of more than 100 dams and numerous reservoirs and canals move water, with pumps in the Delta directing a portion of the flow to Southern California via the 1,151-km-long California Aqueduct.

Wetland loss has been extensive. The estimated 1.6–2 million ha of wetlands in CVCA pre-European settlement were reduced to 1.5 million ha in 1906; 485,600 ha in 1922; 220,415 ha in 1960; 172,000 ha in 1977 (United States Fish and Wildlife Service [USFWS] 1978); and 53,930 ha in 2003 (USFWS and U.S. Bureau of Reclamation 2003), which represents a 97% loss. However, loss estimates vary, ranging from a 91% loss by 1990 (Dahl 1990) to a 96% loss by 2006, based on 83,000 ha of managed wetlands in 2006 (CVJV 2006). The magnitude of loss and types of wetland habitats remaining differ by region. Historically, about 40% of CVCA wetlands occurred in San Joaquin Valley, with 60% in the Sacramento Valley, Delta, and Suisun Marsh (USFWS 1978). The southern San Joaquin Valley had the largest block of wetlands, but most were lost by the 1920s

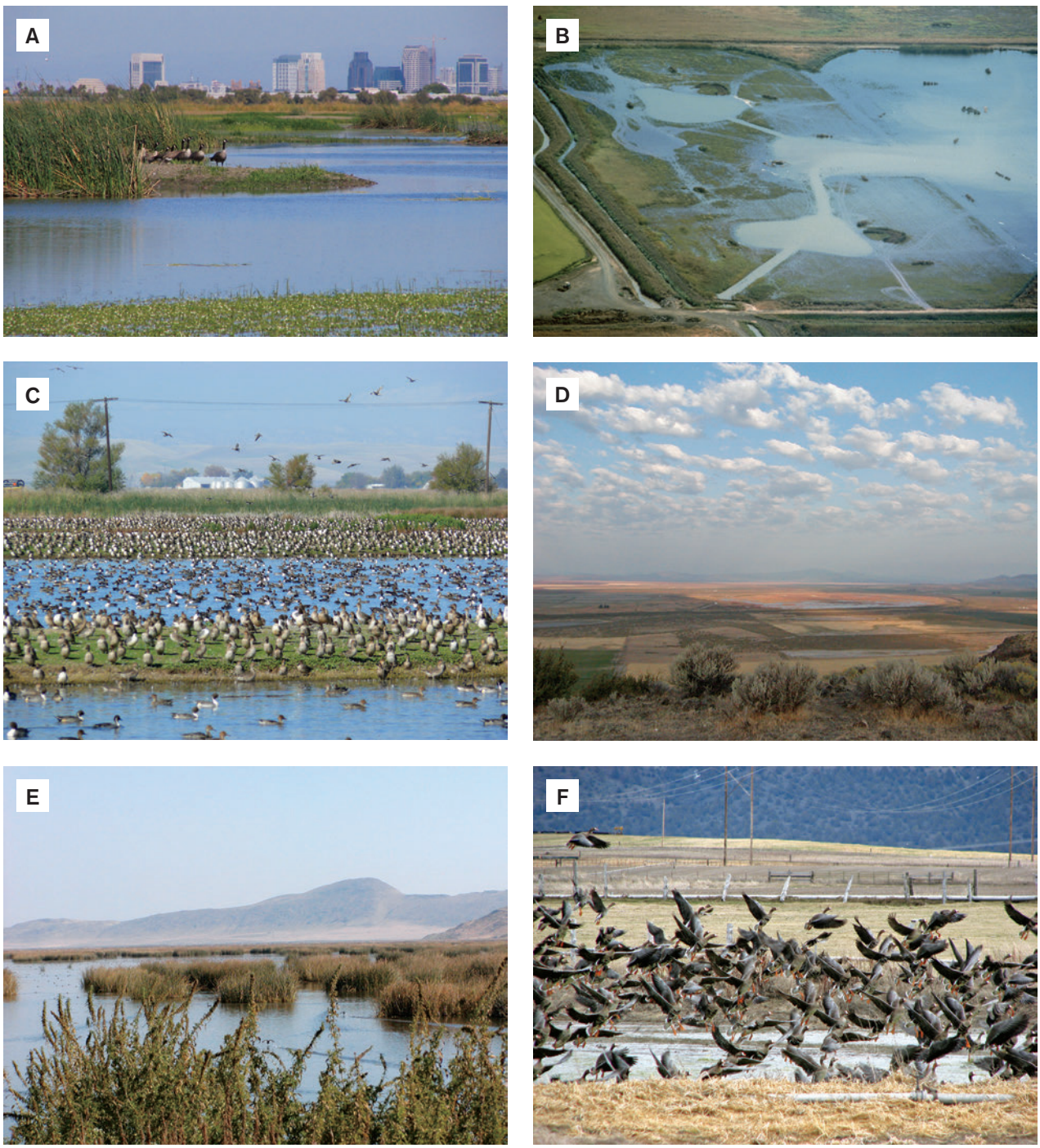

FIG. 25.2. Wetlands in the Central Valley (A, B, C) tend to be smaller, more intensively managed, and situated in more urbanized landscapes than those in the Klamath Basin (D,E,F), but both areas support large populations of waterfowl and other wildlife. A. Wetland on Yolo Bypass State Wildlife Area, with Sacramento in the background. (Dave Feliz, CA DFG.) B. Aerial view of seasonal wetland on Sacramento NWR showing areas of mowed vegetation and constructed islands. (Anonymous, USFWS.) C. Northern pintail and other waterfowl concentrated on a Sacramento NWR wetland. (Robert McLandress, CA Waterfowl Assoc.) D. View of a large wetland complex in Klamath Basin. (Dan Skalos, USGS.) E. Large wetland unit on Lower Klamath NWR. (Dan Skalos, USGS.) F. Greater white-fronted geese flushing from a Klamath Basin wetland. (Colin Tierney, USGS.)

with conversion of Tulare Lake (once the largest freshwater lake west of the Mississippi River) and associated wetlands to agricultural lands (Kirk 1994). Wetland loss in Sacramento Valley and the Delta was also severe, but many wetlands in Sacramento Valley were converted to rice and in the Delta to grain fields that retain higher value for waterbirds than the cotton, orchards, and nongrain croplands that dominate the San Joaquin Valley landscape (Fleskes et al. 2005). Today, wetlands and flooded rice provide nearly contiguous waterbird habitat in Sacramento Valley, whereas in San Joaquin Valley, large expanses of agriculture of relatively low waterbird value separate wetland habitats into three distinct blocks (i.e., Grassland Ecological Area, Mendota Wildlife Area, and Tulare Lake Bed and vicinity).

Klamath Basin

The 20,720-km^2 KLBA lies in a broad, relatively flat basin within a Pleistocene lakebed (Gannett et al. 2007). The KLBA extends along the east slope of the Cascade Range and includes the Klamath River drainage upstream of Iron Gate Reservoir (Fig. 25.1). Geology reflects repeated volcanic activity, erosion, and sedimentary rock deposition. KLBA spans parts of the Cascade Range, and is underlain mostly by late Tertiary and Quaternary volcanic deposits that are generally permeable, with a substantial groundwater system recharged from Cascade Range precipitation. Valleys are 792–1,524 m above sea level, with a high natural water table (Fretwell et al. 1996) and a diverse set of highly organic muck soils of drained lakebeds and sand-to-loam mineral upland soils (Jahnke 1994). However, drainage and subsequent intensive grazing have compacted wetland soils and promoted erosion (USFWS 2009b). The climate is semiarid, characterized by relatively dry, moderate summers and wet, cold winters. Most (e.g., 70% in Klamath Falls, Oregon) of the annual 38–64 cm of precipitation falls during November–April (www.ocs.orst.edu/). Maximum temperatures average 33°C during summer, and winter minimums average –7.2°C; a killing frost can occur during any month.

About 85–90% of KLBA's original wetlands have been lost, with only about 60,000 ha remaining (Akins 1970; Bottorff 1989). In 1905, the U.S. Bureau of Reclamation initiated the Klamath Reclamation Project: three large storage reservoirs, hundreds of diversion structures, > 2,260 km of canals, and a 2.4-km tunnel now deliver water throughout KLBA (Hathaway and Welch 2002).

Current Wetland Hydrology

Hydrology of most wetlands in CVCA and KLBA is extensively modified and intensively managed, primarily to provide food and refuge for the millions of migratory waterfowl that use regional habitats (CVJV 2006). Natural overflow flooding from snowmelt and rain has mostly been replaced by managed flooding via controlled diversions, timed reservoir releases, and pumped water delivery from ditches, rivers, sloughs, and wells. Regional wetlands can be generally classified by hydropattern as semipermanent-permanent (hereafter "semi-perm"), seasonal, or temporary (mostly vernal pools and alkali sinks). In many cases, the lowest parts of wetland basins are semi-perms and the shallower portions are seasonal. Managed wetlands are mostly seasonal and semi-perms. Differences in geomorphology, climate, water availability, and timing of use by waterfowl have resulted in a greater portion of KLBA wetlands managed as semi-perms than in CVCA. For instance, semi-perms comprise 59% of the managed wetlands on Lower Klamath and Tule Lake NWRs (Dugger et al. 2008) versus 13% in CVCA (CVJV 2006).

Hydropattern differs by wetland type. In wetlands managed as semi-perms, water is usually maintained year-round in at least part of the basin to provide habitat for breeding and molting waterfowl as well as other wetland-dependent birds (i.e., waterbirds) and other fauna. However, if emergent vegetation overtakes the basin (which commonly occurs in shallow basins after a few years), and if water levels can be manipulated, wetlands are drained and emergent vegetation disked or burned to restore the desired "hemi-marsh" interspersion of open water and vegetation. Hydrology of most seasonal wetlands, which comprise about 87% of the managed wetlands in CVCA and 41% of the managed wetlands on Lower Klamath and Tule Lake NWRs, is designed to maximize production of waterbird food resources (primarily seeds but also aquatic invertebrates), and on most private and many public lands, provide opportunity for waterfowl sport harvest. Exact timing of flooding differs somewhat among regions and years to match timing of waterfowl use and hunting seasons. Waterfowl from northern breeding grounds begin to arrive in KLBA and CVCA in early August, with most migrants departed by late April. Waterfowl hunting season usually begins in early (KLBA) to mid-October (CVCA) and ends in mid- (KLBA) to late January (CVCA). Thus, most seasonal wetlands are unflooded, but irrigated periodically during summer to promote seed production, and are flooded starting in mid-August to late October, with water maintained through at least January. Due to higher water costs, many southern San Joaquin Valley wetlands are not summer-irrigated and fall flooding is delayed to reduce evapotranspiration and to coincide with the later opening date of the local hunting season. Due to logistical constraints, wetland drawdowns on private lands often begin when hunting season ends, even though drawdowns would be more effective in simultaneously promoting plant growth and providing invertebrate resources for birds if timed to occur with peak migrations (Heitmeyer et al. 1989; Fredrickson 1991). Soil temperature has considerable influence on moist-soil plant community composition and seed production (Fredrickson 1991), and drawdown timing varies regionally and by target species. For instance, in the San Joaquin Valley, wetlands managed for swamp timothy *(Crypsis schoenoides)* are drawn down in mid-April to early May, whereas those managed for alkali bulrush *(Scirpus paludosus)* are drawn down in March (Smith et al. 1994). A small percentage (e.g., 7% in Grassland EA; Chouinard 2000) of seasonal wetlands in CVCA are managed in reverse cycle (i.e., flooded March–August and left dry September–February) to supplement semi-perms as waterbird breeding and brood habitat. The annual vegetation that grows in reverse-cycle wetlands decomposes rapidly when flooded and provides optimal conditions for invertebrate production. Unlike the intensively managed hydropattern of most seasonal and semi-perm wetlands in KLBA and CVCA, hydrology of most temporary wetlands, including the 5–25% of the original vernal pools that still exist (Holland 1978) and most alkali sink wetlands, primarily reflects local precipitation events. Thus, most temporary wetlands are flooded for a shorter duration than seasonal and semi-perm wetlands.

Biogeochemistry and Microbial Processes

Biogeochemical processes regulate the exchange of materials between the abiotic and biotic components of the environment. Microbes alter the chemistry and productivity of wetland environments by performing complex transformations of organic and inorganic molecules. These processes occur in both the soil and water column of wetlands. Biogeochemical processes include settling of suspended matter, adsorption and desorption of chemical elements from particles, transformations between contaminants in surface water and sediments, and uptake, transformation, and release of nutrients and other chemical elements in plants, algae, microbes, and other fauna. Microbes are important for nutrient cycling and soil carbon turnover and sequestration (Frenzel et al. 2000)

and impact the speciation, mobility, bioavailability, and toxicity of toxic elements. Anaerobic microbial processes are especially important, affecting nutrient transport, water quality, and greenhouse gas fluxes (Whitmire and Hamilton 2005). Several processes are especially important to the ecology and conservation of wetlands and wetland fauna in KLBA and CVCA.

NUTRIENT RETENTION AND RELEASE

A variety of interacting factors determine whether wetlands serve as sinks or sources for nutrients. Soils play an important role in wetland water quality and productivity because they serve as sinks, sources, and transformers of nutrients. Thus, differences in soil types as well as source waters and evapotranspiration rates result in variation of water chemistry among regional wetlands. In addition, while wetlands often are net sinks for nutrients, such as phosphorus (P) and nitrogen (N), and even a small area of wetland can greatly improve local water quality (Whitmire and Hamilton 2005), if sediments are disturbed by tillage or other means and then reflooded, the nutrients are often released into the water column. For instance, wetlands restored from agricultural lands adjacent to Upper Klamath Lake released P to surface waters when first flooded (Aldous et al. 2007). At Lower Klamath NWR, water quality impacts of wetlands include higher conductivity and water temperatures but lower turbidity. Outflow P and N concentrations are higher than inflow concentrations, but loads are lower, with 19–51% of the mass of P and 55–77% of the mass of N entering wetlands on Lower Klamath NWR retained; seasonal wetlands retain less P than permanent wetlands. The overall effect of Klamath NWR wetlands is to decrease net N and P loads but increase the ratio of bioavailable P to N in outflows (Mayer 2005).

AGRICULTURAL CHEMICAL SEQUESTRATION

Wetlands also serve as sinks for agricultural chemicals. With numerous urban areas and about 2.8 million ha of irrigated agricultural lands in CVCA (Budd et al. 2009) and 200,000 ha in KLBA (Gannett et al. 2007), a wide variety of agricultural and urban chemicals, including an increasingly potent class of pyrethroid insecticides (Weston et al. 2004), find their way into regional wetlands. Constructed wetlands in the San Joaquin Valley have been shown to be effective at reducing the levels of pyrethroid and organophosphate insecticides (as well as bioavailable P) in agricultural drainwaters, primarily through sedimentation of particles (Budd et al. 2009; Maynard et al. 2009).

MERCURY METHYLATION

Methylation is a product of complex processes that move and transform mercury from its elemental form to its more bioavailable form, methylmercury (Conaway et al. 2008). Sulfate-reducing bacteria are the primary methylators in anoxic estuarine sediment (Compeau and Bartha 1985), although iron-reducing bacteria may also have a role (Kerin et al. 2006). Formation of methylmercury, particularly monomethylmercury, is of environmental concern because it is bioaccumulated and biomagnified to toxic concentrations in higher-trophic-level organisms, including birds and mammals (Conaway et al. 2008). Historical mercury mines in the Pacific Coastal Range and the historical use of mercury for gold amalgamation during gold-mining operations in the Sierra Nevada Mountains introduced large quantities of mercury into CVCA (Domagalski 1998; Alpers et al. 2005). Atmospheric deposition, mostly from coal-fired power plants, is the source of the inorganic divalent form of mercury, which, although occurring in much smaller quantities than mine-derived mercury in CVCA, is more readily converted to methylmercury. Once in surface water, mercury can be converted to another form or attach to particles that settle onto sediments, where it can diffuse into the water column or be resuspended, buried by other sediments, or methylated. Methylmercury can enter the food chain or be released back to the atmosphere by volatilization. Bird feather data (Schwarzbach 2009) indicate that concentrations of mercury in San Francisco Bay have declined over the last 120 years, but Conaway et al. (2007) found no decreasing trends in fish or bivalves. Interestingly, selenium can provide protection from toxic effects of methylmercury in mammals (Yang et al. 2008) and adult birds but worsen them in bird embryos and hatchlings (Hoffman and Heinz 1998).

BIOACCUMULATION AND TRANSFORMATION OF SELENIUM

The toxic effects of selenium in CVCA wetlands made national headlines in the mid-1980s, when waterbird deformities were linked to high levels of selenium in agricultural drainwaters stored in constructed wetlands in Kesterson NWR (Ohlendorf et al. 1986) in the Grassland Ecological Area (Fig. 25.1). Soils in western San Joaquin Valley are rich in selenium, which leaches into the shallow groundwater of the region, a process accelerated by agricultural irrigation. When selenium-rich drainwaters are stored in ponds or wetlands, evaporation can greatly concentrate the element to dangerously high levels. Although removal and burying of contaminated soils was the method used at Kesterson NWR, microbial volatilization of selenium to detoxify soils is also being considered (Wu 2003). These include metal-reducing bacteria such as *Geobacter sulfurreducens, Shewanella oneidensis,* and *Veillonella atypica,* which use different mechanisms to transform bioavailable sodium selenite to less toxic, nonmobile elemental selenium and then to selenide in anaerobic environments (Pearce et al. 2009).

OXIDATION OF PEAT SOILS

In parts of KLBA (Lindenberg and Wood 2009) and in the Delta, microbial oxidation of organic carbon in peat soils is a major factor in the subsidence of drained wetlands (Deverel and Rojstaczer 1996). Exposed wetland soils are subject to aerobic microbial activity, which accelerates organic matter decomposition, mobilizes peat soil nutrients, and increases the subsidence rate. This is accelerated by tillage, especially at high temperatures, which increases air and oxygenated water penetration into the soils. Subsidence occurs as porewater is replaced by air, which more easily compresses than water. Subsidence can be rapid under continual farming (e.g., 6 m in 150 years in the Delta [Miller et al. 2008]), greatly increasing the

potential for levee failure and flooding. Restoring marshes to rebuild organic matter shows promise as a way of reversing or slowing subsidence (Miller et al. 2008).

GREENHOUSE GASES

Wetlands can be both important sinks and sources for greenhouse gases. Because of their low turnover rate of organics, wetlands can be an important sink for C and N. However, because of their water-saturated anaerobic soils, wetlands can be an important source of methane (Intergovernmental Panel on Climate Change 2007), which is a much more potent greenhouse gas than carbon dioxide and responsible for about a quarter of all global warming (Mosier 1998). The amount of methane emitted from a wetland is largely determined by the nature of its vegetation and soil microbes that interfere with the production and consumption of methane (Laanbroek 2010). When sulfate is highly available, as in many brackish and tidal wetlands, production of methane is inhibited. However, most CVCA and KLBA wetlands are freshwater, with low sulfates, and are likely not to sequester enough carbon to offset methane release. One exception is the Delta, where, although now mostly freshwater, wetlands were once tidal. Thus, sulfates are common, and restoration on peat islands there to reverse subsidence (Miller et al. 2008) may also reduce greenhouse gases (http://miller-mccune.com/science_environment/Protect-a-Levee-Protect-the-World-844).

Plant Communities

Community Composition

Wetland plant communities in CVCA and KLBA vary by wetland type, water salinity, soils, and regional climate (Mason 1957). They are greatly impacted by management. Plants in deep semi-perms commonly include milfoil *(Myriophyllum)* and other submergents, floating plants such as water lilies *(Nuphar luteum)* and duckweed *(Lemna),* rooted aquatics such as watercress *(Rorippa nasturtium-aquaticum),* and emergents such as bulrushes *(Scirpus)* and cattails *(Typha)* (Fiedler 1996). Seasonal wetlands usually include more sedges *(Carex),* spikerushes *(Eleocharis),* rushes *(Juncus),* smartweeds *(Polygonum),* horsetails *(Equisetum),* and grasses. Other common plant species include dock *(Rumex)* and various willows *(Salix).*

Most seasonal and semi-perm wetlands in CVCA and KLBA are managed primarily to provide food and refuge for wintering waterfowl. Managers use flooding schedules and periodic disking or burning to encourage plant species that provide abundant seeds and habitat for aquatic invertebrates preferred as food for ducks and to avoid dense stands of less desirable plants such as cocklebur *(Xanthium strumarium),* Baltic rush *(Juncus balticus),* saltgrass *(Distichlis spicata),* and bermudagrass *(Cynodon dactylon)* (Smith et al. 1994). In most CVCA wetlands, managers target growth of swamp timothy, watergrass *(Echinochloa crusgalli),* and smartweed *(Polygonum),* or a mix of these and other wetland (e.g., alkali bulrush, *Juncus, Paspalum distichum*) or moist-soil plants. In KLBA, these include red goosefoot *(Chenopodium rubrum),* witchgrass *(Panicum capillare),* and beggartick *(Bidens)* (Fregien 1998). The plant community of managed wetlands in Suisun Marsh (a naturally brackish marsh) is quite different from elsewhere in CVCA and KLBA (Baldassarre and Bolen 1994). Pickleweed *(Salicornia virginica)* and saltgrass cover the greatest area of Suisun wetlands. However, management has reduced these and encouraged duck food species such as fathen *(Atriplex patula),* brass button *(Cotula coronopifolia),* and alkali bulrush (Rollins 1991), although sea purslane *(Sesuvium verrucosum)* and watergrass seeds were preferred by ducks feeding there in a recent study (Burns 2003). The natural plant communities of vernal pools and alkali sinks differ from those of managed wetlands.

Vernal pools hold water long enough to inhibit upland plants but not long enough to permit typical marsh plants. Vernal pools contain a wide variety of locally unique and endemic plants (e.g., Solano grass, *Tuctoria mucronata;* Holland and Jain 1977) that changes as pools flood and then desiccate after winter rains (Silveira 2000). Exotic species richness and cover are greater in altered than in natural pools (Gerhardt and Collinge 2003). Alkali sinks are shallow basins with prolonged inundations and sparse vegetation due to calcium-derived salts. Typical plants include iodine bush *(Allenrrolfea occidentails),* bush seepweed *(Suaeda moquinii),* saltgrass, saltbush *(Atriplex),* and arrowgrass *(Triglochin).*

Animals

There are 490 vertebrate species that regularly inhabit CVCA (279 bird, 88 mammal, 40 reptile, 18 amphibian, 65 fish; Bunn et al. 2007) and 420 that have been recorded from KLBA (274 bird, 78 mammal, 32 reptile and amphibian, 36 fish; www.fws.gov/klamathbasinrefuges/1KBNWRchecklist.pdf). Specific taxa are important to regional wetlands because of their direct impact on wetland ecology or because they are a focus of management because they are hunted or of conservation concern (i.e., state or federal endangered, threatened, sensitive, or vulnerable species).

Birds

CVCA and KLBA are both internationally renowned for their great abundance and diversity of birds, including North America's largest wintering population of bald eagles *(Haliaeetus leucocephalus)* in KLBA. As part of the Pacific Flyway, CVCA and KLBA regions share many of the same migratory bird species. Although many birds use dry wetland basins and associated habitats, wetland-dependent species (i.e., waterbirds) in KLBA and CVCA can be grouped based on taxonomy and ecology into eight groups (see below). KLBA wetlands are frozen throughout winter, and their primary importance to waterbirds is as breeding and migration habitat. CVCA wetlands rarely freeze, and so they provide wintering habitat for most Pacific Flyway waterbirds in addition to migration and breeding habitat.

WATERFOWL

Most ducks and geese, but not swans, are hunted in KLBA and CVCA during fall and winter. Substantial numbers of waterfowl, mostly dabbling ducks, breed in CVCA and KLBA. California breeding populations during 1990–2008 averaged 605,000 ducks, composed mostly of mallards (*Anas platyrhynchos,* 64%), gadwall (*A. strepera,* 14%), cinnamon teal (*A.*

cyanoptera, 7%), and northern shoveler *(A. clypeata,* 6%), but also 12 other species (USFWS 2009a). About 1,200 pairs of western Canada geese *(Branta canadensis moffitti)* nest in California (Pacific Flyway 2000), primarily in KLBA and Sierra foothills, but also in CVCA.

Although breeding populations are substantial, abundance and species diversity are much greater during winter in CVCA and during spring and fall migration in KLBA, with 20 duck and 5 goose species common. Gilmer et al. (1982) estimated about 10–12 million waterfowl annually winter in or pass through CVCA. Recent (1998–2001) peak abundance averaged 4.8 million in California during early January (> 90% in CVCA) and 1.1 million during fall and 670,000 during spring migration in KLBA (Gilmer et al. 2004). Up to 65% of the northern pintails *(A. acuta)* in North America winter in CVCA, and despite continental declines, they are still the most common species (Fleskes and Yee 2007). During the January 2009 "midwinter" survey, about 3.6 million ducks (33% northern pintail, 20% northern shoveler, 14% green-winged teal [*A. crecca*], 11% American wigeon [*A. americana*], 6% mallard, and 16% other species), 1.3 million geese (61% snow [*Chen caerulescens*] or Ross' goose [*C. rossii*], 30% greater white-fronted goose [*Anser albifrons*], 9% Canada [*Branta canadensis*] or cackling [*B. hutchinsii*] goose), and 98,000 tundra swans *(Cygnus columbianus)* were counted in California (89% of the ducks and > 97% of geese and swans were in CVCA) (USFWS 2009c).

The types of wetlands used by waterfowl vary among species and season. Only diving ducks (mostly ruddy duck [*Oxyura jamaicensis*], canvasbacks [*Aythya valisineria*], redheads [*A. Americana*]), wood ducks *(Aix sponsa),* and some Canada geese and mallards commonly nest over water in emergent vegetation, on muskrat *(Ondatra zibethica)* huts, or (for wood ducks) in trees or nest boxes. Thus, for most breeding waterfowl, wetlands are used primarily for pair isolation, feeding, and brood habitat. Semi-perms also provide critical molting habitat for postbreeding ducks; these habitats are more abundant in KLBA, and many mallards and other waterfowl breeding in CVCA travel to KLBA marshes to undergo feather molt (Yarris et al. 1994). During winter, wetlands are important for roosting, feeding, and courtship. During hunting season, waterfowl concentrate during the day on areas where hunting is not allowed and fly out (ducks primarily at dusk, geese in the morning and evening) to other wetlands and rice (Sacramento Valley) and other crop fields to feed (Fleskes et al. 2003, 2005).

SHOREBIRDS

CVCA supports more shorebirds during winter and spring than any other inland site in western North America and, in fall, is the second most important inland site after Great Salt Lake, Utah (Hickey et al. 2003). About 33 shorebird species migrate through KLBA and CVCA or winter in CVCA, with total abundance in CVCA during the early 1990s averaging 134,000 in August, 211,000 in November, 303,000 in January, and 335,000 in April (Shuford et al. 1998). Most species primarily use open habitats such as seasonal wetlands, mudflats, and agricultural fields. Although shorebirds were widely hunted until the early 1900s, only Wilson's snipe *(Gallinago delicate)* is currently considered a game species. Seven species nest in CVCA and KLBA, with black-necked stilt *(Himantopus mexicanus),* American avocet *(Recurvirostra americana),* and killdeer *(Charadrius vociferus)* most common (Hickey et al. 2003; Shuford 2009).

COOTS AND SECRETIVE MARSH BIRDS

The American coot *(Fulica americana)* is an abundant breeder and migrant in KLBA and CVCA and year-round resident in CVCA (> 550,000 counted in January 2009; USFWS 2009c). Coots are highly visible and use a wide variety of wetland types, whereas other species in this group are more secretive and mostly use dense emergents. The common moorhen *(Gallinula chloropus)* is a common resident in CVCA but is very rare in KLBA (Greij 1994). Sora *(Porzana carolina)* and Virginia rails *(Rallus limicola)* are less common but regular breeders in KLBA and year-round residents in CVCA marshes. Although rails are hunted in many states, only coots and moorhens are currently legal game species in California and Oregon. The yellow rail *(Coturnicops nobeboracensis)* is a rare local breeder in KLBA (previously in CVCA) and a rare winter visitor in Suisun Marsh (Stern et al. 1993; California Department of Fish and Game [CDFG] 2008). The California subspecies of black rail *(Laterallus jamaicensis coturniculus)* is found mostly in tidal marshes of San Francisco Bay but also occur in small numbers in some CVCA and Sierra foothill marshes (Estep et al. 2009). American *(Botaurus lentiginosus)* and least bitterns *(Ixobrychus exilis)* are regular breeders in KLBA and year-round residents in CVCA marshes.

COLONIAL-NESTING WADERS

Waders are common in CVCA and KLBA, nesting in colonies in dense emergent wetland vegetation or trees and feeding in flood-irrigated pastures, hayfields, and wetlands. Shuford et al. (2004) estimated 339 pairs of great egrets *(Casmerodius albus),* 3,162 pairs of white-faced ibis *(Plegadis chihi),* and 98 pairs of great blue herons *(Ardea herodias)* nesting in KLBA in 2003. During the same May–August surveys, they also recorded up to 392 black-crowned night herons *(Nycticorax nycticorax),* 88 snowy egrets *(Egretta thula),* and 2 green herons *(Butorides striatus).* These species are all also common in CVCA, and their populations increased during 1966–89; white-faced ibis, a species of special concern (CDFG 2008), increased faster than others (Fleury and Sherry 1995). Cattle egrets *(Bubulcus ibis)* have been a common resident and local breeder in CVCA since the 1960s, but are rare in KLBA (Garrett and Dunn 1981).

COLONIAL-NESTING SEABIRDS

American white pelicans *(Pelecanus erythrorhynchos),* double-crested cormorants *(Phalacrocorax auritus),* gulls, and terns typically nest in colonies, mostly on islands in large wetlands isolated from disturbance and mammalian predators. An exception is the black tern *(Chlidonias niger)*, which nests in floating-anchored substrates or on mounds in marshes (CDFG 2009). Large wetlands with isolated islands are more prevalent in KLBA, and KLBA is a more important breeding area than CVCA (Shuford et al. 2004; CDFG 2009). Both regions host breeding populations of Caspian *(Sterna caspia),* Forster's *(S. forsteri),* and black terns; ring-billed *(Larus delawarensis)* and some Franklin's gulls *(L. pipixcan)* also breed in KLBA.

GREBES

KLBA and CVCA are important to several species of grebes. KLBA is of regional or continental importance to breeding populations of eared *(Podiceps nigricollis),* western *(Aechmophorus occidentalis),* and Clark's *(A. clarkia)* grebes (Shuford et al. 2004); eared and western grebes also nest irregularly in small numbers on a few wetlands in CVCA (CDFG 2009). Pied-billed grebes *(Podilymbus podiceps)* are common nesters in both regions and year-round residents in many CVCA wetlands. A few horned *(Podiceps auritus)* and red-necked grebes *(P. grisegena)* are present during breeding season and may nest in KLBA.

SANDHILL CRANES

Two populations of sandhill cranes *(Grus canadensis)* migrate through KLBA and winter almost exclusively in CVCA; both have special conservation status (Littlefield and Ivey 2000; CDFG 2008). The CVCA population of the greater sandhill crane *(G. c. tabida)* is state-threatened (CDFG 2008) and breeds in KLBA; about 8,500 winter in CVCA. The Pacific Flyway population of the lesser sandhill crane *(G. c. canadensis)* is a species of state concern and breeds in southern Alaska; about 25,000 winter in CVCA. Nesting in KLBA typically occurs in open-grazed meadow-wetland habitat, and wintering cranes forage mostly in crop, alfalfa, or fallow fields but use open wetlands as night-roost habitat (CDFG 2009).

OTHER WETLAND-DEPENDENT BIRDS

Other birds that rely heavily on flooded wetlands in KLBA and CVCA include blackbirds, marsh wrens *(Cistothorus palustris),* belted kingfishers *(Ceryle alcyon),* and northern harriers *(Circus cyaneus).* Tricolored blackbirds *(Agelaius tricolor)* are largely endemic and resident to California and are of state and federal concern (CDFG 2008). Most nest in large (thousands of birds) colonies in CVCA marshes; a few colonies are in KLBA (Beedy and Hamilton 1999). Populations declined > 90% during 1930–2000 to about 260,000 in 2005 (CDFG 2008). Yellow-headed blackbirds *(Xanthocephalus xanthocephalus)* are also of state concern and occur primarily as a summer breeder and migrant, with some wintering in CVCA (CDFG 2008). They nest in small colonies in emergents over deep water. The red-winged blackbird *(Agelaius phoeniceus)* is an abundant resident, but the rare Kern red-winged blackbird *(A. p. aciculatus)* is a subspecies of concern that breeds only east of, and winters in, San Joaquin Valley (CDFG 2008).

Mammals

Several mammals are important to the ecology of KLBA and CVCA wetlands. Muskrats feed upon emergent vegetation, creating open-water habitat; their houses are also used by nesting waterbirds. Beavers *(Castor canadensis)* create ponds in streams but are often a nuisance to managers when they dam water control structures and destroy tree plantings. River otters *(Lutra canadensis),* mink *(Mustela vison),* and raccoons *(Procyon lotor)* are important predators of waterbirds and their eggs and other wetland wildlife. Several bat species of conservation concern occur in CVCA and KLBA; because these bats forage over water on insects and require drinking water, wetland management plays an important role in their ecology. The San Joaquin antelope squirrel *(Ammospermophilus nelson),* two species of kangaroo rats *(Dipodomys ingens, D. nitratoides)* that occur in San Joaquin Valley alkali sinks, and the salt marsh harvest mouse *(Reithrodontomys raviventris halicoetes)* in Suisun Marsh are of conservation concern (Bias 1995; CDFG 2009).

Amphibians and Reptiles

The California red-legged frog *(Rana aurora draytonii)* has almost completely disappeared from CVCA (Jennings 1995) and, along with the California tiger salamander *(Ambystoma californiense)* and western spadefoot toad *(Spea* [*Scapbioupus*] *hammondii),* which remain largely in rain-pool habitats in San Joaquin Valley (Jennings and Hayes 1994), is of conservation concern. Native western toads *(Bufo boreas)* and Sierran treefrog *(Pseudacris sierra*) are common in both CVCA and KLBA. In KLBA, the Oregon spotted frog *(R. pretiosa),* which remain only in isolated populations, the Southern long-toed salamander *(A. macrodactylum sigillatum),* and Great Basin spadefoot *(S. intermonana)* are also present (www.uoregon.edu/~titus/herp/rangemaps.html). The introduced American bullfrog *(R. catesbiana)* is a very common invader in both regions. Native aquatic reptiles that are the focus of wetland managers are the threatened giant garter snake *(Thamnophis gigas)* in CVCA and Pacific pond turtle *(Actinemys marmorata)* in both CVCA and KLBA. Nonnative red-eared sliders *(Trachemys scripta)* and soft-shelled turtles *(Apalone)* (www.californiaherps.com) may negatively impact native species in some CVCA wetlands.

Fish

CVCA and KLBA wetlands are important fish habitat, with cyprinids (minnows and shiners), centrarchids (sunfish, crappie, and bass), and ictalurids (catfish, bullheads) most common (Moyle 2002). The introduced common carp *(Cyprinus carpio)* is a problem in many semi-perms, uprooting plants and reducing water clarity and invertebrate populations (Smith et al. 1994). The maze of canals that connect many marshes to rivers entrap migrating anadromous fish, including Chinook salmon *(Oncorhynchus tshawytscha),* steelhead trout *(O. mykiss irideus),* lampreys *(Lampetra),* sturgeons *(Acipenser),* and striped bass (*Morone saxatilis,* introduced in CVCA in 1879). Two endangered species, the Lost River *(Deltistes luxatus)* and shortnose *(Chasmistes brevirostris)* suckers, are present in wetlands in Upper Klamath and Tule Lake NWRs (Hicks et al. 1999).

Insects and Other Invertebrates

The community of aquatic and semiaquatic invertebrates in CVCA and KLBA wetlands varies by hydropattern, plant community species and biomass, water chemistry, soil, and wetland age (Eldridge 1990). In seasonal wetlands, Chironomidae, Cladocera, and Copepoda were consistently most numerically dominant in both KLBA and CVCA; Hemiptera (primarily Corixidae) was also dominant in Sacramento Valley. Ostracoda, Oligochaeta, and Hemiptera were also dominant in restored seasonals in KLBA (Fregien 1998). Invertebrates are important to regional wetlands mainly because they are a focus of management due to their importance as water-

fowl food or because they are rare and of conservation concern. Diptera, especially Chironomidae, are very important foods for waterfowl, whereas highly mobile species, such as water boatmen (Corixidae), are generally consumed less than available (Batzer et al. 1993). Species of conservation concern are mostly vernal pool species and include the delta green ground beetle *(Elaphrus viridis),* summer tadpole shrimp *(Triops longicaudatus),* and several species of fairy shrimp *(Linderiella occidentalis, Lepidurus packardi, Branchinecta).*

Key Ecological Controls

Management Objective

With the hydrology of KLBA and CVCA greatly altered and most wetlands under intensive management, the management objective of a particular wetland largely controls its ecology. Thus, two groups of species focused upon by managers, hunted waterfowl and species of conservation concern, are key ecological controls for CVCA and KLBA wetlands.

HUNTED WATERFOWL

Most CVCA and KLBA wetlands are managed primarily to provide food and refuge for wintering, migrating, and breeding waterfowl. These include wetlands on most NWRs and State Wildlife Areas that were purchased and are managed, at least in part, with hunting-based funds, and the > 60% of California's wetlands that are privately owned and managed due to hunter support (Baldassarre and Bolen 1994; CVJV 2006). Hydropatterns, timing of fall flood-up, vegetation, and other wetland characteristics are managed primarily to provide habitat, maximize production of food resources, and facilitate sport harvest of these species.

SPECIES OF CONSERVATION CONCERN

Some wetlands, mostly vernal pools but also others, are protected and managed primarily to support threatened, endangered, or other species of conservation concern. In addition, management practices on all wetlands are restricted in that they must not harm these species. Also, management of many NWR wetlands, even though focused on waterfowl, is often tailored toward improving habitat for species of concern. One key species is the threatened and CVCA-endemic giant garter snake. The giant garter snake has summer-flooded habitat needs that are not fulfilled by seasonal wetlands left unflooded during summer to grow food plants for wintering waterfowl (www.californiaherps.com/snakes/pages/t.gigas.html). Thus, inclusion of some semi-perms in wetland restoration projects is encouraged to avoid negative impacts on the giant garter snake, especially if conversion of rice fields (an important snake habitat) is involved (USFWS 2006). Endangered fish, such as the spring run of Chinook salmon, and in KLBA, the Lost River, shortnose, and Klamath largescale suckers *(Catostomus snyderi),* are key species that compete for water and restrict timing and quality of wetland outflows. In addition, some wetlands in the Yolo Bypass part of the upper Delta region may be managed specifically to provide important rearing habitats for endangered fish (www.yolobypass.net/docs/FINAL_PF_Bypass_Conservation_Measure.pdf). Other rare, endemic, or sensitive species include the native amphibian species that have declined (Fisher and Shaffer 1996) in CVCA due to habitat destruction, windborne pesticides (Davidson et al. 2002), introduced species, and other factors (www.californiaherps.com). Also important are the many locally rare endemic vernal pool plants and invertebrates, and palmate-bracted bird's beak *(Cordylanthus palmatus*), an endangered San Joaquin Valley alkali sink plant (Coats et al. 1993).

Water Availability

In addition to management objectives, the timing, amount, and quality of water supplies available are key factors controlling the types, quality, and amount of wetlands in CVCA and KLBA. Evapotranspiration rates are greater and precipitation lower in CVCA (especially the San Joaquin Valley) than in KLBA. Thus, water required for wetlands in CVCA (seasonals: 4.1–8.5 acre-ft/acre; semi-perms: 7.4–14.3 acre-ft/acre) is much greater than in KLBA (seasonals: 1.8–3.5 acre-ft/acre; semi-perms: 3.1 acre-ft/acre) (Mayer and Thomasson 2004; USFWS 2000). Multiyear drought reduces water availability that restricts summer irrigations, reduces seed production, and delays fall flooding.

The discovery of embryotoxic effects of selenium on waterbird reproduction at Kesterson NWR (Ohlendorf et al. 1986) caused managers to eliminate or modify their use of agricultural drainwaters to manage wetlands, especially in San Joaquin Valley (Paveglio and Kilbride 2007). During the 1960s and 1970s, many wetlands were laser-leveled, especially in San Joaquin Valley, to reduce wetland water needs. However, the Central Valley Improvement Act of 1992 (Davis 1992) enhanced CVCA refuge water supplies and, along with recognition of the value of habitat diversity, has led to reconstruction of wetland basin contours and increased plant diversity (www.dfg.ca.gov/lands/wetland/public.html).

Conservation Concerns and Challenges

The majority of the concerns and challenges that wetlands and wetland-dependent species face in CVCA and KLBA can be traced to the rapid rate of human population growth and the resulting increased pressures on the landscape. The challenges are especially great in CVCA, where the human population is expected to triple by 2040, a much higher rate than in nearly all other regions (American Farmland Trust 1995). The impact of this population growth on wetland conservation can be manifested in several ways.

Urbanization and Agricultural Conversion

Habitat loss and fragmentation due to urbanization and increased need for agricultural production are the most important factors affecting wetland-dependent species in CVCA and KLBA (CDFG 2005). Expansion of urban areas and road and power networks can lead to wetland loss and fragmentation. Recent examples include the District 10 Bypass in the Sacramento Valley (Griffiths et al. 2000), the proposed City of Los Banos expansion (Weissman and Strong 2001), the High Speed Rail route (Grassland Staff 2007) dissecting the Grassland Ecological Area, and routing of proposed power lines through CVCA wetlands (Ducks Unlimited 2009). The quality

of urbanized wetlands is often lower due to altered hydropattern and biogeochemistry, runoff of contaminants and fertilizers, increased mosquito abatement, increased human disturbance, and increased predation by homeowner cats. Although wetlands are protected, development pressure in CVCA is high, and any reduction in official protection status is a concern (Kay 2001).

Inadequate Water Supplies

Water is limited and is key to wetland maintenance in CVCA and KLBA (Mayer and Thomasson 2004). Increased competition from urban and agricultural users, along with in-stream demands for maintaining endangered salmon and other fish species (e.g., suckers in KLBA, delta smelt [*Hypomesus transpacifcus*] in CVCA [CDFG 2005]) will continue to reduce availability and increase costs of water for wetland management. Pumping groundwater is an expensive alternative to surface-water diversions, and some aquifers in southern San Joaquin Valley are already depleted and contain elevated arsenic levels (Welch et al. 2006; Faunt et al. 2009). Add in projected impacts of climate change and an aging water delivery infrastructure, and KLBA and CVCA are among the most likely regions in the United States to experience major water supply conflicts (Dziegielewski and Kiefer 2007). Water shortages can negatively impact wetland-dependent wildlife even if adequate water is maintained for wetlands. Water transfers from water-"rich" regions of CVCA (i.e., the Sacramento Valley rice-growing region) to water-"poor" regions (e.g., Southern California, San Joaquin Valley) are viewed as a useful method of dealing with critical regional shortages (U.S. Department of Interior 2009). However, one potential outcome of water transfers is idling of irrigated crops such as rice, which provide many of the same functions as wetlands (Elphick 2000). The mix of wetlands and flooded rice fields in the Sacramento Valley provides superior waterbird habitat compared with wetlands within a non-rice landscape (Fleskes et al. 2007). Thus, water transfers that reduce acreage or postharvest flooding of rice may be detrimental to waterbirds even if water supplies for wetlands are maintained.

Poor-Quality Wetland Water Supply

Poor-quality water can have detrimental impacts on wetland fauna and result in suboptimal wetland management. With water in short supply in CVCA and KLBA, most water used for wetland management has passed through agricultural lands or has been comingled with urban and agricultural runoff. CVCA waters are laden with up to 40,000 tons of contaminants annually (Bunn et al. 2007), including chemical fertilizers, herbicides, and pesticides, and from San Joaquin Valley soils, trace elements such as selenium that can concentrate to dangerous levels in wetland organisms (Ohlendorf et al. 1986). In addition, the estrogenic activity of some agricultural chemicals is a potential concern for both wildlife and humans (Johnson et al. 1998). Use of agricultural drainwaters can also lead to discharge restrictions that inhibit wetland management. For example, concerns about the quality of waters entering the San Joaquin River from wetlands in the Grassland Ecological Area may require that spring drawdowns be delayed by a month so that the highly saline water enters the river when reservoir releases are adequate to dilute the salts (Quinn and Hanna 2003). This modified hydrology may cause retention of salts, reducing wetland plant productivity and waterbird food availability (Ortega 2009). Waters used for management of KLBA wetlands were found to have high temperatures, elevated pH, low dissolved oxygen, and un-ionized ammonia at levels known to kill fish and cause malformation of developing frog embryos (see Boyer and Grue 1995).

Reduced Support for Wetland Conservation and Management

Concerns over the perceived role that wetlands can play in human disease and contamination of water supplies, and impacts of a perceived oversupply of wetlands on waterfowl hunting success may erode public support for continued wetland conservation and restoration programs in CVCA and KLBA. This could result in fewer resources (monetary and water) available for wetland conservation and management.

HUMAN DISEASE

Wetlands, especially those in CVCA, are interspersed among large centers of human population. Concerns over the possible role of wetlands in harboring vectors of West Nile virus, equine encephalitis, avian flu, and other human diseases may erode public support for continued wetland conservation and restoration programs. As society is confronted with new and emerging mosquito-borne diseases, the need to simultaneously protect human health and wetland functions will only increase (Society of Wetland Scientists 2009). Costs assessed for mosquito abatement may inhibit habitat managers from flooding wetlands when potential liability exists, thus reducing wetland productivity and seasonal availability. In addition, laser leveling to precisely control water levels has been recommended for restored wetlands (Knight et al. 2003), but, at the same time, this reduces habitat diversity. Some commonly used organophosphate (e.g., malathion, naled) and synthetic pyrethroid (e.g., permethrin, resmethrin, sumithrin) adulticides kill not only mosquitoes but also other invertebrates (www.epa.gov/opppmsd1/PR_Notices/pr2005-1.pdf). Widespread introduction of mosquitofish *(Gambusia affinis)* into wetlands can have detrimental impacts on native fauna and may not be any more effective than native species (Pyke 2008). Solutions will depend upon improved communication between the mosquito abatement and wetland management communities (Dale and Knight 2008) to develop protocols that provide adequate wildlife habitat while avoiding creation of habitat for mosquito species that most threaten human health.

METHYLMERCURY

Concerns over the role of wetlands in conversion of environmental mercury to the more dangerous methylmercury form may impede wetland restoration in CVCA. For example, a high proportion of the methylmercury entering the Delta comes from upstream areas (Marvin-Dipasquale et al. 2007), and local governments may restrict that new wetland restoration not contribute further (www.delta.ca.gov/meetings/pdf/2008/112008_item_24_Y.pdf). The production of methylmercury in individual wetlands depends upon an array of factors, including labile organic matter production, timing and

inundation of flooding, and wetland location within a drainage basin. For instance, Delta marshes had higher monomethylmercury/total mercury ratios than open water (Heim et al. 2007), and Ackerman et al. (2010) found that total mercury concentrations were higher in some insects in permanent wetlands than in temporary wetlands or rice fields. However, mercury concentrations in fish were higher in rice fields than in permanent wetlands (Ackerman and Eagles-Smith 2010). This issue will require careful placement and design of wetland restoration projects.

WATERFOWL HUNTER DISSATISFACTION

Over 60% of wetlands in California are privately owned and managed, and since hunters provide much of the political and financial support for wetland conservation in the region, the future of wetland conservation depends heavily on the continued support of the hunting community (Baldassarre and Bolen 1994; CVJV 2006). Wetland restoration and increased postharvest flooding of rice fields (Fleskes et al. 2005b) have improved body condition (Fleskes et al. 2009), reduced daily flight distances, and changed local movement patterns and regional distribution of some hunted species of waterfowl (Fleskes et al. 2005). Thus, hunters in some traditional hunting areas have reported seeing fewer waterfowl and have experienced reduced harvest rates (http://madduck.org). Over time, this could erode hunter support for continued wetland conservation.

Bioenergetics modeling (CVJV 2006) indicates that food resources in CVCA are currently adequate to support current and goal populations of wintering waterfowl. However, food supplies are currently abundant in large part because rice and other crop seeds are plentiful. Modeling indicates that if changes in agricultural policy, cropping patterns, water transfers, or increased harvester efficiency significantly reduce availability of these crop seeds, current wetlands alone could not support desired waterbird populations (CVJV 2006). Thus, to ensure adequate waterbird habitat and food supplies in the future, managers must maintain support for continued wetland conservation from waterfowl hunters, even though doing so may reduce present-day harvest success. Effective communication between conservation program managers and the hunting community will be required to arrive at innovative solutions.

Invasive Species

Invasives are not new to California, likely arriving as early as 1542 with the first European explorers (Williams et al. 2005), but the problem has escalated along with the speed and reach of global trade. Invasive plants are especially problematic in wetlands because they outcompete and hybridize with native plants, reduce habitat value for native wildlife, provide habitat for exotic wildlife and mosquitoes, alter ecosystem functions and hydrology, and reduce efficiency of water delivery by slowing flow, clogging structures, and increasing evapotranspiration (Bossard et al. 2000). Especially or potentially problematic invasive plants in regional wetlands (www.cal-ipc.org/ip/management/plant_profiles/index.php) include (1) perennial pepperweed *(Lepidium latifolium),* an aggressive invader that forms dense rooted stands and has increased greatly since 1995; (2) water-primrose *(Ludwigia hexapetala, L. peploides),* which forms dense mats on and below the water surface and has expanded greatly in CVCA during the 2000s; (3) purple loosestrife *(Lythrum salicaria),* a perennial wetland herb that forms monotypic stands; (4) water hyacinth *(Eichhornia crassipes),* widespread throughout CVCA, with heavy infestations in the Delta that require repeated treatment; (5) Eurasian watermilfoil *(Myriophyllum spicatum),* a submergent that creates dense mats found in several CVCA counties; (6) azolla *(Azolla),* a 1.5–2 cm floating fern that forms dense mats (www.ars.usda.gov/SP2UserFiles/Program/304/ActionPlan2008–2013/3c.pdf), first reported in CVCA in 2008; (7) saltcedar *(Tamarix),* which forms dense thickets in wetland and riparian areas in CVCA that may lower water tables; and (8) bioengineered plants, which provide numerous advantages but also risks (Whitman 2000), and are considered a special class of invasives by some. Although their environmental impact is uncertain, waterfowl and other wetland-dependent wildlife would likely be negatively impacted if cross-contamination by bioengineered rice reduces the overseas market for CVCA rice, and rice acreage declines (Environment California Research and Policy Center 2004).

Other invasive organisms also impact wetlands and wetland-dependent wildlife. Several of the more problematic species in CVCA and KLBA include (1) feral and free-ranging cats *(Felis catus),* which are important predators on birds and small mammals where wetlands are near urban areas (www.dfg.ca.gov/wildlife/nongame/nuis_exo/dom_cat/index.html); (2) red fox *(Vulpes vulpes),* which in CVCA were, until recently, all thought to be nonnative (Lewis et al. 1999) and managed as such (www.dfg.ca.gov/wildlife/nongame/nuis_exo/red_fox/index.html). However, recent genetic analysis indicates red fox in Sacramento Valley are distinct and should be considered native (Moore et al. 2009). Change in red fox status and management could increase predation of wetland birds and their nests, including several of conservation concern (Lewis et al. 1999). Also problematic are (3) bullfrogs, a predator of young endangered giant garter snakes (Wylie et al. 2003) and an obvious threat to native amphibians (but see Hayes and Jennings 1986); (4) chytrid fungus, a fungal pathogen *(Batrachochytrium dendrobatidis*) that has been recently associated with deaths of a wide array of amphibians (Daszak et al. 2003); and (5) exotic crustaceans and mollusks (e.g., Chinese mitten crab [*Eriocheir sinensis;* CDFG 2003], New Zealand mudsnail [*Potamopyrgus antipodarum*], quagga mussel [*Dreissena bugensis*], and zebra mussel [*D. polymorpha*]), capable of impacting water delivery or wetland environments.

Global Climate Change

Climate change models predict substantial changes in temperature and precipitation in CVCA and KLBA watersheds (Cayan et al. 2008), which have potential to exacerbate all of the above issues. These include worsening water shortages and quality by altering timing and amounts of rainwater and snowmelt flooding and increasing evapotranspiration rates that could lead to less water available for wetland management; changing the environment in favor of exotic diseases and invasives; changing ecology of wetlands and wetland-dependent wildlife (Bauer et al. 2008); and altering when and where resources are available and needed for migratory birds. For example, warmer springs may dry CVCA habitats quicker, forcing waterbirds to KLBA earlier, where they may find reduced availability of temporary wetland habitats. Extreme winter storms and sea-level

rise will increase the likelihood of levee collapse in the Delta and conversion of Delta and Suisun Marsh wetlands from fresh to saltwater. Conservation programs and reservoir operations will need to adjust to avoid misdirecting priorities and optimally manage flood risk and water supplies (Brekke et al. 2009).

Conclusions

Wetlands and wetland-dependent wildlife in both KLBA and CVCA face immense challenges due to intense agriculture, increasing urbanization, increasingly limited water resources, and an altered landscape. Despite great losses, both regions are still rich in diversity and immense abundance of natural resources that are the focus of broadly supported conservation efforts. The importance of these wetland ecosystems to the economy and health of humans and natural fauna requires that managers overcome uncertainties of possible climate change impacts and other challenges and work to ensure wetland ecosystems in the regions continue to flourish.

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Wetland Habitats of North America

Ecology and Conservation Concerns

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