United States Department of Agriculture

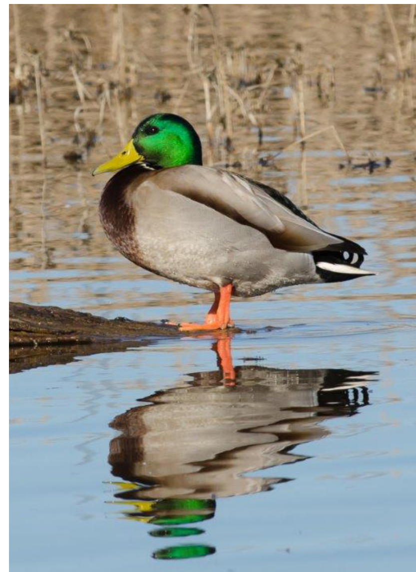
Conservation Effects Assessment Project (CEAP)

Science Note

Effects of Wetland Habitat Quality and Drought on Breeding Waterfowl

Key Takeaways

- California's breeding waterfowl face immense pressure due to the decline of habitat resources exacerbated by drought.
- Breeding waterfowl habitat competes with agriculture and urban areas for limited water supplies, while nest and brood survival are threatened by disturbance and predators.
- At the regional level, drought affects waterfowl populations, generally displacing them from drier to wetter areas.
- While drought severity is a key factor determining waterfowl population fluctuations, population declines in normal and above-normal water years suggest other factors contribute.
- Our findings indicate that adjacent land use threats are an important factor affecting waterfowl populations across all breeding grounds in California.
- As drought frequency and severity increase due to climate change, long term persistence of waterfowl in the state will require conserving more habitats in the Sacramento and Northeastern breeding regions where wetlands and water are more abundant.
- Limiting threat encroachment on breeding habitats and considering proximity to land uses that reduce habitat quality would further wetland conservation and help support management of waterfowl breeding populations in California.



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This study examined the effect of drought and disturbance on waterfowl breeding success in the California Central Valley.

While drought severity is a key factor determining waterfowl population fluctuations, other factors such as threats from adjacent land use are also important in affecting breeding habitat quality.

California's Breeding Waterfowl are Under Pressure

Loss and deteriorating quality of habitat have led to a global decline in wetland dependent species (Finlayson 2019), including waterfowl in California (California Waterfowl Association 2021). Waterfowl declines from pre-settlement numbers in CA are largely attributed to loss of more than 90% of the state's wetlands, mainly to agriculture and urban development (Dahl 1990). While as many as 500,000 waterfowl reside in the state over spring and summer (Skalos and Weaver 2019), little is known about the availability or quality of the habitats on which they rely. As in many areas of North America, waterfowl identify breeding areas based on wetland size and distribution, but in heavily modified landscapes like California's Central Valley (CCV), access to breeding habitat may be limited by anthropogenic disturbances like agricultural activities and urban development that exacerbate the effect of seasonal droughts on reproductive success.

Drought-induced drying of wetlands during mid-summer imperils brood rearing waterfowl, contributing to a 40% drop in California's breeding waterfowl numbers from 2011 to 2015 (Skalos and Weaver 2015). However, population declines in breeding waterfowl have also been reported in years when water availability was considered normal or above normal,

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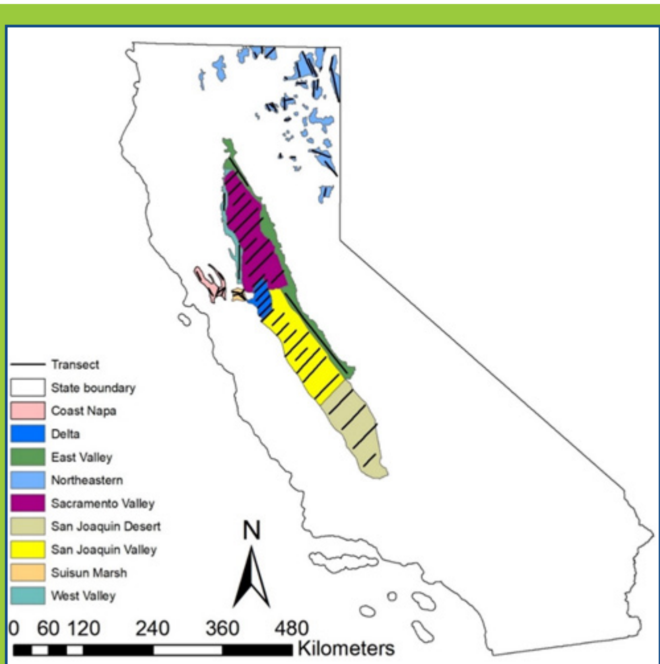

Figure 1. California Department of Fish and Wildlife Breeding Waterfowl Population Survey (CDFW-BPOP) survey areas and transects (solid lines), California, USA, 2007-2019 (Zezulak et al.1991).

suggesting that other factors play a role in population dynamics (Skalos and Weaver 2016). Numerous factors affect habitat quality and breeding success, including anthropogenic disturbance, pollution, and predation that increase stress, energy expenditure, and mortality (Hockin et al. 1992, Horn et al. 2005, Cowardin et al. 1985). Mechanical practices such as mowing, tilling, and harvesting often result in nest losses, or force waterfowl to use suboptimal habitats, making them more prone to predation and exposure to agrochemicals (Hamilton 1993, Duncan and Devries 2018).

The objective of this research was to identify the principal environmental influences on breeding waterfowl populations in the CCV. Our approach was to characterize regional variation and assess population trends along environmental and habitat quality gradients. In order to determine the relative importance of drought severity, wetland area, and habitat quality on mallard (Anas platyrhynchos) and other waterfowl population dynamics, we examined habitat selection as it relates to breeding success in the CCV during a period that included an extended drought (2012-2015) and flooding (2016-2017).

Land Use and Climate Factors in the Breeding Range

The California Department of Fish and Wildlife (CDFW) conducts breeding waterfowl population surveys (BPOP) in nine regions of the state (Figure 1). Our study used BPOP survey data for the years 2007 to 2019 along with land use data for that period, as summarized in Table 1. Four of the nine survey areas are located in the agriculture-intensive CCV basin. Two survey areas lie in the foothills and coastal mountains to the east and west of the CCV and are comprised mostly of cattle pasture with some walnut groves. The Suisun Marsh and Coastal Valley Marshes-Napa regions are dominated by natural habitats, with scant agriculture (<19%) and about 29,000 ha of privately and state managed wetlands that have a long tradition of waterfowl hunting. The remaining survey area is the Northeastern Region, located in the Eastern Cascades and dominated by natural habitats, including lake basins and river valleys that provide habitat for waterfowl, as well as interspersed cropland and pastureland.

Six land cover categories are identified as potential habitat in the nine survey regions (Table 2). The proportion of agricultural and natural land use types varies among the regions, with rice and seasonally flooded and permanent wetlands making up much of the nesting habitat. Other agricultural areas that can serve as habitat are mostly made up of wheat and other cereals (e.g., oat), cover crops (e.g., vetch) and fallow ground. Natural habitats occur mainly on actively managed areas but may include areas of native or non-native vegetation, or a combination of the two. There is little to no managed wetland habitat in the pasture and grove dominated landscape to the east and west of the CCV; in those survey areas, waterfowl rely upon cattle stock ponds, reservoirs, rivers, and riparian areas of streams for breeding habitat. Our estimate of total potential habitat included open water (including aquaculture and flooded bypasses), rice paddies, and privately managed wetlands as well as non-flooded areas of grains, grassland, or pasture. The total area was over 3.5 times that of the previous estimate made in 1982, which was based solely on flooded acres (Gilmer et al. 1982).

CDFW-BPOP Area	***Total Potential Habitat***	***Development***	***Cropland***	***Trees***	***Total Area***
Sacramento Valley	685,740	150,470	146,677	92,994	1,075,881
San Joaquin Valley	511,750	243,048	127,547	206,344	1,088,689
Delta	84,612	4,973	9,188	60,939	159,712
San Joaquin Desert	461,557	181,774	65,793	204,738	913,862
East Valley	475,204	65,053	56,438	12,655	609,350
West Valley	129,104	30,030	10,074	8,062	177,270
Suisun Marsh	39,963	40	1,891	438	42,332
Coast Napa	69,975	8,011	29,148	15,043	122,177
Northeastern	607,161	111,647	18,062	7,465	744,335

Table 1. Land use data for California Department of Fish and Wildlife Breeding Population survey (CDFW-BPOP) areas in California, USA, 2007-2019. Data compiled from U.S. Department of Agriculture National Agricultural Statistics Service's cropland data layer and the Central Valley Joint Venture (USDA NASS 2019, CVJV 2020).

Most of California's climate is classified as Mediterranean, with desert in the southern portions, but the climate, vegetation, and soils of each area vary along longitudinal and elevational gradients. Water shortages occur during droughts, particularly in the Klamath Basin where local wildlife refuges have the lowest priority water rights among the various stakeholders.

Understanding Habitat Quality and Threats to Breeding Waterfowl

Waterfowl use a range of aquatic habitats, but many factors affect the quality and level of use. We estimated breeding waterfowl habitat quality in California using the habitat quality module of the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) modeling platform (Natural Capital Project 2020). The InVEST model is designed to quantify, map, and value the ecosystem services humans derive from nature, The Habitat Quality module of InVEST incorporates the severity and proximity of threats that may influence habitat use. Three parameters are required to calculate habitat quality: 1) habitats used by the organisms in question, ranked from least to greatest in importance; 2) threats to each habitat and the distance at which their effects are apparent; and 3) sensitivity of each habitat to each threat.

Herbaceous and woody wetlands were assigned the greatest habitat importance (a value of 3) due to their contribution to breeding habitat (Webb et al. 2010). We chose to be conservative and assign rice fields (along with open water and aquaculture) an intermediate importance value of 2 because of their lack of diverse topography, natural vegetative food sources, and aquatic invertebrates. Grains and grasslands serve as nesting areas but were given a value of 1 since spring and summer grain crops would be too immature to provide food for breeding waterfowl and unlike rice are not flooded during the summer. Other crops, trees, and developed areas were not considered habitat and given a value of 0. No distinction was made among seasonal, semi-permanent, or permanent wetlands although hydrology (i.e., depth, flood duration, and flood timing) differs and may influence waterfowl use.

CDFW-BPOP Area	Grains	Grass	Rice	Water	Wetlands	Woody Wetlands
Sacramento Valley	107,585	332,612	202,169	11,573	24,435	7,366
San Joaquin Valley	251,677	209,429	2,430	6,855	36,822	4,537
Delta	41,128	17,549	1,401	17,950	5,500	1,084
San Joaquin Desert	220,250	233,450	9	6,500	889	459
East Valley	11,597	431,426	14,622	11,260	615	5,684
West Valley	12,754	112,724	1,650	1,495	65	416
Suisun Marsh	664	7,693	19	11,091	20,449	47
Coast Napa	5,848	47,022	52	6,954	9,475	624
Northeastern	73,933	446,989	230	66,437	18,953	619

Table 2. Average area (ha) of land cover categories identified as potential habitat for breeding waterfowl surveyed by the California Department of Fish and Wildlife Breeding Population (CDFW-BPOP), California, USA, 2007-2019. Data were derived from the National Agricultural Statistics Service Cropland Data Layer (NASS-CDL 2019).

Factors such as human usage, water quality, food availability, and shelter from predators may affect successful nesting, brood rearing and survival. Land uses associated with human disturbance and predator presence are classified as threats when their proximity to habitat results in direct physical harm or causes stress, reduced feeding, or nest abandonment (Korshgen and Dahlgren 1992). The significance and degree to which threats are detrimental to breeding waterfowl (i.e., threat weight) and the distance at which their effects are apparent were determined from literature and incorporated into the InVEST Habitat Quality algorithm to determine the relative level of potential habitat use. For this study, we classified cropland, trees, and developed land use and land cover (LULC) classes as threats.

Cropland was considered a threat due to the potential for disturbance from mechanical soil preparation (tillage, plowing, disking) and agrochemical application (Shutler et al. 2000), with a 5% decrease in duck densities observed for every 1% increase in agricultural land (Wong et al. 2012). Sedimentation due to adjacent soil disturbing activities like tillage may also reduce water depth and increase turbidity of wetlands (Euliss and Mushet 1996, Gleason and Euliss 1998). In addition, agricultural drainage water from cropland can travel via canals and channels, thus damaging effects of croplands may be evident at greater distances than other threats. Forests and orchards were considered threats because they are negatively correlated with breeding waterfowl numbers and potentially serve as perches for aerial predators that depredate nests (Newbold and Eadie 2004, Sedivy 2001). In developed areas, disturbance from human activity leads to responses such as increased vigilance and flushing, which divert birds from feeding and other essential behaviors (Borgmann 2011).

Relative destructiveness of threats is estimated in InVEST by assigning weights between 0 and 1. We tested model sensitivity to threat weight by altering the values of each threat to waterfowl habitat over a range of values and generating model outputs for each scenario. Habitat quantities from model outputs were then used to calculate sensitivity (Table 3) using the method of James and Burges (1982); greater sensitivity (Sr) value indicates greater sensitivity of estimated habitat quantity to a particular parameter. Our weighting of 0.7 for cropland, 0.2 for developed areas, and 0.1 for trees indicates that cropland was nearly 3.5 times more damaging to waterfowl

Sensitivity	Habitat	Habitat Quality Rank	Average S_r Value
By Weight	Trees	Low	-0.47
		Intermediate	-1.82
		High	-27.87
	Cropland	Low	-0.47
		Intermediate	-1.95
		High	**-32.72**
	Development	Low	-0.49
		Intermediate	-1.94
		High	-30.35
By Distance	Trees	Low	-0.55
		Intermediate	-2.04
		High	-31.9
	Cropland	Low	-0.54
		Intermediate	-2.1
		High	**-32.05**
	Development	Low	-0.54
		Intermediate	-2.08
		High	-31.99

Table 3. Sensitivity values (S_r) indicating the direction and strength of influence of threat weight and distance on model estimates of breeding waterfowl habitat quality for each of 3 ranks. Greater S_r values (positive or negative) indicate greater sensitivity to that factor. The greatest S_r values are shown in bold.

habitat than developed areas and 7 times more than trees. Weights for all three were specified to decay linearly to zero at 0.2 km from waterfowl habitats, a conservative distance similar to that used in other wetland studies (Mushet et al. 2014).

Statistical models were then developed using the resulting estimates of habitat area (broken into quality categories) to assess the relative effects of habitat availability and drought severity on waterfowl breeding population size. We used estimates of actual breeding population size based on the annual CDFW breeding population surveys for the period 2007 to 2019 corresponding to available LULC information. Mallards make up about half of the breeding waterfowl population in the CCV, and hunting harvest data demonstrate that most are resident breeders, so separate models were constructed for mallard population counts and for pooled counts of all other waterfowl (Skalos and Weaver 2019, de Sobrino et al. 2017). We constructed both models with parameters based primarily on mallard-habitat relationships; most dabbling duck breeding habitat preferences generally mimic those of mallards and while diving duck and goose breeding habitat requirements differ from those of mallards, they make up only about 7% of the population.

Drought conditions occur regularly each summer in the CCV but occurrence and severity vary annually among regions. For the time frame of the study, we used spatially referenced National Drought Mitigation Center rankings for California to represent specific climate conditions (NDMC 2020).

How Does Habitat Quality Affect Waterfowl Usage?

Habitat quality estimates from the INVEST model varied widely across regions, and final model estimates for the area of low, intermediate, and high-quality waterfowl habitat are provided in Table 4. Habitat quality model outputs ranged from 0 to 3, with 0 indicating no value to waterfowl, 1 low quality, 2 intermediate quality and 3 indicating excellent quality. Low quality habitats may be selected by waterfowl but offer few resources for population growth, while selection of high-quality habitats result in positive population growth. Population growth in intermediate quality habitat falls between that of low and high quality. For example, wetlands surrounded by grassland within 200 meters were assigned the greatest quality rank, whereas wetlands close to cropland, developed areas and trees received a reduced habitat quality ranking depending on their proximity to each threat and that threat's assigned weight. Sensitivity analysis suggested a strong negative influence of cropland on model outcomes, particularly for estimates of the area of high-quality habitat (Table 3; Kahara et al. 2022).

Several a priori statistical models were explored to determine the habitat and climate variables that best explained waterfowl population levels over the study period. Mean population counts were greatest in the Northeastern breeding grounds and Sacramento Valley. Duck populations in all areas were dominated by mallards, but observations of other waterfowl species are detailed in Kahara et al. (2022). The importance of intermediate quality habitat as a determinant of waterfowl numbers was

	Predicted habitat quality area (hectares)					
	Low		Intermediate		High	
CDFW-BPOP Area	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Sacramento Valley	274,487	6,157	164,251	5,139	10,590	1,440
San Joaquin Valley	224,823	19,570	50,177	1,439	11,531	1,033
Delta	32,887	3,224	15,412	235	1,066	142
San Joaquin Desert	252,179	14,237	42,206	1,496	437	109
East Valley	262,248	2,375	24,595	541	1,114	144
West Valley	83,089	1,208	6,037	135	178	17
Suisun Marsh	5,559	146	18,014	395	12,396	588
Coast Napa	22,813	1,032	12,281	222	7,000	143
Northeastern	251,905	13,318	183,519	20,433	9,387	1,083

Table 4. Model predicted mean habitat area (ha) ± standard error (SE) for breeding waterfowl in the California Department of Fish and Wildlife Breeding Population (CDFW-BPOP) survey regions from 2007-2019 in California, USA.

demonstrated by model results for the entire breeding range, with the model that best explained population levels including the natural log transformed area of intermediate habitat quality for both mallards and for pooled waterfowl. The quadratic (i.e. log-log) model of a relationship between area and bird counts predicts use by about 86 more mallards for every 100-ha increase in intermediate quality habitat (Figure 2B). Because the model for all waterfowl, which was mainly based on mallard-habitat relationships, has more variability, that model predicts use by about 13 more waterfowl for every 1000-ha increase (Figure 2A). The observed convex relationship between area of intermediate quality habitat and waterfowl numbers suggests that, above threshold area levels, additional habitat of intermediate quality provides benefits to the population at a declining rate.

The Northeastern region held the most intermediate quality habitat, perhaps explaining the greater abundance of waterfowl as well as observations of greater egg success in that area relative to the Central Valley (Feldheim et al. 2018). The modeled relationship between annual waterfowl population estimates and intermediate habitat quality across all regions was far stronger ($R2=0.81$) than between waterfowl population estimates and wetland area ($R2=0.41$), grasslands ($R2=0.20$), or rice ($R2=0.13$), demonstrating that the influence of adjacent land use, as captured in the habitat quality variable, impacts ultimate habitat selection. In the Suisun Marsh region, the waterfowl model indicated a negative relationship between waterfowl population levels and riparian habitat, but this result was difficult to interpret since there are no known negative effects of riparian areas to waterfowl. In contrast to waterfowl models, rice area was identified as a contributing factor for mallard population dynamics, but the estimated impacts were inconclusive (R2 ranged from -0.17 to 0.29 depending on region). A study by Yarris (1995) indicated that rice paddies flooded in late spring and summer may supplement brood rearing areas of mallards.

The top models did not include the area of high-quality habitat (average 7% of habitat in regions), indicating that the more abundant resources associated with intermediate habitat are a more important determinant of waterfowl distribution across the breeding range. Another possible interpretation is misalignment between our a priori assumptions regarding the influence of threats on habitat quality; however, the relationship between waterfowl nesting and wetland distribution and disturbance in the CCV was similar to that observed in the Prairie Pothole region of North Dakota and Minnesota (Cowardin et al. 1998). The slower rate of increase in waterfowl numbers in the presence of higher levels of intermediate habitat (Figure 2) may suggest populations are approaching the carrying capacity of the region (Soulliere et al. 2017).

Understanding the relationship between spatially referenced environmental variables and waterfowl counts at the regional scale may provide key insights into how exceptional and protracted drought affects habitat availability. The model results indicate that the effects of drought varied among regions, with drought severity the leading factor influencing breeding waterfowl populations (excluding mallards) in all but the Suisun Marsh, where extent of riparian wetlands was the most important factor influencing population levels. Drought severity rose from zero to exceptional in 8 of the 9 areas between 2012 and 2016 (NDMC 2020). Corresponding population declines in some regions and increases in others were likely due to displacement as habitat impairment became apparent with increasing drought severity. In some regions such as the Coast-Napa, and East and West Valleys, increased drought severity resulted in declines in waterfowl populations, while in the Sacramento Valley, Delta, San Joaquin Desert and San Joaquin Valley regions drought severity had a positive initial effect on waterfowl presence. In the normally arid southern CCV, waterfowl may have been drawn to the few remaining wetlands from the even drier San Joaquin Desert and San Joaquin Valley.

In contrast to population models for all waterfowl, mallard population models indicated variation in mallard numbers was influenced by drought in 5 of the 9 regions, but in the Delta, Coast-Napa, East and West Valleys, rice production was (weakly) a more important factor influencing breeding populations. The number of mallard and gadwall pairs per pond has been observed to increase with declining wetland

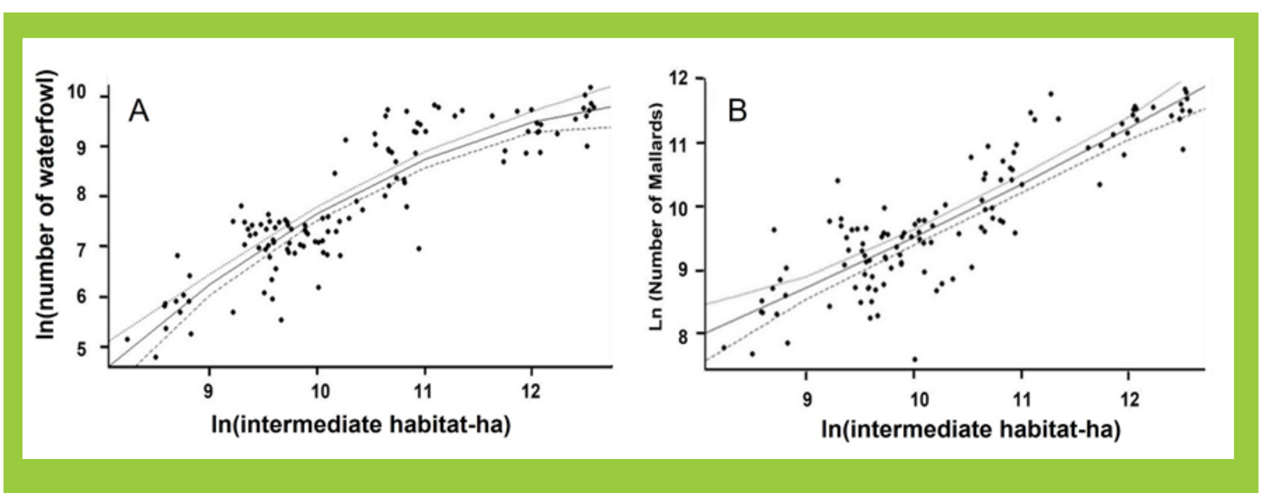

Figure 2. Natural log of model predicted intermediate habitat quality and natural log of pooled waterfowl A) and mallard B) occurrences (n = 117) with 95% confidence intervals in California, USA, 2007-2019.

area, suggesting the possibility that drought induced overcrowding may lead to negative effects such as increased disease (Smith 1970, Cowardin et al. 1998). In regions with salt or brackish wetlands, drought can lead to catastrophic reproductive failure due to lack of fresh water and possibly contributed to mallard population declines in the Suisun Marsh as drought severity increased (U. S. Fish and Wildlife Service. 2013, Siegel 2011).

Our results show the combined effects of drought, land use, and land cover on waterfowl populations in key breeding areas as it relates to environmental gradients and variation in habitat quality (Kahara et al. 2022). Models that include the influence of adjacent land use outperformed those based on wetland area alone. Understanding the spatial relationship between these variables and waterfowl counts at the regional scale may provide key insights into how exceptional and protracted drought affects habitat availability.

Implications for Waterfowl Conservation and Management

Our model results can be used to prioritize areas for conservation based on projected drought frequency and severity. At the regional scale, drought dominated the environmental factors we studied, but statewide (i.e., inter-regionally), habitat quality was the best predictor of mallard and other waterfowl population fluctuations, suggesting that management at this scale may best mitigate for drought impacts. Securing water resources during less severe shortages, particularly in regions such as the southern CCV where wetland habitats are already limited, would allow managers to increase the resilience of waterfowl habitat areas to drought. Water deliveries to brood ponds in addition to irrigated crops will help reduce the risk of overcrowding during the seasonal droughts of summer, particularly in regions of limited wetland area like the San Joaquin Desert. Securing water and maintaining quality habitat in the Sacramento Valley and Northeastern regions in anticipation of drought will support breeding waterfowl during these severe events.

A temporal analysis may help identify shifts in wildlife-habitat relationships that indicate long-term changes in habitat quality and availability (Krapu et al. 1997). In the near term, droughts may limit spring and summer water deliveries to wetlands and irrigated lands when waterfowl broods need them most (Chouinard and Arnold 2007). A more permanent consequence of droughts may be a shift toward production of more drought-tolerant tree crops, which offer far less value to breeding waterfowl than annual crops such as rice, which serves as additional breeding habitat in drought years (Shivers et al. 2018). The combination of hotter years projected for the future coupled with shifting crop types will likely create more lasting challenges for breeding waterfowl in the region.

Our evidence suggests that breeding waterfowl populations in the CCV are limited by condition and availability of habitat for nesting and brood rearing. Conservation planners can further wetland conservation efforts by considering proximity to current and future adjacent land uses and recommending management actions that help mitigate any threats they may present to breeding waterfowl, particularly as shifting climate conditions affect water usage. Protecting buffers around wetland habitats and maintaining regions with low levels of agriculture and development will have immediate conservation benefits. In addition, monitoring of wetlands near farmland could be used to identify threats to nest and brood survival, as well as potential mitigation actions. We also recommend an analysis of nesting and brood rearing success among habitats of varying quality to determine their biological significance and to discount the possibility that intermediate habitats serve as population sinks due to extrinsic factors (Battin 2004).

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Conservation Practices to Benefit Waterfowl Populations

Some threats identified in our model may be addressed by land management practices such as those recommended by organizations like the California Waterfowl Association. While the impacts of these practices were not explored in this study, a few are summarized here. In order to provide sufficient upland habitat for breeding waterfowl, establishment of vegetation such as perennial and annual grasses and forbs is ideal for nesting, preferably within a mile of wetlands or rice fields. A mix of grasses and broad-leafed plants provides structure and shade that can protect late-season nests from heat, and crop fields such as cereals (wheat, oats, triticale) and cover crops (vetch, hay, alfalfa, rye grass) can provide attractive nesting habitat. Perennial and annual plants like cattails, smartweed, and watergrass can provide structure for ducklings to hide in, and increased invertebrate quantity and diversity associated with forbs can provide an important food source. Ducks lose all their flight feathers during wing molt, making them unable to fly for 3-4 weeks, so aquatic habitat with plenty of space, food, and cover that won’t dry up is essential. While irrigation sloughs and ditches can provide necessary water, they are less desirable because they tend to attract nest predators like skunks and raccoons. Keeping upland nesting fields away from roads, levees, ditches, and sloughs can help minimize predation by both nest predators and the avian and mammalian predators that are the main source of duckling and adult mortality outside of hunting season.

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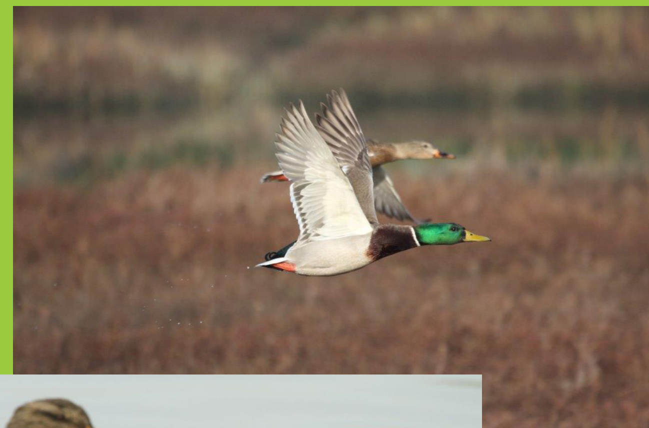
Photo credit: Breana Hernandez

The field crew from California Polytechnic University (Humboldt) surveying restored wetlands in California's Central Valley.



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Conservation Effects Assessment Project: Translating Science into Practice

The Conservation Effects Assessment Project (CEAP) is a multiagency effort to build the science base for conservation. Project findings will help to guide USDA conservation policy and program development and help farmers and ranchers make informed conservation choices.

One of CEAP's objectives is to quantify the environmental benefits of conservation practices for reporting at the national and regional levels. Because wetlands are affected by conservation actions taken on a variety of landscapes, the Wetlands National Component complements the national assessments for cropland, wildlife, and grazing lands. The wetlands national assessment works through numerous partnerships to support relevant assessments and focuses on regional scientific priorities.

This project was conducted through collaboration among researchers with Humboldt State University and the California Department of Fish and Wildlife. Primary investigators on this project were Sharon Kahara, Daniel Skalos,Buddhika Madurapperuma,and Kaitlyn Hernandez. This Science Note was compiled by Drs. Sharon Kahara and Joseph Prenger. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by USDA.

For more information, see http://www.nrcs.usda.gov/wps/portal/nrcs/main/nation-al/technical/nra/ceap, or contact Joseph Prenger (joseph.prenger@usda.gov).