Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment

Dragonflies and Damselflies

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

Vulnerability Component	Score
Sensitivity	Moderate
Exposure	Moderate
Adaptive Capacity	Moderate
Vulnerability	**Low-moderate**

Overall vulnerability of the dragonflies and damselflies species groups was scored as low-moderate. The score is the result of moderate sensitivity, moderate future exposure, and moderate adaptive capacity ratings.

Key climate factors for dragonflies and damselflies include precipitation amount and snowpack. Precipitation and snowpack drive water availability in Odonata aquatic habitat, and declines may affect habitat availability, egg mortality, and the relative abundance of habitat generalists versus habitat specialists. No disturbance mechanisms were identified for this species group. Dragonflies and damselflies exhibit a moderate degree of specialization; they are prey generalists, but rely on aquatic habitat in the egg and larval stage, utilizing lentic and lotic areas and irrigated agricultural land for breeding.

Key non-climate factors for dragonflies and damselflies include urban/suburban development, pollution, and poison. These factors can degrade and alter aquatic habitat availability, affecting Odonata recruitment and abundance. Migratory species are also affected by habitat availability and quality outside of the study area.

Dragonfly and damselfly populations in the Central Valley are fairly stable, and this species group exhibits moderate-high dispersal capacity due to aerial adult life stages. Urban/suburban development and land use change act as landscape barriers, affecting Odonata dispersal by fragmenting habitat. This species group exhibits low-moderate interspecific species diversity, but complex life histories and documented variation in development, pigmentation, and other factors indicates that this species group may exhibit some ability to adapt to climate change. Habitat generalists and migratory species may be more resilient than habitat specialists and non-migrants.

Management potential for this species group is likely influenced by managing aquatic habitat availability, quality, and connectivity at both landscape and local scales.

Table of Contents

Introduction

Description of Priority Natural Resource

Dragonflies and damselflies (hereafter referred to cumulatively as Odonata) are mobile insects considered to be sentinel species for aquatic systems, particularly wetlands (Lunde & Resh 2011), due to aquatic egg and larval life stages. Odonata species within the Central Valley include habitat specialists and generalists; dragonflies can be either resident or migratory, while damselflies do not migrate (Manolis 2003; Ball-Damerow et al. 2014a).

As part of the Central Valley Landscape Conservation Project, workshop participants identified the [PNR] as a Priority Natural Resource for the Central Valley Landscape Conservation Project in a process that involved two steps: 1) gathering information about the species group's management importance as indicated by its priority in existing conservation plans and lists and, 2) a workshop with stakeholders to identify the final list of Priority Natural Resources, which includes habitats, species groups, and species.

The rationale for choosing the dragonflies and damselflies species group as a Priority Natural Resource included the following: the species group has high management importance, and the species group's conservation needs are not entirely represented within a single priority habitat. Please see Appendix A: "Priority Natural Resource Selection Methodology" for more information.

Vulnerability Assessment Methodology

During a two-day workshop in October of 2015, 30 experts representing 16 Central Valley resource management organizations assessed the vulnerability of priority natural resources to changes in climate and non-climate factors, and identified the likely resulting pressures, stresses, and benefits (see Appendix B: "Glossary" for terms used in this report). The expert opinions provided by these participants are referenced throughout this document with an endnote indicating its source[1]. To the extent possible, scientific literature was sought out to support expert opinion garnered at the workshop. Literature searches were conducted for factors and resulting pressures that were rated as high or moderate-high, and all pressures, stresses, and benefits identified in the workshop are included in this report. For more information about the vulnerability assessment methodology, please see Appendix C: "Vulnerability Assessment Methods and Application." Projections of climate and non-climate change for the region were researched and are summarized in Appendix D: "Overview of Projected Future Changes in the California Central Valley".

Vulnerability Assessment Details

Climate Factors

Workshop participants scored the resource's sensitivity to climate factors and this score was used to calculate overall sensitivity. Future exposure to climate factors was scored and the overall exposure score used to calculate climate change vulnerability.

Climate Factor	Sensitivity	Future Exposure
Extreme events: drought	Moderate	Moderate
Precipitation (amount)	Moderate-high	-
Snowpack amount	Moderate-high	-
Water temperature	Low	-
Overall Scores	**Moderate**	**Moderate**

Shifts in water availability as a result of climate change and human water demand could alter available wetland, stream, and flooded cropland habitat used by Odonata species. For example, Medellín-Azuara et al. (2007) project a 22-41% decrease in annual streamflow in the Central Valley by mid-century. Similarly, excessive drying or drought could shift some permanent wetlands to seasonal wetlands (Stromberg et al. 2010), but drought effects on wetland habitat may be reduced or delayed in the Sacramento Valley where water resources are not as scarce (Medellín-Azuara et al. 2007; Reiter et al. 2015). Statewide, 1% or less of the current area of freshwater marsh will remain suitable by the end of the century, and the small areas of marsh that are still suitable will likely occur as vegetation refugia (Thorne et al. 2016). Drought and variable precipitation are also projected to contribute to small declines in flooded cropland production (Jackson et al. 2009; Lee et al. 2011). Compounding climate-induced changes in hydrology is future water demand, which is expected to increase with expanding urban and suburban populations (Medellín-Azuara et al. 2007), placing additional stress on existing water supplies (Kahara et al. 2012). Statewide water scarcity is projected to increase from 2% (current gap between water needs and water delivery) to 20% by the year 2050, even taking adaptive factors into account (Medellín-Azuara et al. 2007). Cumulatively, all of these changes are likely to affect Odonata aquatic habitat availability.

Precipitation (amount)

Sensitivity: *Moderate-high (high confidence)*

Odonata require water for breeding success, and Odonata species richness and overall occurrence is positively correlated with precipitation in California (Ball-Damerow et al. 2014b). In general, changes in the frequency and nature of precipitation events will affect regional hydrology and the persistence and functioning of regional wetlands (Null et al. 2012; Meyers et al. 2010), influencing breeding habitat availability for Odonata.

Snowpack amount

Sensitivity: *Moderate-high (high confidence)*

Snowmelt from mountainous areas surrounding the Central Valley plays a large part in water storage and supply, releasing meltwater gradually to recharge aquifers and flow downstream into the Central Valley (Knowles & Cayan 2002; Scanlon et al. 2012; California Rice Commission 2013). As one of the primary sources of water for irrigation and wetland management throughout the Central Valley (Domagalski et al. 2000; Scanlon et al. 2012), reduced snowpack could lead to summer water shortages and altered streamflow patterns (Miller et al. 2001; Knowles & Cayan 2002; Kiparsky & Gleick 2003; Vicuna et al. 2007), impacting Odonata habitat.

Drought

Sensitivity: *Moderate (moderate confidence)*
Future exposure: *Moderate (moderate confidence)*

Over the coming century, the frequency and severity of drought is expected to increase due to climate change (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015), as warming temperatures exacerbate dry conditions in years with low precipitation, causing more severe droughts than have previously been observed (Cook et al. 2015; Diffenbaugh et al. 2015). Regardless of changes in precipitation, warmer temperatures are expected to increase evapotranspiration and cause drier conditions (Cook et al. 2015). Recent studies have found that anthropogenic warming has substantially increased the overall likelihood of extreme California droughts, including decadal and multi-decadal events (Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015).

Drought periods may reduce Odonata aquatic habitat availability (Boulton 2003; Bêche et al. 2009), potentially contributing to higher dominance of migratory and habitat generalist species relative to non-migratory and habitat specialists by affecting water permanence (Ball-Damerow et al. 2014a). In addition, many Odonata species are vulnerable to egg and nymph desiccation during drought periods, reducing the reproductive success of this species group (Hassall & Thompson 2008). However, some species exhibit drought resistance; for example, the overwintering eggs of the spotted spreadwing (*Lestes congener*) are desiccation resistant (Manolis 2003).

Water temperature

Sensitivity: *Low (moderate confidence)*

Shifts in phenology due to warmer water temperature may alter prey availability (Hassall & Thompson 2008).

Climate factors that may benefit the species group:

- Slight water temperature increases will benefit dragonfly/damselfly reproduction and development by increasing primary and secondary production. These organisms have a relatively broad range of water temperature tolerance.

Non-Climate Factors

Workshop participants scored the resource's sensitivity and current exposure to non-climate factors, and these scores were then used to assess their impact on climate change sensitivity.

Non-Climate Factor	Sensitivity	Current Exposure
Agriculture & rangeland practices	Moderate	Moderate-high
Pollution & poisons	High	High
Urban/suburban development	Moderate-high	Moderate
Overall Scores	**Moderate-high**	**Moderate-high**

Pollution & poisons

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

An aquatic life stage makes Odonata dependent on good water quality, and this species group is sensitive to changes in dissolved oxygen levels, pesticides, acidity, and nutrients (de Barruel & West 2003; Van Dijk et al. 2013). Odonata declines have been linked with urban runoff and low dissolved oxygen levels (de Barruel & West 2003) and insecticide use (Van Dijk et al. 2013). Dragonflies inhabiting irrigation drainage ponds in the Central Valley have also been found to bioaccumulate selenium (Rieuwerts 2015).

Urban/suburban development

Sensitivity: *Moderate-high (high confidence)*
Current exposure: *Moderate (moderate confidence)*
Pattern of exposure: *Consistent across the landscape.*

Urban/suburban development in the Central Valley and broader western U.S. have altered water quality, streamflow, and aquatic habitat structure, contributing to reduced, altered, and fragmented Odonata habitat and altered Odonata abundance (de Barruel & West 2003; Ball-Damerow et al. 2014a, 2014b). Wetland loss and channelization are common aquatic habitat changes as a result of urban development; these alterations leave no substrate and increase sediment delivery[1]. These and other changes as a result of development have increased homogeneity between dragonfly and damselfly assemblages at different California study sites, largely due to a decline in habitat specialists and an increase in migratory generalist species, which are better able to cope with habitat fragmentation (Ball-Damerow et al. 2014a, 2014b). Development has also been linked with altered water quality and reduced Odonata abundance, likely due to higher nutrient runoff and reduced dissolved oxygen (de Barruel & West 2003).

Agriculture & rangeland practices

Sensitivity: *Moderate (moderate confidence)*
Current exposure: *Moderate-high (low confidence)*

Pattern of exposure: *Localized; Sacramento Valley.*

Less water for agriculture could reduce rice production and other agricultural activities that provide ponded water (Jackson et al. 2009; Lee et al. 2011), reducing habitat for this species group.

Dependency on habitat and/or other species

Overall degree of specialization*: Moderate (high confidence)*
Dependency on one or more sensitive habitat types: *High (high confidence)*
Description of habitat: *Wetland habitat and moderate stream flows.*
Dependency on specific prey or forage species: *Low-moderate (moderate confidence)*
Dependency on other critical factors that influence sensitivity: *Moderate (moderate confidence)*
Description of other dependencies: *Agricultural wetlands (rice) being inundated for long periods.*

Dragonflies and damselflies require aquatic habitat for reproduction, and they occupy both lentic and lotic habitats in California (Manolis 2003; Ball-Damerow et al. 2014a). Dragonflies and damselflies also utilize irrigated croplands, and could be affected by reductions in agricultural wetland extent (Ball-Damerow et al. 2014a). Although all Odonata rely on seasonal water, some can be categorized as habitat specialists, while others are considered habitat generalists (Ball-Damerow et al. 2014a). Adult dragonflies are prey generalists, consuming a variety of insects and aquatic invertebrates (Manolis 2003). Nymphs and larvae are also prey generalists (Manolis 2003).

Adaptive Capacity

Workshop participants scored the resource's adaptive capacity and the overall score was used to calculate climate change vulnerability.

Adaptive Capacity Component	Score
Extent, Status, and Dispersal Ability	Moderate-high
Landscape Permeability	Moderate-high
Intraspecific Species Group Diversity	Low-moderate
Resistance & Recovery	Low-moderate
Other Adaptive Capacity Factors	Moderate
Overall Score	**Moderate**

Extent, status, and dispersal ability

Overall degree extent, integrity, connectivity, and dispersal ability: *Moderate-high (moderate confidence)*
Geographic extent: *Occurs across the study region (low confidence)*

Health and functional integrity: *Moderately healthy (low confidence)*
Population connectivity: *Continuous (moderate confidence)*
Dispersal ability: *Moderate-high (high confidence)*

Despite modifications to aquatic habitat in California over the past decade, overall Odonata species richness has not declined significantly (Ball-Damerow et al. 2014a). There are 72 dragonfly species (10 of which are migratory) and 41 damselfly species in California. Some dragonfly species are migratory and transboundary, but most are localized populations [1].

Due to their airborne adult stage, Odonata may have higher dispersal capacity than other aquatic affiliate species (Conrad et al. 1999; Heino et al. 2009). For example, in a British study, Odonata exhibited the farthest northward dispersal in response to climate warming of all freshwater taxa tested (Hickling et al. 2006). However, dispersal ability likely varies by species and will be influenced by habitat availability and continuity (Hassall & Thompson 2008). Damselflies are non-migratory and tend to exhibit lower dispersal distances than dragonflies (Conrad et al. 1999).

Landscape permeability

Overall landscape permeability: *Moderate-high (high confidence)*
Impact of various factors on landscape permeability:
Land use change: *Low-moderate (high confidence)*
Urban/suburban development: *Low-moderate (moderate confidence)*

Habitat fragmentation as a result of agricultural and urban development favors migratory Odonata over habitat specialists and non-migratory species (Ball-Damerow et al. 2014a), and may impair migration in the face of climate change (Hassall & Thompson 2008). Land use change (i.e., shifts from rice production to anything else) and urban development require damselflies to travel larger distances to breed (de Barruel & West 2003; Ball-Damerow et al. 2014a, 2014b).

Resistance and recovery

Overall ability to resist and recover from stresses: *Low-moderate (low confidence)*
Resistance to stresses/maladaptive human responses: *Low-moderate (low confidence)*
Ability to recover from stresses/maladaptive human response impacts: *Low-moderate (low confidence)*

Odonata habitat generalists may be more resilient to climate change due to their ability to utilize different aquatic habitat types (Ball-Damerow et al. 2014a). In general, Odonata are able to recolonize areas previously affected by drought (Hassall & Thompson 2008 and citations therein) and are fairly resilient to temperature increases (Hassall et al. 2007; Ball-Damerow et al. 2014b). Odonata are less resilient to human impacts on the environment, such as altered aquatic habitat availability and quality (de Barruel & West 2003; Raebel et al. 2012).

Species group diversity

Overall species group diversity: *Low-moderate (moderate confidence)*
Diversity of life history strategies: *Low (moderate confidence)*
Genetic diversity: *Moderate (low confidence)*
Behavioral plasticity: *Low-moderate (moderate confidence)*
Phenotypic plasticity: *Low-moderate (moderate confidence)*

Although this species group has a short breeding life that requires water (Manolis 2003; Ball-Damerow et al. 2014a), complex and diverse life histories, including diapause and non-diapause strategies, allow this species group to inhabit different aquatic niches across broad environmental gradients, which may buffer physiological climate change impacts (Hassall et al. 2007). Odonata have also exhibited variable body size (Johansson 2003) and altered activity and development rates to facilitate dispersal and maximize reproductive potential (Johansson & Rowe 1999; Hassall et al. 2007). Similarly, some species exhibit altered pigmentation and heat thresholds in response to different abiotic controls (Hassall & Thompson 2008 and citations therein), indicating they may have moderate plasticity and capability to deal with environmental fluctuations associated with climate change. However, nymphs are more sensitive than adults due to immobility (e.g., see Hassall & Thompson 2008).

Other Factors

Overall degree to which other factors affect adaptive capacity: *Moderate (moderate confidence)*

Habitat availability and quality outside of the Central Valley for migratory species

Habitat availability/quality outside of the Central Valley for migratory species

Some dragonfly species common in California, including the green darner (*Anax junius*) and black saddlebags (*Tramea lacerata*), migrate between California/Mexico and the northern United States/southern Canada (Manolis 2003). These species typically migrate north in late winter and early spring, reproducing and dying in summer in northern areas (Manolis 2003). New adults emerge in late summer and fall, and then migrate south and breed in southern locations by early winter (Manolis 2003). Climate change and human land use may affect these migration patterns by altering habitat continuity and availability, particularly for migratory habitat specialists (Hassall & Thompson 2008 and citations therein).

Management potential

Workshop participants scored the resource's management potential.

Management Potential Component	Score
Species value	Moderate
Societal support	Low
Agriculture & rangeland practices	Moderate
Extreme events	Low
Converting retired land	Low
Managing climate change impacts	Moderate
Overall Score	**Low-moderate**

Value to people

Value to people: *Moderate (high confidence)*
Description of value: *People enjoy seeing dragonflies and damselflies.*

Support for conservation

Degree of societal support for management and conservation: *Low (high confidence)*
Description of support: *Support is limited to fly fishing industry outside of the Central Valley.*

Degree to which agriculture and/or rangelands can benefit/support/increase resilience: *Moderate (moderate confidence)*
Description of support: *They can be managed to maintain permanent wetlands.*

Degree to which extreme events (e.g., flooding, drought) influence societal support for taking action: *Low (high confidence)*
Description of events: *This species group is an indicator of poor water quality, so large die-offs could be a cautionary flag for aquatic systems in the state.*

Likelihood of converting land to support species group

Likelihood of (or support for) converting retired agriculture land to maintain or enhance species group: *Low (high confidence)*
Description of likelihood: *There is little support for converting retired agricultural lands to wetland habitat. There is low likelihood that the public would support habitat enhancement efforts for dragonflies.*

Likelihood of managing or alleviating climate change impacts: *Moderate (moderate confidence)*
Description of likelihood: *Warmer and drier wetlands could be managed to ensure they remain wet all year.*

Maintaining aquatic habitat availability, quality, and connectivity will be important for Odonata species as climate change progresses (Hassall & Thompson 2008; Raebel et al. 2012). Buffer strips around water bodies may help improve water quality and maintain Odonata abundance and species richness (Raebel et al. 2012). Management activity will likely be required at both the landscape and local scales in order to benefit both dragonflies and damselflies due to their variable life histories, resource use patterns, and dispersal patterns (Raebel et al. 2012).

Literature Cited

Ball-Damerow JE, M'Gonigle LK, Resh VH. 2014a. Changes in occurrence, richness, and biological traits of dragonflies and damselflies (Odonata) in California and Nevada over the past century. Biodiversity and Conservation **23**:2107–2126.

Ball-Damerow JE, M'Gonigle LK, Resh VH. 2014b. Local and regional factors influencing assemblages of dragonflies and damselflies (Odonata) in California and Nevada. Journal of Insect Conservation **18**:1027–1036.

Bêche LA, Connors PG, Resh VH, Merenlender AM. 2009. Resilience of fishes and invertebrates to prolonged drought in two California streams. Ecography **32**:778–788.

Boulton AJ. 2003. Parallels and contrasts in the effects of drought on stream macroinvertebrate assemblages. Freshwater Biology **48**:1173–1185.

California Rice Commission. 2013. Rice-specific groundwater assessment report. Prepared for Central Valley Regional Water Quality Control Board. California Rice Commission.

Conrad KF, Willson KH, Harvey IF, Thomas CJ, Sherratt TN. 1999. Dispersal characteristics of seven Odonate species in an agricultural landscape. Ecography **22**:524–531.

Cook BI, Ault TR, Smerdon JE. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances **1**:e1400082.

de Barruel M, West N. 2003. A benthic macroinvertebrate survey of Secret Ravine: the effects of urbanization on species diversity and abundance. Water Resources Center Archives. Available from http://escholarship.org/uc/item/44r0s4c2 (accessed March 21, 2016).

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences **112**:3931–3936.

Domagalski JL, Knifong DL, Dileanis PD, Brown LR, May JT, Connor V, Alpers CN. 2000. Water quality in the Sacramento River Basin, California, 1994–98. Page 36. U.S. Geological Survey Circular 1215. U.S. Geological Survey, Sacramento, CA. Available from http://pubs.water.usgs.gov/circ1215/ (accessed March 7, 2016).

Hassall C, Thompson DJ. 2008. The effects of environmental warming on Odonata: a review. International Journal of Odonatology **11**:131–153.

Hassall C, Thompson DJ, French GC, Harvey IF. 2007. Historical changes in the phenology of British Odonata are related to climate. Global Change Biology **13**:933–941.

Hayhoe K et al. 2004. Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Sciences **101**:12422–12427.

Heino J, Virkkala R, Toivonen H. 2009. Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. Biological Reviews **84**:39–54.

Hickling R, Roy DB, Hill JK, Fox R, Thomas CD. 2006. The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology **12**:450–455.

Jackson LE et al. 2009. Potential for adaptation to climate change in an agricultural landscape in the Central Valley of California. CEC-500-2009-044-D. California Energy Commission, PIER Energy-Related Environmental Research Program.

Johansson F. 2003. Latitudinal shifts in body size of Enallagma cyathigerum (Odonata). Journal of Biogeography **30**:29–34.

Johansson F, Rowe L. 1999. Life history and behavioral responses to time constraints in a damselfly. Ecology **80**:1242–1252.

Kahara SN, Duffy WG, DiGaudio R, Records R. 2012. Climate, management and habitat associations of avian fauna in restored wetlands of California's Central Valley, USA. Diversity **4**:396–418.

Kiparsky M, Gleick PH. 2003. Climate change and California water resources: A survey and summary of the literature. Pacific Institute for Studies in Development, Environment, and Security, Oakland, CA.

Knowles N, Cayan DR. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters **29**:1891.

Lee J, Gryze SD, Six J. 2011. Effect of climate change on field crop production in California's Central Valley. Climatic Change **109**:335–353.

Lunde KB, Resh VH. 2011. Development and validation of a macroinvertebrate index of biotic integrity (IBI) for assessing urban impacts to Northern California freshwater wetlands. Environmental Monitoring and Assessment **184**:3653–3674.

Manolis T. 2003. Dragonflies and damselflies of California. University of California Press.

Medellín-Azuara J, Harou JJ, Olivares MA, Madani K, Lund JR, Howitt RE, Tanaka SK, Jenkins MW, Zhu T. 2007. Adaptability and adaptations of California's water supply system to dry climate warming. Climatic Change **87**:75–90.

Miller NL, Bashford KE, Strem E. 2001. Climate change sensitivity study of California hydrology: A report to the California Energy Commission. Lawrence Berkeley National Laboratory, University of California.

Null SE, Viers JH, Deas ML, Tanaka SK, Mount JF. 2013. Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change **116**:149–170.

Raebel EM, Merckx T, Feber RE, Riordan P, Thompson DJ, Macdonald DW. 2012. Multi-scale effects of farmland management on dragonfly and damselfly assemblages of farmland ponds. Agriculture, Ecosystems & Environment **161**:80–87.

Reiter ME, Elliott N, Veloz S, Jongsomjit D, Hickey CM, Merrifield M, Reynolds MD. 2015. Spatio-temporal patterns of open surface water in the Central Valley of California 2000-2011: drought, land cover, and waterbirds. JAWRA Journal of the American Water Resources Association **51**:1722–1738.

Rieuwerts J. 2015. The elements of environmental pollution. Routledge.

Scanlon BR, Faunt CC, Longuevergne L, Reedy RC, Alley WM, McGuire VL, McMahon PB. 2012. Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. Proceedings of the National Academy of Sciences **109**:9320–9325.

Stromberg JC, Lite SJ, Dixon MD. 2010. Effects of stream flow patterns on riparian vegetation of a semiarid river: implications for a changing climate. River Research and Applications **26**:712–729.

Thorne JH, Boynton RM, Holguin AJ, Stewart JAE, Bjorkman J. 2016. A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife (CDFW), Sacramento, CA. Available from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=116208&inline.

Van Dijk TC, Staalduinen MAV, Sluijs JPV der. 2013. Macro-invertebrate decline in surface water polluted with Imidacloprid. PLOS ONE **8**:e62374.

Vicuna S, Maurer EP, Joyce B, Dracup JA, Purkey D. 2007. The sensitivity of California water resources to climate change scenarios. JAWRA Journal of the American Water Resources Association **43**:482–498.

Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE, Cook ER. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. Geophysical Research Letters **in press**:1–10.

[1] Expert opinion, Central Valley Landscape Conservation Project Vulnerability Assessment Workshop, Oct. 8-9, 2015