

## **TECHNICAL MEMORANDUM**

### **DEVELOPMENT, LAND USE, AND CLIMATE CHANGE IMPACTS ON WETLAND AND RIPARIAN HABITATS – A SUMMARY OF SCIENTIFICALLY SUPPORTED CONSERVATION STRATEGIES, MITIGATION MEASURES, AND BEST MANAGEMENT PRACTICES**

#### **CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE NORTHERN REGION**

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#### **INTRODUCTION AND DOCUMENT PURPOSE**

California Department of Fish and Wildlife (Department) Northern Region staff has analyzed the most recent and best available scientific research on the essential relationships of fish and wildlife to wetland, stream and riparian habitats, the impacts of land use and development on these habitats, and potentially effective conservation strategies to minimize these impacts. This technical memorandum is a summary of this analysis and has three principal objectives: 1) present a scientific analysis of fish and wildlife habitat needs and potential development and land use impacts, 2) detail potential conservation strategies and mitigation measures that have been effective in minimizing these impacts, and 3) make this scientific analysis available in the Northern Region to project proponents, consulting engineers and biologists, planners, California Environmental Quality Act (CEQA) lead agencies, the public, and to Department staff to inform project and land use plan design and review subject to CEQA. The Department's Northern Region serves Del Norte, Humboldt, Lassen, Mendocino, Modoc, Shasta, Siskiyou, Tehama and Trinity counties.

This Technical Memorandum also reviews relevant potential impacts of climate change and sea level rise on the Northern Region's wetland and riparian habitats. Over the current century, climate change will alter the fundamental character, production, and distribution of the ecosystems upon which the economy of California relies (Snyder et al. 2002, Snyder and Sloan 2005, California Energy Commission 2009a, 2009c). This climate change and sea level rise analysis is intended to inform Department staff and the public of these impacts as they relate to wetland and riparian habitat conservation and future local and regional land use and development decisions. This analysis does not address land use and development-related greenhouse gas emissions or their effect on climate change.

This document is intended to be a resource during the Department's participation in CEQA project review and land use planning in the Northern Region and to assist local agencies and the public during land use planning and development permitting processes. However, the Department affirms that project-specific circumstances always necessitate project-specific analysis of impacts and mitigation measure efficacy.

This summary of scientific literature is provided as a tool to be used, where appropriate, to support site specific project review and is not intended to be relied upon absent, or in lieu of, a site or project-specific analysis of environmental impacts and mitigation measures.

This technical memorandum includes the following:

- 1) Review of the Department's conservation and management role and legal authority;
- 2) Definitions;
- 3) Discussion of the historic loss and degradation of wetland and riparian habitats;
- 4) Review of the importance of these habitats and some of the species assemblages that depend upon them;
- 5) Assessment of potential development and land use impacts on these habitats;
- 6) Evaluation of projected climate change impacts for northern California;
- 7) Review of habitat buffer effectiveness;
- 8) Key findings that summarize effective mitigations and conservation strategies;
- 9) Commonly used methods for implementing wetland and riparian habitat buffers;
- 10) References that comprise the scientific basis of this Technical Memorandum.

## **DEPARTMENT ROLE AND LEGAL AUTHORITIES**

Under Fish and Game Code section 711.7, the Department is designated as trustee for the State's fish and wildlife resources. The Department has jurisdiction over the conservation, protection, and management of fish, wildlife, native plants, and habitat necessary for biologically sustainable populations of those species (Fish & G. Code, § 1802). The Department administers the California Endangered Species Act (CESA) and other provisions of the Fish and Game Code that conserve the State's fish and wildlife public trust resources.

California lawmakers have identified a public interest in protecting and maintaining the State's wetland and riparian habitats. (Fish & G. Code, §§ 1385, 2780). In 1993, Executive Order W-59-93 established a comprehensive wetlands policy for the State that sought no overall net loss and long-term net gain in the quantity, quality and permanence of wetlands acreage and values. The Fish and Game Commission also has adopted a non-regulatory Wetlands Resources Policy, which recognizes the habitat values of wetlands and the damage to fish and wildlife resources from projects resulting from net loss of wetland acreage or habitat values (Fish and Game Commission 2013a). The policy, available at: <http://www.fgc.ca.gov/policy/> and most recently amended in 2005, states:

*"...it is the policy of the Fish and Game Commission to seek to provide for the protection, preservation, restoration, enhancement and expansion of wetland habitat in California.*

*Further, it is the policy of the Fish and Game Commission to strongly discourage development in or conversion of wetlands. It opposes, consistent*

*with its legal authority, any development or conversion which would result in a reduction of wetland acreage or wetland habitat values. To that end, the Commission opposes wetland development proposals unless, at a minimum, project mitigation assures there will be "no net loss" of either wetland habitat values or acreage.*

*The Commission strongly prefers mitigation which would achieve expansion of wetland acreage and enhancement of wetland habitat values."*

The Department is a trustee agency pursuant to CEQA and also frequently serves as a responsible agency (Pub. Resources Code §§ 21069, 21070). The Department's role in wetland protection is primarily advisory in nature. The Department fills this role by reviewing and commenting on lead agencies' environmental documents and making recommendations to avoid, minimize, and mitigate potential negative impacts to those resources held in trust for the people of California.

## **WETLAND AND RIPARIAN DEFINITIONS**

According to the U.S. Fish and Wildlife Service classification of wetlands (Cowardin et al. 1979), wetlands include swamps; freshwater, brackish water, and saltwater marshes; bogs; vernal pools; periodically inundated saltflats; intertidal mudflats; wet meadows; wet pastures; springs and seeps; portions of lakes, ponds, rivers and streams; and all other areas which are periodically or permanently covered by shallow water; or dominated by hydrophytic vegetation, or in which the soils are predominantly hydric in nature. Pursuant to the Fish and Game Commission Wetlands Resources Policy, the Department utilizes the U.S. Fish and Wildlife Service wetlands definition for purposes of wetland identification. The U.S. Fish and Wildlife Service wetlands definition is (Cowardin et al. 1979):

*"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."*

The State Water Resources Control Board (SWRCB), through a Technical Advisory Team, has also developed a working definition for wetlands, though this definition is not yet formally adopted (SWRCB 2012a):

*"An area is wetland if, under normal circumstances, (1) the area has continuous or recurrent saturation of the upper substrate caused by groundwater or shallow surface water or both; (2) the duration of such saturation is sufficient to cause anaerobic conditions in the upper substrate*

*and; (3) the area either lacks vegetation or the vegetation is dominated by hydrophytes.”*

The SWRCB has also developed a working definition for riparian areas, which is based in part on Brinson et al. (2002) (SWRCB 2012b):

*“Riparian Areas are areas through which surface and subsurface hydrology interconnect aquatic areas and connect them with their adjacent uplands (Brinson et al. 2002). They are distinguished by gradients in biophysical conditions, ecological processes, and biota. They can include wetlands, aquatic support areas, and portions of uplands that significantly influence the conditions or processes of aquatic areas.”*

## **HABITAT LOSS AND DEGRADATION**

Temperate freshwater wetlands are threatened globally by urbanization, agriculture, hydrologic modification, and other land use practices and continued reductions in wetland area and function is likely to continue over the coming decades (Brinson and Malvarez 2002). On a national, state-wide, and regional scale, wetland and riparian habitats have undergone substantial declines. Over the past 200 years, the contiguous 48 states have lost an estimated 53 percent of their original wetlands, with California losing the largest percentage (91 percent) (Dahl 1990). An estimated 93 to 98 percent of California's and 75 percent of the North Coast's riparian habitat has been converted to other land uses (Katibah 1984, Dawdy 1989). On a local scale, salt marsh habitat in Humboldt Bay, California's second largest estuary has been reduced by 85 to 90 percent since 1897, due to diking and filling (Barnhart et al. 1992).

California and the nation continue to lose wetland acreage and value, despite both state and national regulations and “no net loss” wetland policies (National Research Council 2001). Between 1982 and 1987, the western United States experienced a net loss of 151,600 hectares (374,600 acres) of wetland habitat, a 5.7-percent loss in total wetland area (Brady and Flather 1994). Of the 67 aquatic habitat types in the Sierra Nevada, nearly two-thirds are in decline (California Department of Fish and Game 2007). Reasons for this loss are numerous and include: agricultural conversion, water diversions, construction of levees and flood control structures, dam and reservoir construction, excessive livestock grazing, and urbanization (Abell et al. 2000, Zedler 2004). According to Brady and Flather (1994), urban, industrial, and residential development was the greatest human-induced cause of wetland loss from 1982-1987.

According to the U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (USEPA), wetland creation and the restoration and enhancement of existing wetlands are a common means to mitigate for wetland loss (see USEPA, USACE 2008). However, on average, the quality of created, restored, and enhanced wetlands achieved through mitigation is lower than that of intact, reference wetlands, according to SWRCB-funded studies (Ambrose and Lee 2004, Ambrose et al. 2006). This suggests that projects conducted in wetlands, as currently permitted, are

contributing to a net loss of wetland functions and values. According to Zedler (2004), mandatory compensatory wetland mitigation measures continue to result in a net loss of wetland habitat and the cumulative effects of historical and future wetland degradation will be difficult to abate.

An analysis of 45 Washington State compensatory wetland mitigation projects required pursuant to the Clean Water Act showed only 29 percent were implemented according to plan and also met the project's ecological performance standards (Johnson et al. 2000). This study also found that of 23 compensatory mitigations actually implemented, only 45 percent were implemented according to plan. Numerous studies have shown that wetland mitigation projects often do not meet their required USACE permit conditions (Kihlsinger 2008). Along with the risk of mitigation underperformance or failure, the temporal loss of wetland function from the time of impact to the time a mitigation site is fully functional is also a factor in potentially diminishing the value of compensatory restored wetlands (Zedler 2004). Such temporal loss may vary depending on habitat type and other factors. For the above reasons, the Department, the California Coastal Commission, and others have often recommended mitigation for the loss of high-quality wetlands and riparian habitat at creation-to-loss ratios of 3:1 or greater.

Today, almost all of California's major rivers are dammed and diverted to provide water for agriculture and domestic use and many are channelized and constrained by levees to provide flood control for the farms and cities that now occupy land that was once seasonally flooded wetland and riparian habitats (Mount 1995, Moyle 2002, California Department of Fish and Game 2007, Mac et al. 2008). Maintaining the hydrologic connectivity of these floodplain habitats with the surrounding landscape, even if the habitats themselves are already protected from development, is critical to maintaining their biological integrity and ecosystem functions (Pringle 2001, Correll 2005, Tockner et al. 2008). California's wetland and riparian habitats are often part of an integrated ecosystem. California has 251,000 acres of riverine wetlands, approximately 9 percent of the state's total wetland acreage, and these wetlands are associated with 410,000 miles of rivers and streams (Snow 2010).

Isolating a river's floodplain from overbank flows degrades riparian habitat (Poff et al. 1997, Reckendorfer et al. 2013). When levees, berms, and canals disconnect rivers from their natural floodplains, they change the river's natural flow regime and eliminate the benefits of natural flooding such as deposition of river silts on valley-floor soils and the recharging of wetlands (Poff et al. 1997, California Department of Fish and Game 2007). In addition, disconnecting natural floodplains simplifies riverine and riparian habitat and diminishes braided channel structure and off-channel backwater areas, thus degrading habitat suitability for salmonid fishes (Moyle 2002, California Department of Fish and Game 2007, Tockner et al. 2008).

Non-structural approaches to floodplain management, such as not rebuilding flood-damaged structures in flood-prone areas and moving people out of harm's way are congruent with floodplain and riparian habitat restoration (National Research Council

1992, Sparks 1995). According to the Interagency Flood Management Review Committee (1994), the nation should discourage new development in floodplains as a means to prevent future flood damages and to help restore ecosystem function. Furthermore, global threats to human water security and to river biodiversity are well correlated Vörösmarty et al. (2010), as exemplified by enduring conflicts over water use and protection of declining species in the Klamath River Basin and Sacramento/San Joaquin River systems. Thus efforts to restore and protect riverine ecosystems, including floodplains and riparian habitat, will likely benefit both biodiversity and California's needs for a safe and reliable water supply.

As described in detail below, many California fish and wildlife populations that rely on wetland and riparian habitat, e.g. willow flycatcher (*Empidonax traillii*), western red bat (*Lasiurus blossevillii*), and coho salmon (*Oncorhynchus kisutch*), have plummeted in recent decades due, in part, to habitat loss and degradation. Wetland and riparian habitats remain vulnerable to impacts from projected population growth, development, invasive species, climate change and sea level rise (California Department of Fish and Game 2007, Point Reyes Bird Observatory Conservation Science 2011). Land use, specifically development within and adjacent to wetland and riparian areas, is a principal cause of habitat loss and degradation. According to the California Fish and Game Commission Wetlands Resources Policy, "Projects which impact wetlands are damaging to fish and wildlife resources if they result in a net loss of wetland acreage or wetland habitat value."

As described in this review, the scientific literature establishes that certain conservation strategies and mitigation methods are likely to be effective in protecting and minimizing development and land use-related impacts to wetland and riparian habitats. Individual development projects can have site-specific and cumulative effects on adjacent habitats; however, land use is the major driver of freshwater ecosystem conditions (Allan 2004, Langpap et al. 2008, Tockner et al. 2008). Land use activities and intensity profoundly affect riverine and other freshwater aquatic habitats on a watershed, regional, and global scale through habitat conversion and fragmentation, increasing road density, alterations of peak flows and floods, degradation of soil and water, increases in nutrient and pollution inputs, spreading invasive species, wildfire suppression, and altering local climate (Ziemer and Lisle 1998, Theobald et al. 2005, Allan 2004, Foley et al. 2005, Stein et al. 2005). For instance, in a detailed, site-specific analysis, California Department of Forestry and Fire Protection (2003) found that whereas only 4 percent of natural habitat in El Dorado County, CA. was lost to development, nearly 40 percent had greatly reduced habitat quality.

Habitat destruction through land use alterations is generally considered a primary cause of species endangerment (Wilcove et al. 1998). Consequently, to achieve the long-term maintenance of wetland, riparian, and riverine habitats, effective watershed, regional, or landscape-level planning that addresses the ecological effects of land use is equally as important as protecting these habitats from the direct impacts of adjacent development (Michalak and Lerner 2007).

The California Fish and Game Commission's Land Use Planning Policy (California Fish and Game Commission 2013b) recognizes the importance of land use planning in the conservation of California's fish and wildlife. To provide maximum protection of fish and wildlife, this policy directs the Department to: 1) promote the development of regional conservation planning, 2) review, coordinate and provide comments and recommendations on federal, state, local planning efforts, and 3) participate in local land use planning processes for the purpose of conserving and protecting fish or wildlife habitat (California Fish and Game Commission 2013b). Other landscape level planning approaches employed by the Department to protect wetland and riparian habitats include implementation of California's Wildlife Action Plan (California Department of Fish and Game 2007) and the Recovery Strategy for California Coho Salmon (California Department of Fish and Game 2004) and participation in the Riparian Bird Conservation Plan (Riparian Habitat Joint Venture 2004).

## **IMPORTANCE OF WETLAND AND RIPARIAN HABITATS**

California's Wetland and riparian habitats are essential for a wide variety of important resident and migratory fish and wildlife species (California Department of Fish and Game 2001, Riparian Habitat Joint Venture 2004, California Department of Fish and Game 2007). The role of riparian habitat in supporting biodiversity is well documented and its relative ecologic importance greatly exceeds the proportion of the landscape it occupies (Allan and Flecker 1993, Naiman et al. 1993, 2000, Crow et al. 2000, Dahl 2000). According to Naiman et al. (1993, 2000), natural riparian corridors are the most diverse, dynamic, and complex terrestrial habitat type, and thus, they play an essential role in conserving regional biodiversity.

Because of their seasonal or year-round water supply, cool microclimate, productivity, nutrient cycling and food availability, wetlands and riparian habitats are vital to the majority of California's wildlife species (California Department of Fish and Game 2007). According to the California Fish and Game Commission Wetlands Resources Policy, "Wetland habitat is also recognized as providing habitat for over half of the listed endangered and threatened species in California." Wetlands are required by 50 percent of animals and 28 percent of plants listed pursuant to the federal Endangered Species Act (ESA) (Niering 1988). In the Pacific Coast Ecoregion, which includes much of the Department's Northern Region, 60 percent of amphibian species, 16 percent of reptiles, 34 percent of birds, and 12 percent of mammals can be classified as riparian obligates (Kelsey and West 1998, in Naiman et al. 2000). Wetlands and riparian corridors also serve as important wildlife migration and dispersal routes for both aquatic and terrestrial wildlife.

Riparian areas provide an ecological linkage or transition between aquatic and terrestrial habitats and directly affect the delivery, routing, and composition of water, nutrients, sediment, and wood into and through a stream system (Franklin 1992, Naiman et al. 1993, Crow et al. 2000, Naiman et al. 2000, Bolton and Shellberg 2001). Recurrent flooding in riparian habitats results in frequent disturbances related to episodic or chronic inundation, sediment transport, and the abrasive and erosive forces

of the transport of water, large wood, and bedload (Naiman and Decamps 1997, Crow et al. 2000). Seasonal or continual water availability and regular nutrient inputs also create an especially fertile and productive floodplain habitat (Naiman et al. 1993, 2000, Crow et al. 2000). The combination of these processes, in turn, creates habitat complexity and variability in time as well as in space, resulting in ecologically diverse plant and animal communities (Franklin 1992, Naiman and Decamps 1997, Crow et al. 2000, Robinson et al. 2002).

California's wetland and riparian habitats are also important for the valuable ecosystem services they provide and the many recreational opportunities they offer. For instance, wetlands and floodplains store and meter floodwaters, recharge groundwater aquifers, trap sediment, filter pollution, help minimize erosion, lessen peak flow velocities, and protect against storm surges (Mitsch and Gosselink 2000, Tockner et al. 2008). In doing so, they protect adjacent upland, down-stream, and coastal properties from loss and damage during flooding and help maintain surface and groundwater during summer months. These habitats are also popular destinations for people that enjoy camping, fishing, hunting, boating, wildlife viewing and other outdoor recreational activities. According to the National Research Council (2002), "because riparian areas perform a disproportionate number of biological and physical functions on a unit area basis, their restoration can have a major influence on achieving the goals of the Clean Water Act, the Endangered Species Act, and flood damage control programs."

### Birds

California's wetland and riparian habitat has been identified as the most critical habitat for conserving Neotropical migrant birds (California Department of Fish and Game 2003, Riparian Habitat Joint Venture 2004). Of the 63 bird taxa designated as California Species of Special Concern (SSC), 27 taxa (43 percent) primarily utilize wetland habitats and another 11 taxa (17 percent) are riparian forest inhabitants (Shuford and Gardali 2008). SSC are designated by the Department for species with declining population levels, limited ranges, and/or continuing threats that make them vulnerable to extinction. Though not listed pursuant to the ESA or CESA, the goal of designating taxa as SSC is to halt or reverse their decline by calling attention to their plight and addressing habitat conservation issues early enough to secure their long-term viability. A combined total of 60 percent of California's bird SSC are dependent upon wetland and riparian habitats, demonstrating both ecological importance and the threat to these habitats. The greatest factor in the decline of the willow flycatcher (*Empidonax traillii*), a State-endangered species, is the extensive loss, fragmentation, and modification of riparian breeding habitat (Bombay et al. 2003). Likewise, wetland loss is the principal threat to the State-threatened greater sandhill crane (*Grus canadensis tabida*) (Meine and Archibald 1996).

### Fish

Native fish populations are dependent upon healthy aquatic ecosystems (Moyle 2002). Wetland, riparian vegetation, and associated floodplain provide many essential benefits to stream and river fish habitat (Moyle 2002, California Department of Fish and Game 2007). These features influence channel geomorphology and stream flow by providing



channel roughness, bank stability, habitat heterogeneity and complexity. Riparian forests provide thermal protection, shade, and large woody debris. Large woody debris stabilizes substrate, provides shelter and cover from predators, facilitates pool establishment and maintenance, maintains spawning bed integrity, and creates habitat for aquatic invertebrate prey. Wetland and riparian areas also provide critical fish habitat in the form of off-channel and back-water winter-rearing sites and floodwater refugia (California Department of Fish and Game 2007).

Fish across North America are under severe ecological pressure from land use changes. During the past century, three genera, 27 species, and 13 subspecies of North American fish have become extinct (Miller et al. 1989). Habitat loss and introduced species were the most common factor responsible for these extinctions, 73 percent and 68 percent of cases, respectively, followed by chemical pollution (38 percent) (Miller et al. 1989). According to Williams et al. (1989), approximately one out of three North American freshwater fish species and subspecies are now either threatened, endangered, or deserving of special consideration.

In California, complex and resilient natural ecosystems for fish are being replaced by simplified, highly altered systems that are unpredictable in structure and dominated by non-native species (Moyle and Williams 1990, California Department of Fish and Game 2004, 2007). Habitat loss and modification including loss of riparian forest, and increased water pollution, non-native species, and water diversions are some of the most significant factors negatively affecting California's native fishes (Moyle 2002). These impacts are the result of numerous human activities, including mining, logging, road construction on unstable slopes, over-grazing and urban/exurban development (Moyle 2002). More recently, large-scale outdoor marijuana cultivation in northern California has also been documented as having substantial negative impacts on fish and other aquatic and terrestrial wildlife species (Department unpublished data).

The threats to California's fishes mirror those to other North American taxa. Of California's 67 native inland fish species, seven (10 percent) are extinct in the state or globally; 13 (19 percent) are State or federally listed (as of 2001), and 19 (29 percent) are listed as SSC (Moyle 2002). Few fishes have been more significantly impacted by loss and alteration of habitat than Pacific salmon and anadromous trout (Moyle 2002). These species, including Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and coastal cutthroat trout (*O. clarkii*) are vitally important ecological and economic keystone species in California. Coho salmon, for instance, has undergone at least a 70-percent decline in abundance since the 1960s, and is currently at 6 to 15 percent of its abundance during the 1940s (California Department of Fish and Game 2004). If present population trends continue, Katz et al. (2012) anticipate 25 (78 percent) of California's 32 native salmonid taxa will likely be extinct or extirpated within the next century.

### Amphibians and Reptiles

California's aquatic habitats and their adjacent uplands are essential habitat for numerous aquatic and semi-aquatic amphibian and reptile species. The Department's

Special Animal List recognizes 45 amphibian species as listed pursuant to CESA, ESA, or some other “watch list” including SSC. Of these 45 species, 13 occur in the Department’s Northern Region. Ten of these 13 species rely upon streams and wetlands for breeding habitat and adjacent upland habitat for other critical life functions.

Some of Northern Region’s numerous amphibian and reptile SSC, which rely upon wetland and riparian habitats include: southern torrent salamander (*Rhyacotriton variegatus*), Del Norte salamander (*Plethodon elongatus elongatus*), Cascades frog (*Rana cascadae*), northern red-legged frog (*R. aurora*), California red-legged frog (*R. draytonii*), Oregon spotted frog (*R. pretiosa*), foothill yellow-legged frog (*R. boylei*), coastal tailed frog (*Ascaphus truei*), and Pacific pond turtle (*Actinemys marmorata*).

Amphibians are currently undergoing a global collapse (Lannoo 2005, Wake and Vrendenburg 2008). On a regional and state-wide scale numerous amphibian species and populations are also documented in decline (Fellers et al. 2008). For instance, because of the decline in aquatic habitat types, half of 29 native amphibian species in the Sierra Nevada and Cascades Region are at risk of extinction (California Department of Fish and Game 2007). While this decline appears to have multiple causes, habitat loss and fragmentation are now considered among the greatest threats to amphibian populations (Lannoo 2005, Cushman 2006).

All 47 amphibian species occurring in the Pacific Northwest are either facultative or obligate stream-riparian associates (Olson et al. 2007). Ninety percent of these occur in forested habitats and about a third are stream-riparian obligate species (Olson et al. 2007). Of particular conservation significance is that a quarter of these forest-dwelling amphibians are tied to smaller headwater streams (Olson et al. 2007). Despite substantial evidence that small headwater streams are important to amphibian populations, as well as providing vital ecosystem services to downstream watersheds, small headwater streams face the most substantial threat of elimination by urbanization (Elmore and Kaushal 2008). Also, compared to larger stream types, small headwater streams typically receive the narrowest streamside buffers in local and state-wide mitigation approaches, e.g. the California Forest Practice Rules (California Department of Forestry and Fire Protection 2012).

### Bats

The loss and fragmentation of quality foraging habitat is a major threat to bat populations worldwide (Racey and Entwistle 2008). Populations of many bat species in North America and globally are declining and currently approximately 25 percent of the global bat fauna are listed as threatened by the International Union for Conservation of Nature. According to the California Natural Diversity Database (CNDDDB), 12 of California’s 25 bat species are designated SSC, USDA Forest Service Sensitive, or federally Endangered.

Many North American bat species forage near or directly over open water, while others feed in a variety of habitats but are often associated with riparian vegetation (Pierson 1998). All 15 bat species occurring on northern California and the Pacific Northwest are

insectivorous. Riparian habitats are of disproportionate importance for many bat species because they are insect-rich environments and provide roosting, foraging sites, and drinking water (Wunder and Carey 1996, Grindal et al. 1999). As such, bats were identified as an important species group whose conservation justified enhanced riparian buffer protection in the management guidelines of the federal Northwest Forest Plan (Seidman and Zabel 2001).

In Douglas-fir forests of the Washington Cascade Range and the Oregon Coast Range, foraging activity of *Myotis* bat species was found to be 10 times greater over water than within the forest interior (Thomas 1988). In coastal British Columbia, the little brown bat (*Myotis lucifugus*) was found to be 75 times more active over lakes and ponds than in forested habitat (Lunde and Harestad 1986). In northern California, Seidman and Zabel (2001) found substantial foraging utilization on intermittent streams, and importantly, streams with discontinuous flows had similar levels of bat activity as streams with continuous flowing or standing water.

Drastic population declines of the formerly abundant cave myotis (*Myotis velifer*) from California's Colorado River basin (Pierson 1998) and the western red bat (*Lasiurus blossevillii*) from the Sacramento and San Joaquin River basins are associated with the loss of cottonwood-dominated riparian forests. According to Pierson et al. (2006), the western red bat in California would greatly benefit from riparian restoration, particularly the recruitment of cottonwood/sycamore forests and the reinstatement of natural flood regimes. According to Ober and Hayes (2008), the best strategy for Pacific Northwest bat fauna conservation over broad spatial scales is the maintenance or creation of a diversity of riparian vegetation conditions.

#### Sensitive Plants and Natural Communities

Northern California is globally renowned as a biodiversity hotspot for rare, endemic, and unusual plants, many of which are associated with aquatic habitats. Because of this botanical diversity, the Klamath-Siskiyou Ecoregion, which encompasses much of northwestern California, has been named an Area of Global Botanical Significance (one of seven in North America) by the World Conservation Union (Ricketts et al. 1999). It has also been proposed as a World Heritage Site and UNESCO Biosphere Reserve (Ricketts et al. 1999). Sacramento River Valley vernal pools, for example, are globally unique habitats and threatened throughout their range while the Northern Region's coastal lagoons and peatlands are some of the largest in the state and recognized botanical hotspots (Leppig 2004).

Northern California's diverse wetland and riparian habitats are home to more than 116 sensitive plant species. According to the CNDDDB, approximately one third of the region's sensitive plant species occur in aquatic and riparian habitats. In northern California's redwood forests, 40 percent of sensitive plant species occur in wetland and riparian habitats (Golec et al. 2006). According to Comer et al. (2005), California has more at-risk plant species occurring within isolated wetlands (143 species) and also more plant species listed pursuant to the ESA (32 species) tied to isolated wetlands, than any other state.

Certain vegetation types or natural communities are rare or threatened in their own right and thus have ecological importance and conservation status in addition to the environmental services and wildlife habitat they provide. The CNDDDB classifies vegetation for the primary purpose of assisting in determining the state-wide significance and rarity of various vegetation types. CNDDDB first classifies vegetation types into specific “alliances” based upon species dominance. CNDDDB ranks these alliances based upon their rarity and threat. Alliances designated with a State (S) ranking of S1, S2, and S3 are considered rare and of high priority for inventory. See [http://www.dfg.ca.gov/biogeodata/vegcamp/natural\\_comm\\_list.asp](http://www.dfg.ca.gov/biogeodata/vegcamp/natural_comm_list.asp) for more detailed information on how CNDDDB addresses natural communities.

In northern California, 16 riparian vegetation alliances, dominated by alder (*Alnus viridis*), willow (*Salix* spp.), birch (*Betula* spp.), and cottonwood (*Populus* spp.), have State rankings of S2 or S3 (CNDDDB 2013). Numerous other non-woody wetland vegetation types in the region also have State rankings of S1 to S3. The high number of riparian vegetation alliances designated as rare and of high priority for inventory is another indication of the ecological significance of these habitats and the need for effective conservation strategies to prevent their further loss and degradation.

## **DEVELOPMENT AND LAND USE IMPACTS**

Development can result in permanent wetland and riparian habitat loss through conversion to non-habitat, and conversion of wetlands to uplands. In addition to direct habitat loss, development also has three principal indirect effects on adjacent habitat: 1) fragmentation of habitat into smaller, non-contiguous areas of less-functional habitat by structures, roads, driveways, yards and associated facilities; 2) the introduction or increased prevalence of exotic species or species that are habitat generalists, termed “human adapted” or “urban exploiters,” and 3) decreases in native species abundance and biodiversity and the loss of “human-sensitive” species that require natural habitats (Davies et al. 2001, Hansen et al. 2005, California Department of Fish and Game 2007). In general, these effects occur because development tends to favor species well-adapted to human habitation with subsequent negative effects on sensitive species and those species best adapted to natural habitats (Marzluff and Neatherlin 2006). For example, numerous studies document how human activities in natural areas disturb bird populations and reduce bird diversity, abundance, and reproductive success (Rodgers et al. 1997, Fernandez-Juricic 2002, Burger et al. 2004, Banks and Bryant 2007).

Even low-density residential development can result in habitat loss and degradation because: 1) structures require 100-foot-wide defensible space fire-safe buffers—which necessitates vegetation clearing around them (Pub. Resources Code § 4291), 2) local wildlife populations’ response to development can continue several decades after habitat alteration or construction (Hansen et al. 2005), and 3) in addition to local effects, development has been shown to alter the ecological processes and biodiversity in areas more far-removed from the development, including in parks, preserves, and national forests (Hansen et al. 2005, Johnston and Klemens 2005b). Other studies have also

demonstrated that the surrounding landscape “matrix” and the amount of urbanization can strongly influence riparian and wetland species even if development is not directly adjacent to these habitats (Rodewald and Bakermans 2006, Roe and Georges 2007).

Additional adverse effects from development adjacent to wetland habitats include: vegetation removal; water diversions and altered hydrology; diminished water quality from the discharge of pollutants such as sediment, toxic substances, and pathogens; disturbance to wildlife from pets, noise, and human activities; filling and refuse dumping; and altered microclimate. Human development also negatively impacts wildlife through increased road-kill (Trombulak and Frissell 2000, Malo et al. 2004, Beebee 2013), light pollution (Longcore and Rich 2004, Rich and Longcore 2006), the killing of and disturbance to wildlife by domestic and feral animals such as house cats, and increased human conflict with wildlife such as black bear, mountain lion, and fox. Development in close proximity to natural areas often provides attractive nuisances such as orchards, gardens, pets, compost bins, and garbage receptacles, which results in human-wildlife conflicts that often resulting in the killing (depredation) of these animals. For an in-depth review of the impacts of land use and urbanization on stream ecosystems see Paul and Meyer (2001) and Allan (2004).

Development-related loss of native species abundance and diversity or the increase in exotic and native generalist species has been shown for bird assemblages (Beissinger and Osborne 1982, Wilcove 1985, Luginbuhl et al. 2001, Odell et al. 2003), mammals (Maestas et al. 2001), fish (Paul and Meyer 2001), amphibians (Davidson et al. 2001, Ridley et al. 2005), terrestrial and freshwater invertebrates (Miyashita et al. 1998, Paul and Meyer 2001), and plants (Galatowitsch et al. 1999, Mack and Lonsdale 2001, Reichard and White 2001).

Many studies have shown that habitat fragmentation from urban and exurban development and other human activities results in significant declines in species richness in a broad range of avian communities (Wilcove 1985, Engels and Sexton 1994, Marzluff 2001, Hansen et al. 2005). Rottenborn (1999) found that urbanization on lands adjacent to intact riparian woodlands has substantial impacts on riparian bird communities. Human-adapted corvids (ravens, crows, and jays) are effective nest predators whose abundance has increased dramatically due to urbanization in western North America and worldwide in the last century (Luginbuhl et al. 2001). Increased nest predation by corvids and other human-adapted species has had a significant effect on bird populations adjacent to urbanized areas (Wilcove 1985, Engels and Sexton 1994, Marzluff 2001, Odell et al. 2003, Hansen et al. 2005).

Bank erosion is a fundamental riverine process that drives lateral channel migration, thus creating and maintaining off-channel habitats, affecting recruitment of sediment and large woody debris and acting as a key regulator of aquatic habitat in the main stem and riparian habitat in the floodplain (USFWS 2004, CALFED 2008). Development often leads to streambank stabilization, which prevents bank erosion and channel migration. Bank stabilization (also known as armoring) such as placement of revetment (large boulders known as rip-rap) and efforts to dredge channels or build flood-control

levees, commonly occur where development is placed in flood plains or too close to stream and river channels and is then threatened by flooding and bank erosion.

Revetment can negatively impact riparian vegetation, stream bank morphology, stream flow characteristics and aquatic and terrestrial habitat quality (USFWS 2000, USFWS 2004). Revetment can eliminate structural bank features such as large wood and overhanging banks and vegetation, which provide fish with refuge from high flows, needed habitat complexity, and cover from potential predators (Peters et al. 1998, USFWS 2000, USFWS 2004). In redwood forests, stream reaches with revetment were shown to have lower plant species richness, vegetation cover, and tree seedling density compared with streambanks without revetment (Russell and Terada 2009).

Loss of California's wetland and riparian habitats has resulted in many water quality impairments. For example, removal of riparian vegetation is a contributing factor to impairment of over three quarters of the water bodies listed by the North Coast Regional Water Quality Control Board pursuant to the Clean Water Act Section 303(d)(SWRCB 2002). According to SWRCB (2002), more than 50 water bodies in northern California, including reaches of almost all major river systems, are listed pursuant to Clean Water Act section 303(d) as impaired for any of the following reasons: temperature, sedimentation/siltation, nutrients, and bacteria.

#### Impacts to Amphibians and Reptiles

Amphibians appear to be particularly vulnerable to habitat loss and fragmentation due to multiple factors (Carr and Fahrig 2001, Houlahan and Findlay 2003, Cushman 2006). These factors include: 1) relatively short distances traveled; 2) high vulnerability to death when moving across roads and through inhospitable terrain; 3) narrow habitat tolerances; and 4) high vulnerability to pathogens, invasive species, climate change, increased ultraviolet-B exposure and environmental pollution (Gibbs and Shriver 2005, Cushman 2006, see also Olson et al. 2007).

Traffic-caused mortality ("road-kill") is a major cause of amphibian mortality and may contribute to their global decline (Fahrig et al. 2005, Gibbs and Shriver 2005, Glista et al. 2008). Amphibians may be especially vulnerable to traffic mortality because they often migrate *en masse* to and from breeding wetlands (Glista et al. 2008) and because of their relatively slow speed. For example, as reported in Fahrig et al. (2005) and Ehmann and Cogger (1985) a conservative estimate of 5,480,000 reptiles and amphibians are killed annually by traffic in Australia. Rosen and Lowe (1994) estimate that tens or hundreds of millions of snakes have been killed by automobiles in the United States since the advent of the automotive age.

Development adjacent to wetlands and riparian areas can eliminate native habitat for amphibians and reptiles. Until recently, wetlands and streams were thought to be core habitat for semi-aquatic amphibians and reptiles, and adjacent riparian and upland habitats were considered merely a buffer zone to protect aquatic habitat (Semlitsch and Jensen 2001). However, many reptiles and amphibians that utilize wetlands and streams for reproduction and juvenile life stages depend upon, and range widely into,

adjacent uplands as adults (Semlitsch and Bodie 2003, Rittenhouse and Semlitsch 2007, Harper et al. 2008). Numerous studies have documented the critical importance of upland areas for migration and adult habitat for amphibians and reptiles that breed in insolated wetlands (Joyal et al. 2001, Gibbons 2003, Semlitsch and Bodie 2003, Cushman 2006, Denoel & Ficetola 2008). In an analysis of six North American salamander species, Semlitsch (1998) determined that 125 meters (410 feet) was the mean distance individuals were found from the edge of aquatic habitats and that state and federal wetland protections do not take into account the wide upland use of these aquatic organisms.

The western pond turtle is a case in point. It is listed as state endangered in Washington, Sensitive–Critical in Oregon, and a SSC in California. Primary threats to this species are loss and alteration of both aquatic and terrestrial habitats (Bury and Germano 2008). However, in no state is its upland habitat effectively protected (Bury and Germano 2008). Uplands adjacent to aquatic habitats are critical to this species, as some individuals can spend as much as seven months of each year on land as reported by Reese and Welsh (1998) in Bury and Germano (2008). According to this study, females lay eggs as many as 400 meters (1,312 feet) from streams, however most nests are within 50 meters (164 feet) of the water's edge.

In northern California, many amphibians, including the federally threatened California red-legged frog, the Cascades frog, northern red-legged frog, and foothill yellow-legged frog, all depend upon upland habitats for adult life stages (Bulger et al. 2003). In a California red-legged frog study, Bulger et al. (2003) found adults as far as 500 meters (1,640 feet) from water. These researchers suggest adequate protection around California red-legged frog breeding sites can be achieved by maintaining at least 100 meters (328 feet) of suitable habitat around wetlands. To prevent the imminent regional extirpation of the Cascades frog, Fellers et al. (2008) recommend restricting habitat alterations within proximity to their breeding grounds. In a study of Appalachian salamanders, Crawford and Semlitsch (2007) found that 95 percent of salamanders occupied a core terrestrial habitat within 27 meters (89 feet) of a stream.

Harper et al. (2008) determined that regulations protecting 30 meters (98 feet) or less of surrounding terrestrial habitat are inadequate to support viable populations of pool-breeding amphibians. A summary of data on use of terrestrial habitats by wetland-associated amphibians and reptiles found that core habitats ranged from 159 to 290 meters (521 to 951 feet) for amphibians and 127 to 289 meters (416 to 948 feet) for reptiles from the edge of aquatic habitats (Semlitsch and Bodie 2003). A California tiger salamander (*Ambystoma californiense*) habitat analysis determined 50 percent of an adult population was found greater than 150 meters (492 feet) from a breeding pond (Trenham and Shaffer 2005).

Thus riparian or upland habitat surrounding wetlands and streams is documented to function as essential and core habitat for many aquatic and riparian-dependent amphibian and reptile species and should not be viewed merely as a disturbance buffer for aquatic habitat from surrounding land-use practices (Semlitsch and Jensen 2001).

The conservation of reptile and amphibian biodiversity is one of the most compelling biological reasons to protect small, isolated wetlands (Batzer et al. 2006) and to implement wider and more effective upland buffers adjacent to aquatic habitats.

#### Fragmentation and Altered Microclimate

Riparian habitat adjacent to streams and rivers has a controlling influence on microclimate characteristics of the stream corridor (FEMAT 1993). Land management, such as removal of forest canopy creates an “edge effect” that results in microclimate changes to the remaining habitat, including changes in relative humidity, solar radiation, soil and water temperature, average high and low ambient temperatures, and wind velocity within forested areas adjacent to forest openings (FEMAT 1993, Davies et al. 2001). Riparian microclimate, which is often more cool and moist than adjacent habitats, together with stream temperatures, are important and related habitat characteristics of stream and river ecosystems (Franklin 1992, Moore et al. 1995).

Numerous studies on the edge effects and fragmentation from adjacent land use, (especially forest removal) have documented significant indirect biotic and abiotic impacts on remnant habitats (FEMAT 1993, Brososfske et al. 1997, Chen et al. 1999). For example, microclimate changes in remnant habitat patches resulting from adjacent land use practices have been documented to extend from 15 meters (50 feet) to greater than 250 meters (820 feet) into remnant patches (Jules and Rathcke 1999, Gehlhausen et al. 2000, Zheng 2000, Davies et al. 2004, Concilio 2005).

Impacts to vegetation structure in remnant forest patches adjacent to forest openings have been documented to include changes in species density, growth rate, volume, above- and below-ground biomass, and vegetation height (Brothers 1993, Fraver 1994, Malcolm 1994, Young and Mitchell 1994, Lovejoy et al. 1996, Laurance et al. 1998, Stinton et al. 2000, Franklin et al. 2004, Harper et al. 2005).

Edge effect changes in vegetation composition in adjoining remnant forests, including species composition, species richness, and plant community have been documented by Russell and Jones (2002), Benito-Malvido and Martinez-Ramos (2003), Moen and Jonsson (2003), Watkins et al. (2003), Harper et al. (2005), Halpern et al. (2005), Nelson et al. (2005a), and Nelson et al. (2005b). While changes to plant life history and plant/animal interactions in forest fragments, including survival, growth, development, reproduction, pollination, seed set and dispersal are documented by Jules and Rathcke (1999), Ozanne et al. (2000), Tallmon et al. (2003), and Nelson and Halpern (2005a).

In their study sites in coniferous forests in Washington State, Brososfske et al. (1997) concluded that a minimum 45-meter buffer width (147 feet) on both sides of a stream (90 meter (295 feet) total buffer width) is necessary to maintain a natural riparian microclimate along streams. Changes in humidity and wind speed were documented to extend greater than 240 meters (787 feet) from clear-cut edges into an old-growth Douglas-fir forest (Chen et al. 1995). Based upon the studies cited here and elsewhere, there is strong evidence that adjacent land use can have a significant indirect effect on



the microclimate and vegetation characteristics of wetland and riparian habitats, especially if the land use entails habitat conversion or removal of forest vegetation.

### Domestic and Feral Cats

The scientific literature suggests wildlife would substantially benefit if proposed residential development adjacent to wetland and riparian habitats required that domestic housecats be kept indoors. Winter and Wallace (2006) report there are at least 90 million pet cats in the United States and perhaps an equal number of feral cats. Free-roaming cats in the United States annually kill millions of birds, mammals, amphibians and reptiles—including endangered species—and predation by feral and free-ranging house cats is now considered one of the greatest threats to avian biodiversity (Winter and Wallace 2006). Domestic cats are considered primarily responsible for the extinction of 33 bird species world-wide since the 1600s (Winter and Wallace 2006).

During a five month period, Great Britain's estimated nine million domestic cats brought home (killed) an estimated 92 million prey items, including 57 million mammals, 27 million birds, and five million reptiles and amphibians (Woods et al. 2003). According to the Florida Fish and Wildlife Conservation Commission (2003), Florida has an estimated 5.3 million owned and un-owned (feral) domestic cats that are sometimes outdoors. It is estimated Florida cats annually kill millions of wildlife prey and that their ecological impact is best documented and has the most damaging effect on endangered species and other taxa with small population sizes or limited distributions (Florida Fish and Wildlife Conservation Commission 2003).

In California, cat predation is a threat to numerous sensitive bird species, including California least tern, western snowy plover, California black rail, burrowing owl, and tricolored blackbird (Winter and Wallace 2006). A study of the impacts of residential development adjacent to fragmented natural habitats in San Diego County showed: 32 percent of residences owned cats; each residence had on average 1.7 cats; 78 percent let their cats outdoors; and 84 percent of outdoor cats brought back kills to the residence (Crooks and Soule 1999). In this study, cat owners with outdoor cats that hunted returned on average 24 rodents, 15 birds, and 17 lizards to the residence annually. In addition to direct predation of birds, domestic cats have been shown to have substantial sub-lethal effects on birds through the loss of reproductive capacity (reduced fecundity) (Bonnington et al. 2012).

### Night Light Pollution

Artificial light is a consequence of development. Roads and buildings typically include exterior night lighting and have the potential to introduce light pollution to adjacent wetland, marine, and riparian habitats. Adverse ecological effects of artificial night lighting on terrestrial, aquatic, and marine resources such as fish, birds, mammals, and plants are well documented (Johnson and Klemens 2005a, Rich and Longcore 2006). Some of these effects include altered migration patterns and reproductive and development rates, changes in singing behavior in bird species Miller (2006), changes in foraging behavior and predator-prey interactions, altered natural community assemblages, and phototaxis (attraction and movement towards light), disorientation,

entrapment, and temporary blindness (Longcore and Rich 2004). The Department has determined that artificial night lighting can significantly affect marine and near-shore wildlife (California Department of Fish and Game 2007). Light pollution disrupts the abilities of night-foraging birds, renders seabirds more vulnerable to predation, and has resulted in nest abandonment and low reproductive success for brown pelicans (California Department of Fish and Game 2007). Johnston et al. (2004) list artificial lighting as a permanent impact to bat roosts and recommend that artificial lighting be directed away from bat roosts or possibly shaded by trees.

In an experimental study, Becker et al. (2013) found that artificial light associated with human-made structures has the potential to alter fish communities within urban estuarine ecosystems by creating optimal conditions for predators. Future coastal development should consider the ecological implications of lighting on aquatic communities. They recommend lighting be minimized around coastal infrastructure and the use of red lights, which have limited penetration through water, be considered (Becker et al. 2013). Research on the effects of artificial lighting on salmonid populations indicate that increased light intensity appears to slow or stop out-migrating juvenile salmon and affects feeding patterns. Juvenile salmonids in the presence of increased artificial night lighting may be more vulnerable to predation (McDonald 1960, Patten 1971, Ginetz and Larkin 1976, Tabor et al. 2004).

#### Stormwater Runoff Pollution

Non-point source pollution found in urban stormwater runoff is recognized as a leading threat to the nation's water quality (USEPA 1999). Two comprehensive assessments of the nation's management of oceans and coastal resources determined non-point source pollution is one of the most significant emerging threats to aquatic species and that non-point source pollution represents the greatest pollution threat to oceans and coasts (Pew Ocean Commission 2003, U.S. Commission on Ocean Policy 2004). According to the California Department of Fish and Game (2007), 40,000 tons of contaminants (heavy metals, pesticides, fertilizers, polychlorinated biphenyls, etc.) enter the Bay Delta annually from urban and agricultural runoff.

Urbanization and other forms of development increase the runoff of pollutants from terrestrial landscapes to aquatic habitats. Non-point source pollutants in stormwater runoff, such as petroleum products, metals, pathogens, nutrients, pesticides, and domestic animal feces are well documented as having acute and chronic lethal and sub-lethal effects on salmonids and other aquatic organisms. For instance, polycyclic aromatic hydrocarbons, a byproduct of petroleum use, are a pervasive component of stormwater runoff and are documented to have numerous detrimental health effects on salmonid fishes (Incardona et al. 2004, 2005). These contaminants originate from commercial, industrial, residential and agricultural land uses and are mobilized from roads, roofs, farms, lawns, crops and other surfaces and transported by rainwater to aquatic habitats. Stream habitat quality has been shown to degrade when impervious surfaces, such as buildings, roads, and parking lots cover greater than 10 percent of a watershed, with severe degradation expected beyond 25 percent (Arnold and Gibbons 1996, Watershed Protection Research 2003). In West Virginia, biological integrity

ratings of poor or very poor occurred in catchments with less than 7 percent urban land use (Snyder et al. 2003).

Moore and Palmer (2005) studied invertebrate biodiversity in 29 small headwater streams in rapidly urbanizing agricultural lands near Washington, D.C. They made two significant findings with important conservation implications: 1) Invertebrate biodiversity was extremely high in agricultural headwater streams and progressively declined along a land-use gradient toward urbanization. 2) In urban streams, there was a strong positive relationship between intact riparian forest buffers and in-stream biodiversity. This suggests agricultural preservation programs (e.g. regional conservation approaches that include sufficient buffers and other appropriate conservation measures) are likely important to conserve freshwater biodiversity in urbanizing areas. Their study suggests that efforts to preserve and restore urban riparian buffers may mitigate some of the impacts of urbanization on watersheds, even where there is a substantial amount of development. They conclude that from a biodiversity perspective, headwater streams in areas already highly urbanized should not be viewed as “lost causes” given the on-site and down-stream ecosystem services they provide (Moore and Palmer 2005).

Essentially any surface which does not have the capability to pond and infiltrate water will produce runoff during storm events. When a land area is altered from a field, farm or forest ecosystem to an impervious urbanized land use the hydrology of the system is altered. Water, which was previously infiltrated into the soil and converted to groundwater, utilized by plants and evaporated or transpired into the atmosphere, is now converted directly into surface runoff (USEPA 2000, OPR 2009).

As watersheds urbanize, streams receive larger volumes of stormwater runoff, which results in a greater frequency and intensity of flood events (USEPA 2000, Office of Planning and Research 2009). This in turn often leads to stream channel instability, channel widening and scour, and the introduction of larger amounts of sediment to urban streams. Visible impacts include eroded and exposed stream banks, fallen trees, sedimentation, and recognizably turbid conditions. The increased flooding frequency of urban areas also poses a threat to public safety and property. In the Russian River watershed of Sonoma County, Lohse et al. (2008) found that even low-density exurban development resulted in fine sediment inputs to streams, which negatively and significantly degraded endangered salmon spawning and rearing habitat. Both water quality and water quantity impacts associated with stormwater runoff combine to degrade stream habitats.

Paved surfaces such as roads, parking lots, and driveways create effective conduits for oil, grease, and other toxic pollutants to enter into coastal waters. Every eight months, nearly 11 million gallons of oil runs off streets and driveways into the nation’s waterways (Pew Ocean Commission 2003). Rooftops, another fixture of development and urbanization, are also known to be both sources and pathways for contaminated runoff (Van Metre and Mahler 2003). Metal roofing, for instance, is a source of cadmium and zinc, while asphalt shingles are a source of lead. Asphalt shingle and galvanized metal roofs can leach numerous contaminants to stormwater, but they also catch and deliver

fallout from airborne contaminants released from vehicles, such as copper from brake pads and cadmium from tires (Van Metre and Mahler 2003). Concentrations of zinc and lead from rooftop runoff samples have been shown to exceed established sediment quality guidelines for probable toxicity of bed sediments to benthic biota (Van Metre and Mahler 2003).

Motor vehicles are a major source of toxic stormwater contaminants such as copper, a metal that originates from vehicle exhaust and brake pad wear and is then transported to aquatic habitats via stormwater runoff. Dissolved copper has become a common non-point source pollutant in urbanized watersheds and is now a widely distributed contaminant in lakes, rivers, and coastal marine environments (Linbo et al. 2006, McIntyre et al. 2008). Dissolved copper is neurotoxic to fish and is especially known to interfere with the normal function of the peripheral olfactory nervous system (McIntyre et al. 2008). Copper-containing stormwater runoff from urban landscapes has the potential to cause chemosensory deprivation and increased predation mortality in exposed salmon (Sandahl et al. 2007).

California leads the nation in agricultural pesticide use and pesticides are a common component of stormwater pollution in the State. According to the California Department of Pesticide Regulation, more than 173 million pounds of pesticides were used in California in 2010 (California Department of Pesticide Regulation 2012). While agriculture is the major category of pesticide use in California subject to reporting, other commercial and residential uses such as landscaping utilize millions of pounds annually (California Department of Pesticide Regulation 2012). Pesticides are frequently detected in northern California salmon habitats (Guo et al. 2004, Scholz et al. 2006, Gilliom 2007). Transport of pesticides by surface runoff during rainfall events is a major process contributing to pesticide contamination in the Sacramento River (Guo et al. 2004). More than half of the water samples from certain drainages in California's Central Valley contained more than seven different pesticides (Scholz et al. 2006).

Mixtures of pesticides that have been commonly reported in salmon habitats may pose a greater challenge for species recovery than previously anticipated (Domagalski et al. 2000, Laetz et al. 2009). Certain combinations of pesticides occurring in salmon streams can have additive cumulative neurotoxicity and behavioral effects on salmon under natural exposure conditions, and therefore the ecological risk of pesticide impacts on salmon recovery may be underestimated (Scholz et al. 2006). Another study concluded that several combinations of organophosphates were lethal to Pacific salmon at concentrations that were sub-lethal in single-chemical trials (Laetz et al. 2009). Exposures to low, environmentally realistic concentrations of one type of pesticide (chlorpyrifos) are closely correlated to reductions in swimming speed and feeding rates of salmon (Sandahl et al. 2005). Reductions in salmon feeding rates are likely to lead to reductions in the size of exposed salmon at the time of their seaward migration—an important determinant of individual salmon survival at sea. According to McCarthy et al. (2008), toxic stormwater runoff, urbanizing coastal streams, and coho salmon die-offs "...foreshadow potential future threats to wild salmon populations in developing watersheds in northern California and the Pacific Northwest."

There is also ample research that links pesticides to amphibian declines (Sparling et al. 2001, Davidson 2004). Extensive experimental data show that insecticides and herbicides have profound impacts to the biodiversity and productivity of aquatic communities, including severe tadpole mortality (Relyea 2005). Organophosphate pesticides are “ubiquitous in the environment and are highly toxic to amphibians” and are directly related to their declines in California (Sparling and Fellers 2007, 2009). Their data suggest that because of pesticide use, agricultural runoff in California’s Central Valley is toxic to amphibians.

The scientific literature suggests that unmitigated stormwater runoff has a variety of negative impacts to wetland and riparian resources, and measures to reduce stormwater runoff from developed areas are imperative. Low-impact development elements such as pervious surface technologies for driveways and walkways, vegetated (green) roofs (Voelz 2006), disconnected downspouts, water gardens and vegetated swales may be used to maximize pervious surfaces and capture and maintain on-site stormwater percolation and treatment and maintain and improve the water quality of aquatic habitats (USEPA 2000). In essence, the purpose of low-impact development is to slow, spread, and sink (infiltrate into the ground) stormwater on-site to the maximum extent practicable, rather than to store, concentrate and drain stormwater off-site as quickly as possible.

By using low-impact development, projects generally seek to maintain to the greatest extent practicable, post-project pervious surfaces and minimize off-site stormwater runoff (USEPA 2000, OPR 2009). Low-impact development design elements benefit aquatic resources by: 1) filtering out pollution and increasing the quality of stormwater runoff; 2) decreasing peak flows, flood risks and erosion in downstream waters; and 3) increasing ground water recharge and therefore helping maintain biologically-important summer low flows in adjacent streams and wetlands (USEPA 2000, OPR 2009). Low-impact development has been shown to be economical, has documented effectiveness in reducing stormwater pollution, protecting stream integrity and ocean health, and therefore its use has become highly promoted (California Ocean Protection Council 2008, SWRCB 2008).

## **CLIMATE CHANGE IMPACTS**

According to the California Global Warming Solutions Act of 2006, climate change is now considered one of the greatest threats to California’s ecosystems. Based upon current projections, by the end of this century California’s climate will be considerably warmer than today’s, snowpack will be substantially diminished, what snowpack occurs will melt much earlier in the year, and relative sea levels will have risen (California Energy Commission 2005, 2009a, 2009b, 2009c, USGCRP 2009).

California is especially vulnerable to the impacts of climate change and sea level rise because of its geographic location, long coastline, Mediterranean climate, extensive mountain and river systems, large population, and massive agricultural output (Snyder

et al. 2002, Snyder and Sloan 2005, California Energy Commission 2009a, 2009c). California is also more vulnerable to climate fluctuations, relative to the rest of the U.S., because it derives a disproportionate percentage of its water supply from only a small number of winter storms, typically in the form of “atmospheric rivers” (Dettinger 2011, Dettinger et al. 2011).

In the coming decades, climate change is anticipated to exacerbate further the loss of California’s ecosystems and the services they provide (California Energy Commission 2009d). Already there is sufficient experimental and empirical evidence to generate high confidence that climate change is presently impacting wildlife species and natural systems across the globe (Parmesan and Yohe 2003, Parmesan 2006, California Energy Commission 2009d).

Regional climate models, based upon future greenhouse gas (GHG) emission scenarios, suggest warmer average temperatures and changes in precipitation patterns will occur, the total amount of water availability in California will decrease over this century, water needs will increase, and the timing of water availability will be greatly perturbed (Leung and Ghan 1999, Snyder et al. 2002, Leung et al. 2004, Snyder et al. 2004, Snyder and Sloan 2005, California Energy Commission 2009c).

These climatic changes are anticipated to result in region-wide deficits in spring and summer runoffs, which will intensify human competition for a diminishing water supply and leave natural systems and aquatic and riparian species severely impacted (Snyder et al. 2004, Snyder and Sloan 2005, Schlenker et al. 2007).

Air Temperature Increase /Extreme Heat Days

When averaged across the state, and across all GHG emission scenarios, both minimum and maximum air temperatures are projected to increase over the 21st Century (California Energy Commission 2009d). Three recent air temperature climate change projections are included in the table below.

**Projected Changes in Air Temperature for Three Regions and Time Periods under Existing GHG Emission Conditions.**

Region	Next Two Decades	Mid-21 <sup>st</sup> Century	End of 21 <sup>st</sup> Century
Klamath Basin	---	1.1 to 2.0 °C (+2.1 to 3.6 °F)	2.5 to 4.6 °C (+4.6 to 7.2 °F)
California	0.6 to 1.3 °C (~1.1 to 2.3°F)	0.8 to 2.3 °C (~1.4 to 4.1°F)	1.5 to 4.2 °C (~2.7 to 7.5°F)
Pacific Northwest	1.6 °C (+3.0 °F)	2.0 to 2.8 °C (+3.6 to 5.0 °F)	2.8 to 4.6 °C (+5.1 to 8.3 °F)

Source: California Energy Commission 2009d, Koopman et al. 2009, USGCRP 2009; Barr et al. 2010.

Water Temperature Increase

Warmer air temperatures and other effects of climate change are expected to result in higher water temperatures in California’s streams and rivers, which in turn could significantly decrease suitable habitat for some freshwater fishes (Poff et al. 2002, Mohseni et al. 2003, Yates et al. 2008, Wenger et al. 2011). Increased water temperatures reduce growth rates in fish and increase their susceptibility to disease,

while warmer water also holds less dissolved oxygen, which can reduce survival in juvenile salmonids (Moyle 2002, California Department of Fish and Game 2007). Klamath River water temperature is projected to increase by approximately 2.8 to 3.3 °C (5 to 6 °F) during the 21st century (Reclamation 2011). Wenger et al. (2011) project substantial declines in habitat for trout species in the interior western United States due to climate change-related altered flow regimes and increased water temperatures. Due to a warming climate, by 2090, 25 to 41 percent of currently suitable California streams may be too warm to support trout (O'Neal 2002). In the upper Sacramento River Basin, increased water temperatures could exceed the physiological tolerances of eggs and juveniles of winter and spring run Chinook salmon (Yates et al. 2008).

#### Decreased Snowpack, Earlier Snowmelt, Lower Spring and Summer Flows

Numerous studies indicate that a warmer future climate in California will result in more winter precipitation falling as rain instead of snow and will cause snowmelt runoff to shift earlier in the season (Kim 2001, Kim et al 2002, Knowles and Cayan 2002, Snyder et al. 2002, Miller et al. 2003, Hayhoe et al. 2004, Leung et al. 2004, Snyder et al. 2004, Vanrheenen et al. 2004, Snyder and Sloan 2005).

By 2090, a projected 2.1 °C (~3.8°F) temperature increase is expected to reduce the April snowpack of the Sacramento/San Joaquin Basin by approximately half, with losses being most severe in the northern Sierra Nevada and Cascade Mountains—which would lose 66 percent of their April snowpack (Knowles and Cayan 2002). This would in turn result in an approximate 20-percent reduction in historical annual spring runoff, and associated increases in winter flood peaks for the Sacramento/San Joaquin watershed (Knowles and Cayan 2002). With a doubling of atmospheric carbon dioxide from 280 to 560 parts per million, Snyder et al. (2002) project an 82-percent decrease in snow accumulation by the end of February in the central Sierra Nevada. Using two new climate models with different emission scenarios, Hayhoe et al. (2004) project a 50 to 75-percent and a 73 to 90-percent reduction in Sierra Nevada snowpack before 2100. A 60 to 70-percent reduction in snowpack in the Coast Ranges of California and Oregon is projected by 2040-2060 (Leung et al. 2004).

According to Maurer (2007), changes in precipitation, temperature, and snow water equivalence, will result in an earlier arrival of annual flow volume of 36 days in the Sierra Nevada by 2071-2100, with related decreases in spring and summer flows. As a result of less snowpack and earlier snowmelt, California can expect significantly less spring and summer runoff (Snyder et al. 2004) resulting in less water for ecosystem services, less reservoir capture, a diminished water supply for human uses, and greater conflict over the allocation of a diminished supply (Knowles and Cayan 2002, Kim et al. 2002, Snyder et al. 2004, Schlenker et al. 2007, Oregon Climate Change Research Institute 2010, Mayer and Naman 2011). A higher percentage of winter precipitation falling as rain rather than snow and the potential for more rain-on-snow events, also indicates greater flood frequencies during the cold season (Kim et al. 2002).

Aquatic ecosystems are likely to be impacted by these changes. Plants and animals that rely on snowmelt runoff or regular summer flows will experience streams and rivers

with substantially lower summer flows or that goes dry much earlier in the year. Water temperatures are also likely to be warmer due to the decreased contribution of snowmelt (Carpenter et al. 1992, Snyder et al. 2004). In arid and semi-arid regions especially, riparian ecosystems are extremely sensitive to altered flow regimes and are likely to be degraded by diminished stream flows (Carpenter et al. 1992, Poff et al. 1997).

### Extreme Precipitation and Flood Events

In a global study assessing the effects of a doubling of atmospheric carbon dioxide concentrations, Zwiers and Kharin (1998) project greater and more frequent extreme precipitation events almost everywhere, with a globally-averaged 20-year return event increasing by about one centimeters of rain per day, or less than 10 percent, and return periods for extreme precipitation events shortening by a factor of two. Regional climate projections indicate northern California is likely to experience an increase in the frequency and intensity of high precipitation and high runoff (extreme) storm events during the 21<sup>st</sup> Century (Bell et al. 2004, Kim 2005, Kim et al. 2002, Snyder et al. 2002, Kunkel 2003, Maurer 2007, California Energy Commission 2009c, USGCRP 2009, Mannshardt-Shamseldin et al. 2010, Dettinger 2011, Ralph and Dettinger 2011).

By projecting changes in streamflow output for eighteen stream gauging stations statewide, California Energy Commission scenarios show all California rivers studied will have an increase in average flow during January to April by the end of the century (years 2070–2099) compared to historical periods (California Energy Commission 2009c). Projections under certain high GHG scenarios predict spikes in February river flows of 60 percent above historic levels, and increases in December river flows of 20 percent to almost 40 percent in other scenarios (California Energy Commission 2009c).

Diffenbaugh (2005) projected an increase of up to 10 extreme precipitation events per year in the Pacific Northwest (up to a 140-percent increase) under a higher emission scenario with some variation depending on location within the region. While Bell et al. (2004) project the North Coast and North Lohontan (Modoc and Lassen Counties) basins average an additional 2.5 heavy rainfall events per year with a doubling of atmospheric carbon dioxide concentrations.

Future changes in the frequency and magnitude of extreme temperature and precipitation events could severely impact natural ecosystems such as wetland and riparian habitats (Anderegg et al. 2012), through changes in plant community composition and distribution, increased risk of species invasions and exotic diseases, and extinction (Diffenbaugh 2005). Based upon the scientific literature, climate change impacts on wetland and riparian habitats are anticipated to increase in the future, while simultaneously, the importance of these habitats to mitigate the impacts of climate change on fish and wildlife will become even more valuable.

### Sea Level Rise

Sea level rise has enormous implications for coastal planning, land use, development, and the conservation of fish and wildlife habitat along California's 1,350 kilometer-long



(~840 miles) coast and is therefore of significant statewide concern (California Energy Commission 2006, 2009a, Executive Order S-13-08). The Intergovernmental Panel on Climate Change, IPCC (2007), estimates that global sea level rose an average of  $1.7 \pm 0.5$  millimeters per year over the 20<sup>th</sup> century, based on tide gauge data from around the world and that sea level rose an average  $3.1 \pm 0.7$  millimeters per year from 1993 to 2003, based upon precise satellite altimetry measurements. Tidal gauge data for California and the west coast of the United States have shown a similar trend in sea level rise (California Energy Commission 2006, 2009a).

Using future warming scenarios from IPCC (2007), Rahmstorf (2007) projected sea level rise by 2100 of 50 to 140 centimeters (~20 to 55 inches) above the 1990 level. A more recent analysis by Vermeer and Rahmstorf (2009), also using IPCC (2007) future warming scenarios, projects a sea level rise ranging from 75-190 centimeters (~30 to 75 inches) for the period 1990-2100. The most recent and detailed analysis of sea level rise for California's coast projects the following: south of Cape Mendocino, sea level will rise 4-30 centimeters by 2030 relative to 2000, 12-61 centimeters by 2050, and 42-167 centimeters by 2100; north of Cape Mendocino, sea level is projected to change between -4 centimeters (sea-level fall) and +23 centimeters by 2030, -3 centimeters and +48 centimeters by 2050, and 10-143 centimeters by 2100 (National Academy of Sciences 2012). The relative difference in sea level projected north and south of Cape Mendocino is primarily related to differences in coastal uplift rates due to plate tectonics. Changes in relative sea level rise are geographically variable because of local and regional differences in tectonic uplift; land subsidence; post-glacial isostatic rebound; compaction of sedimentary soils; oil, natural gas, and water withdrawal; and gravitational and deformational effects related to melting polar ice (USEPA 1988, Galbraith et al. 2002, Scavia et al. 2002, National Academy of Sciences 2012).

There is strong scientific consensus that coastal marine ecosystems, along with the goods and services they provide, are threatened by sea level rise (Church and Gregory 2001, Scavia et al. 2002, Harley et al. 2006, Nicholls and Tol 2006, California Energy Commission 2009a, USGCRP 2009). As a result of sea level rise, coastal areas worldwide are expected to experience higher rates of coastal erosion, flooding, inundation, and storm surges over the coming decades (USEPA 1988, Church and Gregory 2001, California Energy Commission 2006, 2009a, USGCRP 2009). According to Nicholls et al. (1999), by the 2080s, sea level rise could cause the loss of up to 22 percent of the world's coastal wetlands.

Increased sea levels, especially in combination with storm-driven surges, extreme waves, intense low-pressure autumn or winter storms, high tides, and El Niño conditions, are predicted to result in extensive flooding in coastal regions of California and the Pacific Northwest and significant damage to coastal infrastructure (California Energy Commission 2006, USGCRP 2009, National Academy of Sciences 2012). Kelvin waves, for instance, are generated in the tropical western Pacific during El Niño events and can intensify the impact of Northcoast winter storms. These waves move northward up the California coast bringing an influx of warm water and raising sea level by 15-25 centimeters (6-10 inches) as they pass (California Energy Commission 2006).

In an analysis of 140 years of tidal data from central California, Bromirski et al. (2003) found that since about 1950, California has experienced a significant increasing trend in extreme winter storms resulting in extreme high sea level residuals. Intense storm events cause the greatest coastal erosion and have the greatest impact on coastal development (Bromirski et al. 2003). In the past two decades, California has experienced significant increases in annual maximum wave heights and in the number of waves classified as extreme as a result of more intense El Niño events, though it is yet unclear if this trend is related to climate change (Seymour 2003).

Climate models predict the number of occasions when high sea levels and high river flows coincide will increase markedly in this century (California Energy Commission 2009b). According to California Energy Commission (2009b), "The combined impacts of sea level rise (and high sea-level stands) with concurrent river flood flows have the potential to imperil many smaller coastal and estuarine settings and communities along the California coast." Sea level rise and related coastal erosion are expected to result in substantial losses of coastal wetland and intertidal habitats in the future (Nicholls et al. 1999, Galbraith et al. 2002, California Energy Commission 2006, 2009a).

A significant amount of coastline on the North Coast is located in the Erosion High Hazard Zone delineated on the California Flood Risk Sea Level Rise Maps and the built environments in these areas are threatened by sea level rise (California Climate Change Portal 2013). Because coastal wetlands are also particularly vulnerable to sea level rise-related inundation, flooding, and coastal erosion, undeveloped lands in or immediately adjacent to the coastal floodplain may be the only areas suitable for future wetland or estuarine habitat maintenance, restoration, and inland migration.

The California Energy Commission (2009a) includes the following sea level rise-related principles for adaptation and recommended practices and policies:

- Sea level rise must be integrated into the design of all coastal structures.
- Current efforts to build, maintain, or modify structures in coastal areas at risk of sea-level rise must be based on current estimates of projected rise.
- Development should be prohibited on land immediately adjacent to wetlands at risk of sea level rise. These buffer areas may be the only areas suitable for future wetland restoration projects.
- In areas at risk from sea level rise that are not heavily developed, local communities and coastal planning agencies have the opportunity to limit development and reduce future threats to life and property.

In summary, climate science indicates that in the coming decades, northern California is likely to experience warmer air and surface water temperatures, wetter winters, less snowpack and faster snowmelt, more frequent and severe drought, an increase in the frequency and severity of winter storms and flood events, and a rise in relative sea levels. Based upon the above, wetland and riparian habitat's stream shading and cooling abilities, erosion-buffering properties, floodwater storage capacity, and groundwater recharge capabilities will be of even greater importance to fish and wildlife

in the future. The scientific literature indicates that over the coming decades, it is highly likely climate change will magnify the already substantial adverse effects of land use and development on California's wetland and riparian habitats, even as their ecosystems services become more valuable. For these reasons, effective land use planning and project impact analysis and mitigation should include an assessment of future climate change and sea level rise impacts, when appropriate.

## **BUFFER EFFECTIVENESS**

In its recommendations regarding the California Fish and Game Commission's Wetland Resources Policy, the Department stated that wetlands and associated uplands complement one another and that numerous animals found in wetlands are, nevertheless, at least partially dependent upon associated uplands. The Department recommended that buffers between proposed development and aquatic habitats should be included as an integral component of all mitigation plans for project impacts. The Department concluded that a "(f)ailure to retain this ecological bond between wetland and associated uplands will result in the creation of isolated wetland enclaves scattered throughout highly urbanized areas and result in indirect loss of wetland habitat values."

Riparian buffer or reserve guidelines developed by various jurisdictions reflect a diversity of management objectives, including the protection of water quality and wildlife habitat (Richardson et al. 2005). Riparian and wetland vegetation improves stream and wetland water quality by removing sediment, organic and inorganic nutrients, and toxic materials (Belt and O'Laughlin 1994, Mitsch and Gosselink 2000, USDA 2000, Meyer et al. 2006). Riparian buffers help keep pollutants from entering adjacent waters through a combination of processes including dilution, sequestration by plants and microbes, biodegradation, chemical degradation, volatilization, and entrapment within soil particles. The scientific literature shows effective wetland, stream and riparian buffers, in combination with other conservation strategies, may help to avoid and mitigate for the land use and development impacts described in the preceding sections of this Technical Memorandum. Site specific conditions may justify wider or narrower, or variable buffer widths. Such circumstances may include, for example, the presence of State or federally-listed species, SSC or especially sensitive or significant habitats, such as coastal lagoons or vernal pool complexes. Special consideration should be given to vernal pool buffer widths because vernal pool hydroperiods are acutely driven by the characteristics of surrounding uplands such as soil characteristics, gradient, size and configuration of the uplands, and potential hydrologic project impacts.

While no set habitat buffer width or mitigation strategy can be shown to be effective or necessary in all instances, the most recent and best available science provides technical guidance on buffer width and other buffer characteristics that are likely to be most effective on a landscape-scale. For example, road construction and forest removal on surrounding lands was shown to significantly affect biodiversity in adjacent wetlands (Findlay and Houlihan 1997). Their data suggest wetland policies that only protect the wetland or a narrow buffer zone around its perimeter, "...are unlikely to provide adequate protection for wetland biodiversity (Findlay and Houlihan 1997)."

There is substantial evidence showing narrow buffers are considerably less effective in minimizing the effects of adjacent development than wider buffers (Castelle et al. 1992, Brosofske et al. 1997, Dong et al. 1998, Kiffney et al. 2003, Moore et al. 2005). Hilty and Merelender (2002), for instance, studied the use of stream corridors by predatory mammals in Sonoma Co. California, and found habitat use varied greatly by riparian corridor width. They sampled three riparian corridors types: 1) denuded corridors had very little natural vegetation along the creek; 2) narrow corridors had a strip of vegetation ranging from 10 to 30 meters on each side of the creek; and 3) wide corridors had more than 30 meters of natural vegetation on each side of the creek. Key results of their study include: 1) "Significantly more species of mammal predators were detected in wide riparian corridor sites than narrow or denuded sites;" 2) "A greater diversity of all mammalian predators and more native mammal predators were found in wide riparian corridors, compared to narrow or denuded corridors;" 3) "Large native predators were detected primarily in wide riparian corridors, and smaller native and non-native mammalian predators, especially the domestic cat, were more active in narrow and denuded riparian corridors" (Hilty and Merelender 2002).

Substantial research conducted in diverse riparian habitats across North America has shown that buffers of at least 50 to 100 meters wide (164 to 328 feet) are required to maintain avian biodiversity (Fischer and Fischenich 2000). Friesen et al. (1995) found that Neotropical songbirds consistently decreased in diversity and abundance as the level of adjacent development increased. Their study showed 10 acre (four hectare) woodlots without any nearby houses had on average a richer, more abundant Neotropical bird community than 61 acre (25-hectare) urban woodlots. On streams in southeastern British Columbia, Canada, Kinley and Newhouse (1997) determined that riparian reserves averaging 70 meters wide (230 feet) are needed to support near-natural densities of riparian-associated birds. In a study of boreal mixed-wood forest in Alberta, Canada, Hannon et al. (2002) found forest-dependent bird species declined as riparian buffer widths narrowed from 200 to 100 meters (656 to 328 feet). They found 20-100 meter (65-328 feet ) riparian buffers would not conserve forest songbird populations, but 200 meter-wide (628 feet) buffers would maintain pre-timber harvest passerine bird communities (Hannon et al. 2002).

Numerous other studies document how human activities in natural areas disturb bird populations and reduce bird diversity, abundance, and reproductive success (Burger et al. 2004, Banks and Bryant 2007, Fernandez-Juricic 2002, Rodgers and Smith 1997). According to the USACE technical note, "If avian habitat is a management objective, managers should consider managing for riparian zones that are at least 328 feet (100 meters) wide." (Fischer 2000). This USACE recommendation applies to either side of the channel in larger river systems and to total width for lower-order streams and rivers (Fischer 2000).

Because of the impacts of edge effects on riparian habitat, Crawford and Semlitsch (2007) recommend an overall buffer of 97 meters (318 feet) for southern Appalachian salamander streams. Harper et al. (2008) determined that regulations protecting 30

meters (98 feet) or less of surrounding terrestrial habitat are inadequate to support viable populations of pool-breeding amphibians. Olson et al. (2007) recommend a conservation approach that utilizes riparian management zone buffers of 40 to 150 meters wide (131 to 492 feet) on headwater streams to accommodate terrestrial life history functions of riparian associated fauna.

According to the USEPA, riparian buffers are a best management practice that should be used in conjunction with comprehensive watershed management plans to control and reduce point and non-point sources of nitrogen into the nation's aquatic habitats (Mayer et al. 2006). As buffer width increases, the effectiveness of removing pollutants from surface water runoff increases (Castelle et al. 1992). To protect water quality in Oklahoma's streams, a 29 meter-wide (95-foot) riparian buffer is recommended by the Oklahoma Cooperative Extension Service (Harmel et al. undated). By using benthic macroinvertebrate levels and salmonid egg development, studies generally found 30 meter (approximately 100 feet) buffers were effective in preventing water quality impacts from stormwater runoff (Castelle et al. 1992). For Georgia streams, a 30 meter (approximately 100 feet) wide riparian buffer is considered sufficiently wide to trap sediments under most circumstances, although it is recommended buffers should be extended for steeper slopes (Wenger and Fowler 2000).

Effective buffers also minimize disturbance to wetland and riparian habitats by limiting human access, minimizing refuse dumping and invasive species introductions, and by blocking transmittal of light and noise. In an analysis of wetland buffer width effectiveness on 100 coastal wetland sites in New Jersey, Shisler et al. (1987) found disturbance levels (dumping, vegetation removal, illegal lot build-out, etc.) were double at sites with narrow buffers, less than 50-feet (15 meters), than buffers 30 meters (approximately 100 feet) wide or greater. Buffers of 100-feet and greater (>30 meters) provided significantly more protection and lower levels of disturbance than buffers less than 50-feet wide (Shisler et al. 1987, Castelle et al. 1992). This study recommends buffer widths of 100, 100, and 150-feet (approximately 30, 30, and 45 meters), respectively for salt marshes, hardwood swamps, and tidal freshwater marshes for high intensity land uses such as high-density residential and industrial/commercial development (Shisler et al. 1987, Castelle et al. 1992). According to the Natural Resources Conservation Service, "...a minimum buffer of 30 meters (approximately 100 feet) on both sides of the stream is recommended for sufficient stream protection. This usually amounts to a buffer that is 3-5 mature trees wide on each side of the stream" (Natural Resource Conservation Service 2004).

From a literature review conducted by Castelle et al. (1994), it appears buffers of less than 5 to 10 meters (16 to 33 feet) provide little protection of aquatic resources under most conditions. Based upon their analysis, buffers necessary to protect wetlands and streams should be 15 to 30 meters (approximately 50 to 100 feet) in width under most circumstances (Castelle et al. 1994). However, these authors note that site-specific conditions may indicate a need for substantially larger buffers or somewhat smaller buffers.

Brosofske et al. (1997) studied the effect timber harvesting had on the microclimate of adjacent riparian forests in western Washington State. Their research concluded that a buffer at least 45 meters wide (approximately 150 feet) on each side of a stream is necessary to maintain a natural riparian microclimate along the streams they studied, which were characterized as having a 70 to 80-percent overstory canopy of predominantly conifers, and a regional climate typified by hot, dry summers and mild, wet winters (Brosofske et al. 1997). However, these researchers also found, depending on the microclimate variable, buffer widths of up to 300 meters (984 feet) may be needed to maintain an unaltered microclimate (see Chen et al. 1999).

In California's Coastal Zone, development buffers on streams, wetlands, and other environmentally sensitive habitat areas are determined by local coastal plans (LCPs). The most common buffer dimension required in city and county LCPs is 100 feet (California Coastal Commission 2007). According to a report by the California Coastal Commission, the majority of LCPs state a 100-foot (30 meter) buffer is the minimum standard, and especially sensitive habitats may require a larger buffer. Despite this, the report found that across the state, the width of currently applied LCP buffers fall short of buffer dimensions shown to be effective by the scientific literature (California Coastal Commission 2007). The Coastal Commission's analysis showed 30 to 59 meter-wide (approximately 100 to 195 feet) riparian buffers are generally accepted in the scientific literature as effectively protecting aquatic resources (California Coastal Commission 2007).

The scientific literature indicates an appropriate wetland or riparian buffer width would depend upon a number of site-specific characteristics, including: the area and type of habitat being buffered; presence of habitat for sensitive species and their potential habitat use (e.g. breeding vs. foraging or resting); sensitivity of the habitat or target wildlife species to disturbance; site topography, slope, slope stability, and soils; the habitat's rarity, quality, and connectivity or isolation from other natural communities; the habitat's potential for restoration; and the potential direct and indirect impacts from proposed adjacent development or other land use.

Utilizing the California Rapid Assessment Method (CRAM) is one tool that may help evaluate some of these habitat characteristics (California Wetlands Monitoring Workgroup 2009). However, given the diversity of wetland and riparian-dependent species and variability in potential direct and indirect impacts of development and land uses, numerous science-based buffer widths have been recommended to protect and maintain water quality and wildlife habitat.

For instance, according to a summary of the scientific literature by Fischer et al. (2000), buffer widths to protect and maintain the following are recommended: water quality ( $\geq 4$  meters to  $\geq 30$  meters) (12 to 98 feet); reptile/amphibian habitat ( $\geq 30$  meters and up to 1,000 meters) (98 to 3280 feet); bird habitat ( $> 40$  meters and up to 1,600 meters) (131 to 5,250 feet); mammal habitat ( $\geq 50$  meters) (164 feet); and plant diversity ( $\geq 30$  meters) (98 feet). An analysis of 65 wetland and riparian-dependent amphibian and reptile species showed their core upland habitats ranged more than 100 meters (328

feet) from aquatic habitats, indicating that buffers would need to be at least that wide to effectively protect wetland and riparian-dependent amphibians and reptiles (Semlitsch and Bodie 2003). According to Fischer and Fischenich (2000), buffer widths of 100 meters (328 feet) or more are usually needed to ensure protection of wildlife habitat values and use as migration corridors; while increasing widths to encompass the geomorphic floodplain is likewise desirable to optimize flood-reduction benefits.

In summary, wetland and riparian buffers, in combination with other conservation strategies, can effectively avoid or mitigate development and land use impacts on wetland, stream and riparian habitats. While no set habitat buffer width or mitigation strategy can be shown to be effective or necessary in all instances, the most recent and best available science provides technical guidance on buffer width and other buffer characteristics that are likely to be most effective on a site-specific or landscape-scale. The scientific literature indicates that to maintain viable habitat for many of California's riparian and wetland dependent bird, amphibian, and reptile populations, an undeveloped upland habitat buffer of at least 50 meters wide (164 feet), and often considerably wider, would likely be necessary. The appropriate buffer width for a project should be based on project-specific direct and indirect impacts and habitat needs.

## **KEY FINDINGS**

The following key findings are based on the preceding review of the scientific literature related to development, land use, and climate-change-related impacts on wetland and riparian resources. These findings highlight issues to consider when developing or reviewing individual projects or land use plans, but they are not to be relied on as a replacement for project or site-specific review and analysis.

- 1) The Governor of California and the Fish and Game Commission have developed policies seeking no overall net loss and long-term net gain in the quantity, quality, and permanence of wetlands acreage and values in California.
- 2) California's wetland and riparian habitats and the fish and wildlife they support are valuable and finite resources that benefit the people of the State and are threatened with loss and degradation. Consequently, the public interest requires coordinated efforts to preserve these natural resources and the ecological, recreational and economic benefits they provide.
- 3) Effective regional land use planning can be one of the best means to protect and restore California's remaining wetland and riparian habitats.
- 4) Wetland and riparian buffers, in combination with other conservation strategies, can effectively avoid or mitigate development and land use impacts on wetland, stream and riparian habitats. While no set habitat buffer width or mitigation strategy can be shown to be effective or necessary in all instances, the most recent and best available science provides technical guidance on buffer width

and other buffer characteristics that are likely to be most effective on a site-specific or landscape-scale. The scientific literature indicates that to maintain viable habitat for many of California's riparian and wetland dependent bird, amphibian, and reptile populations, an undeveloped upland habitat buffer of at least 50 meters wide (164 feet), and often considerably wider, would likely be necessary. The appropriate buffer width for a project should be based on project-specific direct and indirect impacts and habitat needs.

- 5) To most effectively protect wetland and riparian habitats in flood-prone areas and to avoid or decrease the risk of inundation, erosion, and flood damage to development, floodplains not already protected by levees are best managed for natural riverine processes such as floodwater storage and channel migration.
- 6) The scientific literature anticipates climate change and sea level rise will worsen many of the current threats to wetland and riparian resources. In addition, tools for modeling climate change, including changes in precipitation patterns, flood frequency and magnitude, and drought and wildfire patterns are evolving. Therefore, utilizing the most recent and best available climate science data will enable lead agencies and the public to most effectively and accurately evaluate the future impacts and implications of climate change and sea level rise on a project or land use plan.
- 7) Low-impact development techniques to slow, spread, and infiltrate stormwater on-site, rather than a more traditional approach to store, concentrate and drain stormwater off-site as quickly as possible, can benefit wetland and riparian habitats in three ways: 1) filtering out pollution and increasing the quality of stormwater runoff; 2) decreasing peak flows, flood risks and erosion in downstream waters; and 3) increasing ground water recharge and therefore helping maintain biologically-important summer low flows.
- 8) There is strong scientific evidence that requiring domestic housecats to be kept indoors at residential developments adjacent to wetland and riparian habitats could minimize the substantial impacts of outdoor housecats on wildlife populations. This can be enforced through covenants, conditions and restrictions enforceable by homeowner's groups or through general plan policies, zoning or land use ordinances.
- 9) Utilizing exterior light fixtures and street standards that are fully-shielded and designed and installed to minimize off-site glare and photo-pollution into wetland and riparian habitats and buffer areas can be an effective mitigation measure to minimize the impacts of artificial night lighting.

Conservation science is an ever-changing field. The scientific understanding of species, habitats, and threats changes over time as new research is conducted. The rarity, abundance, distribution, vulnerability, and listing status of species also change over time. Local, state, and federal regulations are not static. Land use and landscape



characteristics change over time due to drought, flood, wildfire, development patterns, restoration efforts, and climate change. For these reasons, this Technical Memorandum should not be considered the definitive science on this subject. Stakeholders involved in assessing and avoiding impacts on wetland and riparian resources should rely on the best available science, baseline conditions, current law and policy, and the restoration potential of the site.

### **Commonly Used Methods for Implementing Wetland and Riparian Habitat Buffers**

Habitat buffers require certain implementation techniques or methods to guide their design and ensure effectiveness. Numerous effective habitat buffer implementation methods exist. As discussed above, environmental impact analysis and mitigation require site-specific analysis and consideration, and the design and criteria appropriate for a specific buffer should be based on site-specific analysis and circumstances. The Department has worked with many stakeholders to implement habitat buffers. Below are a number of commonly used buffer implementation methods that the Department is familiar with and has considered effective:

- 1) Riparian habitat buffers begin at the outer edge (drip-line) of riparian canopy, if present, or top of stream bank, if riparian canopy is absent.
- 2) Wetland buffers begin at the edge of the delineated wetland.
- 3) Habitat buffers are measured using horizontal distance, perpendicular to the stream or wetland, regardless of slope.
- 4) Habitat buffers are applied to both left and right banks of streams and rivers.
- 5) Habitat buffers are considered undeveloped, no-disturbance areas. Hardscape such as structures and parking areas, septic systems, and stormwater treatment facilities are situated outside of habitat buffers. Exceptions may include trails for non-motorized use.
- 6) Where project construction necessitates temporary ground disturbance and vegetation removal in the habitat buffer, the disturbed buffer area should be restored to enhance fish and wildlife habitats and water quality. This enhancement could include decompacting soil, site recontouring, and revegetation with native species of local genetic stock.
- 7) Habitat buffers are graphically shown on project drawings and subdivision maps submitted for lead and permitting agency approval and subsequent recordation.
- 8) Habitat buffers are legally described and recorded on the appropriate Assessor's Parcel Maps. At the request of the property owner, a local agency may accept an offer of dedication and accept fee title to the habitat buffer area.

- 9) Habitat buffers are clearly marked and barrier fences are installed in the field during construction activities to prevent impacts from equipment operations.

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## REFERENCES

- Abell, R.A., D.M. Olson, E. Dinerstein, P.T. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnut, C.J. Loucks, and P. Hedao. 2000. *Freshwater Ecoregions of North America: A Conservation Assessment*. Island Press. Washington D.C.
- Allan, J.D., and A.S. Flecker. 1993. Biodiversity Conservation in Running Waters. *BioScience* 43:32-43.
- Ambrose, R.F., and S.F. Lee. 2004. An evaluation of compensatory mitigation project permitted under the Clean Water Act of the Los Angeles Regional Water Quality Control Board, 1991-2002. Los Angeles Regional Water Quality Control Board, Los Angeles, CA.
- Ambrose, R.F., J.C. Callaway, and S.F. Lee. 2006. An evaluation of Compensatory mitigation project permitted under the Clean Water Act of the California State Regional Water Quality Control Board, 1991-2002. California State Water Resources Control Board, Sacramento, CA.
- Arnold, C.L., and C.J. Gibbons. 1996. Impervious surface coverage, the emergence of a key environmental indicator. *Journal of the American Planning Association* 62:247-258.
- Baldwin, D.H., J.F. Sandahl, J.S. Labenia, and N.L. Scholz. 2003. Sublethal effects of copper on coho salmon impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. *Environmental Toxicology and Chemistry* 22:2266–2274.
- Banks, P.B., and J.V. Bryant. 2007. Four-legged friend or foe? Dog walking displaces native birds from natural areas. *Biology Letters* 3:611-613.
- Barnhart, R.A., M.J. Boyd, and J.E. Pequegnat. 1992. *The ecology of Humboldt Bay, California: an estuarine profile*. U.S. Fish and Wildlife Service, Biological Report 1.
- Barr, B.R., M.E. Koopman, C.D. Williams, S.J. Vynne, R. Hamilton, and B. Doppelt. 2010. *Preparing for Climate Change in the Klamath Basin*. National Center for Conservation Science & Policy and the Climate Leadership Initiative. Ashland, CA.

- Bartlett, J.G., D.M. Mageean, and R.J. O'Connor. 2000. Residential expansion as a continental threat to U.S. coastal ecosystems. *Population and the Environment* 21:429-468.
- Batzer, D.P., R. Copper, and S.A. Wissinger. 2006. Wetland animal ecology. pages 242-284 in D.P. Batzer and R.R. Sharitz (eds.). *The ecology of freshwater and estuarine wetlands*. University of California Press, Berkeley, CA.
- Becker, A., A.K. Whitfield, P.D. Cowley, J. Jarnegren and T.F. Naesje. Potential effects of artificial light associated with anthropogenic infrastructure on the abundance and foraging behaviour of estuary-associated fishes. *Journal of Applied Ecology* 50:43–50.
- Beebee, T.J.C. 2013. Effects of Road Mortality and Mitigation Measures on Amphibian Populations. *Conservation Biology* 27:657-668.
- Beissinger, S.R., and D.R. Osborne. 1982. Effects of urbanization on avian community organization. *The Condor* 84:75-83.
- Bell, J.L., L.C. Sloan, and M.A. Snyder. 2004. Regional changes in extreme climate events: a future climate scenario. *Journal of Climate* 17:81-87.
- Belt, G.H., and J. O'Laughlin. 1994. Buffer strip design for protecting water quality and fish habitat. *Western Journal of Applied Forestry* 9:41-45.
- Benito-Malvido, J., and M. Martinez-Ramos. 2003. Impact of forest fragmentation on understory plant species richness in Amazonia. *Conservation Biology* 17:389-400.
- Bombay, H.L., T.M. Benson, B.E. Valentine, and R.A. Stefani. 2003. A Willow Flycatcher Survey Protocol for California. May 29, 2003. Unpublished report, California Department of Fish and Game, Sacramento, CA.
- Bonnington, C., K.J. Gaston, and K.L. Evans. 2013. Fearing the feline: domestic cats reduce avian fecundity through trait-mediated indirect effects that increase nest predation by other species. *Journal of Applied Ecology* 50:15-24.
- Brady, S.J., and C.H. Flather. 1994. Changes in wetlands on nonfederal rural lands of the conterminous United States 1982 to 1987. *Environmental Management* 18:693-705.
- Brinson, M.M and A.I. Malvarez. 2002. Temperate freshwater wetlands: types, status, and threats. *Environmental Conservation* 29:115–133
- Brinson, M.M., L.J. MacDonnell, D.J. Austen, R.L. Beschta, T.A. Dillaha, D.A. Donahue, S.V. Gregory, J.W. Harvey, M.C. Molles Jr, E.I. Rogers, J.A. Stanford and L.J. Ehlers. 2002. *Riparian areas: functions and strategies for management*. National Academy Press, Washington, D.C.
- Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. *Ecological Applications* 7:1188-1200.
- Brothers, T.S. 1993. Fragmentation and edge effects in central Indiana old-growth forests. *Natural Areas Journal* 13:268-274.
- Bulger, J.B., J.S. Norman Jr., and R.B. Seymour. 2003. Terrestrial activity and the conservation of adult California red-legged frogs *Rana aurea draytonii* in coastal forests and grasslands. *Biological Conservation* 110:85-95.

- Burger, J., C. Jeitner, K. Clark, and L.J. Niles. 2004. The effect of human activities on migrant shorebirds: successful adaptive management. *Environmental Conservation* 31:283-288.
- Bury, R.B., and D.J. Germano. 2008. *Actinemys marmorata* (Baird and Girard 1852) western pond turtle, Pacific pond turtle. *Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group*. Chelonian Research Monographs.
- CALFED. 2008. Sacramento River ecological flows study: final report. CALFED Ecosystem Restoration Program. Sacramento, CA.
- California Climate Change Portal. 2013. California Environmental Protection Agency, Climate Change Unit. Sacramento, CA. <http://www.climatechange.ca.gov/>
- California Coastal Commission. 2007. Policies in local coastal programs regarding development setbacks and mitigation ratios for wetlands and other environmentally sensitive habitat areas. California Coastal Commission, San Francisco, CA.
- California Department of Fish and Game. 2001. The status of rare, threatened, and endangered animals and plants of California: annual report for 2000. California Department of Fish and Game, Sacramento, CA.
- California Department of Fish and Game. 2003. Atlas of the biodiversity of California. California Department of Fish and Game, Sacramento, CA.
- California Department of Fish and Game. 2004. Recovery strategy for California coho salmon. California Department of Fish and Game, Report to the California Fish and Game Commission, Sacramento, CA.
- California Department of Fish and Game. 2007. California wildlife: conservation challenges. California Department of Fish and Game, Sacramento, CA.
- California Department of Forestry and Fire Protection. 2003. The changing California: forest and range 2003 assessment. California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. Sacramento, CA.
- California Department of Forestry and Fire Protection. 2012. California Forest Practice Rules. Title 14, California Code of Regulations Chapters 4, 4.5 and 10. California Department of Forestry and Fire Protection, Sacramento, CA.
- California Department of Pesticide Regulation. 2012. Pesticide use analysis and trends from 1991 to 1996. California Pesticide Information Portal (CalPIP). Sacramento, CA. <http://www.cdpr.ca.gov/>
- California Energy Commission. 2006. Projecting future sea level. CEC-500-2005-202-SD. March 2006. California Energy Commission, Sacramento, CA.
- California Energy Commission. 2009a. The impacts of sea-level rise on the California coast. CEC-500-2009-024-F. March 2009. California Energy Commission, Sacramento, CA.
- California Energy Commission. 2009b. Projections of potential flood regime changes in California. CEC-500-2009-050-D. March 2009. California Energy Commission, Sacramento, CA.
- California Energy Commission. 2009c. The impact of climate change on California's ecosystem services. CEC-500-2009-025-D. March 2009. California Energy Commission, Sacramento, CA.

- California Energy Commission. 2009d. Climate change scenarios and sea level rise estimates for the California 2009 climate change scenarios assessment. California Energy Commission. CEC-500 2009 014F. Sacramento, CA.
- California Fish and Game Commission. 2013a. Wetlands Resources Policy. (Amended: 08/04/94; 08/18/05). California Fish and Game Commission, Sacramento, CA.
- California Fish and Game Commission. 2013b. Land Use Planning Policy. (Amended: 11/13/84; 03/03/94). California Fish and Game Commission, Sacramento, CA.
- California Ocean Protection Council. 2008. Resolution of the California Ocean Protection Council regarding low impact development, May 15, 2008, as amended. Sacramento, CA.
- California Wetlands Monitoring Workgroup (CWMW). 2009. Using CRAM (California Rapid Assessment Method) to Assess Wetland Projects as an Element of Regulatory and Management Programs. California Environmental Protection Agency, Sacramento, CA.  
[http://www.mywaterquality.ca.gov/monitoring\\_council/wetland\\_workgroup/index.shtml](http://www.mywaterquality.ca.gov/monitoring_council/wetland_workgroup/index.shtml).
- Carpenter, S.R., S.B. Fischer, N.B. Grimm, and J.F. Kitchell. 1992. Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics* 23:119-139.
- Carr, L.W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. *Conservation Biology* 15:1071-1078.
- Castelle, A.J., C. Conolly, M. Emers, E.D. Metz, S. Meyer, M. Witter, S. Mauermann, T. Erickson, S.S. Cooke. 1992. Wetlands buffers use and effectiveness. Adolfson Associates, Inc., Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, WA. Pub. No. 92-10.
- Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements—a review. *Journal of Environmental Quality* 23:878–882.
- Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M.D. Dettinger, and R.E. Flick. 2008. Climatic Change projections of sea level extremes along the California coast. *Climate Change* 87 (Supplement 1): S57-S73.
- Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climate Change* 87 (Supplement 1): S21-S42.
- Cayan, D.R., K.T. Redmond, and L.G. Riddle. 1999. ENSO and hydrologic extremes in the western United States. *Journal of Climate* 12:1881-2893.
- Chen, J., S.D. Saunders, T. Crow, K.D. Brosofske, G. Mroz, R. Naiman, B. Brookshire, and J. Franklin. 1999. Microclimatic in forest ecosystems and landscapes. *BioScience* 49:288-297.
- Chen, J., J.F. Franklin, and T.A. Spies. 1995. Growing season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests from clearcut edges. *Ecological Applications* 5:74-86.
- Church, J. A., and J.M Gregory. 2001. Changes in sea level. pages 639-694 in: J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.) *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel (2001)*.

- CNDDDB. 2013. California Natural Diversity Database. California Department of Fish and Wildlife, Sacramento, CA. <http://www.dfg.ca.gov/biogeodata/cnddb/>
- Comer, P., K. Goodin, G. Hammerson, S. Menard, M. Pyne, M. Reid, M. Robles, M. Russo, L. Sneddon, K. Snow, A. Tomaino, and M. Tuffly. 2005. Biodiversity values of geographically isolated wetlands: an analysis of 20 U.S. States. NatureServe, Arlington, VA.
- Concilio, A., S. Ma, Q. Li, J. LeMoine, J. Chen, M. North, D. Moorhead, and R. Jensen. 2005. Soil respiration response to experimental disturbance in mixed conifer and hardwood forests. *Canadian Journal of Forest Research* 35:1581-1591.
- Correll, D.L. 2005. Principles of planning and establishment of buffer zones. *Ecological Engineering* 24:433-439.
- Cowardin, L.M., V. Carter V., F.C. Golet, E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service Report No. FWS/OBS/-79/31. Washington, D.C.
- Crawford, J.A., and R.D. Semlitsch. 2007. Estimation of core terrestrial habitat for stream-breeding salamanders and delineation of riparian buffers for protection of biodiversity. *Conservation Biology* 21:152-158.
- Crooks, K.R., and M.E. Soule. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature* 400:563-566.
- Crow, T.R., M.E. Baker, and B.V. Barnes. 2000. Diversity in riparian landscapes. pages 43-66 in E.S. Verry, J.W. Hornbeck, and C.A. Dolloff (eds.) *Riparian Management in Forests of the Continental Eastern United States*. CRC Press, Boca Raton, FL.
- Cushman, S.A. 2006. Effect of habitat loss and fragmentation on amphibians: a review and prospectus. *Biological Conservation* 128:231-240.
- Dahl, T.E. 1990. Wetland losses in the United States, 1780s to 1980s. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.
- Dahl, T.E. 2000. Status and Trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.
- Davidson, C., H.B. Shaffer, and M.R. Jennings. 2001. Declines of the California red-legged frog: climate, UV-B, habitat, and pesticide hypotheses. *Ecological Applications* 11:464-479.
- Davidson, C. 2004. Declining downwind: Amphibian population declines in California and historical pesticide use. *Ecological Applications* 14:1892-1402.
- Davies, K.F., C. Gascon, and C.R. Margules. 2001. Habitat fragmentation: consequences, management, and future research priorities. pages 81-97 in: M.E. Soule and G.H. Orians, (eds.) *Conservation Biology: Research Priorities for the Next Decade*. Island Press, Washington, DC.
- Dawdy, D.R. 1989. Feasibility of mapping riparian forests under natural conditions in California. pages 63-68 in: *Proceedings of the California Riparian Systems Conference*. GTR PSW-110. Davis, CA.
- Denoel, M., and G.F. Ficetola. 2008. Conservation of newt guilds in an agricultural landscape of Belgium: the importance of aquatic and terrestrial habitats. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18:714-728.

- Dettinger, M. 2011. Climate change, atmospheric rivers, and floods in California: a multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association* 47:514-523.
- Dettinger, M.D., F.M. Ralph, T. Das, P.J. Neiman, and D.R. Cayan. 2011. Atmospheric rivers, floods, and the water resources of California. *Water* 3:445-478.
- Diffenbaugh, N.S., J.S. Pal, R.J. Trapp, and F. Giorgi. 2005. Fine-scale processes regulate the response of extreme events to global climate change. *Proceedings of the National Academy of Sciences* 104:15774-15778.
- Domagalski, J.L., D.L. Knifong, P.D. Dileanis, L.R. Brown, J.T. May, and V. Connor. 2000. Water quality in the Sacramento River Basin, California, 1994–98. U.S. Geological Survey, Reston, VA.
- Dong, J., J. Chen, Brososke, K.D., and R.J. Naiman, 1998. Modeling air temperature gradients across managed small streams in western Washington. *Journal of Environmental Management* 53:309-321.
- Dupuis, L.A., N.M. Smith, and F. Bunnell. 1995. Relation of terrestrial-breeding amphibian abundance to tree-standing age. *Conservation Biology* 9:645-653.
- Ebersole, J.L., P.J. Wigington, Jr., J.P. Baker, M.A. Cairns, M.R. Church, B.P. Hansen, B.A. Miller, H.R. LaVigne, J.E. Compton, and S.G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. *Transactions of the American Fisheries Society* 135:1681-1697.
- Ehmann, H., and H. Cogger. 1985. Australia's endangered herpetofauna: a review of criteria and policies. pages 435-447 in: G. Grigg, R. Shine, and H. Ehmann (eds.) *The biology of Australasian amphibians and reptiles*. Surrey Beatte, Sydney, Australia.
- Elmore, A.J., and S.S. Kaushal. 2008. Disappearing headwaters: patterns of stream burial due to urbanization. *Frontiers in Ecology and the Environment* 6:308-312.
- Engels, T.M., and C.W. Sexton. 1994. Negative correlation of blue jays and golden-cheeked warblers near an urbanizing area. *Conservation Biology* 8:286-290.
- Executive Order S-13-08. 2008. California Governor Arnold Schwarzenegger. <http://gov.ca.gov/news.php?id=11036>
- Fahrig, L., R.H. Pedlar, S.E. Pope, P.D. Taylor, and J.F. Wegner. 2005. Effect of road traffic on amphibian density. *Biological conservation* 73:177-182.
- Fellers, G.M., K.L. Pope, J.E. Stead, M.S. Koo, and H.H. Welsh Jr. 2008. Turing population trend monitoring into active conservation: can we save the Cascades frog (*Rana cascadae*) in the Lassen Region of California? *Herpetological Conservation and Biology* 3:28-39.
- FEMAT. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Team. U.S. Government Printing Office 1993-793-071.
- Fernández-Juricic, E. 2002. Can human disturbance promote nestedness? A case study with breeding birds in urban habitat fragments. *Oecologia* 131:165-324.
- Findlay, C.S., and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. *Conservation Biology* 11:1000-1009.
- Fischer, R.A. 2000. Width of riparian zones for birds. EMRRP Technical Notes Collection (TN EMRRP-S1-09), U.S. Army Engineer Research and Development Center. Vicksburg, MS. [www.wes.army.mil/el/emrrp](http://www.wes.army.mil/el/emrrp).

- Fischer, R.A., and J.C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. EMRRP Technical Notes Collection (TN EMRRP-SR-24), U.S. Army Engineer Research and Development Center. Vicksburg, MS. [www.wes.army.mil/el/emrrp](http://www.wes.army.mil/el/emrrp).
- Fischer, R.A., C.O. Martin, and J.C. Fischenich. 2000. Improving riparian buffer strips and corridors for water quality and wildlife. pages 457-62 in: P.J. Wigginton and R.L. Beschta, Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association. Middleburg, VA.
- Florida Fish and Wildlife Conservation Commission. 2003. Impacts of feral and free-ranging domestic cats on wildlife in Florida. Feral Cat Issue Team, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.
- Franklin, J.F. 1992. Scientific basis for new perspectives in forests and streams. pages 25-72 in: R.J. Naiman (ed.) *Watershed Management: Balancing Sustainability and Environmental Change*. Springer-Verlag, New York, NY.
- Franklin, J.F., T.A. Spies, R. Van Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, D.B. Lindenmayer, M.E. Harmon, W.S. Keeton, D.C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155:399-423.
- Fraver, S. 1994. Vegetation responses along edge-to-interior gradients in the mixed hardwood forests of the Roanoke River Basin, North Carolina. *Conservation Biology* 8:822-832.
- Friesen, L.E., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. *Conservation Biology* 13:1-9.
- Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. 1999. Invasiveness in wetland plants in temperate North America. *Wetlands* 19:733-755.
- Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002. Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. *Waterbirds* 25:173-183.
- Gaston, K.J., T.W. Davies, J. Bennie, and J. Hopkins. 2012. Reducing the ecological consequences of night light pollution: options and developments. *Journal of Applied Ecology* 49:1256-1266.
- Gehlhausen, S.M., M.W. Schwartz, and C.K. Augspurger. 2000. Vegetation and microclimate edge effects in two mixed-mesophytic forest fragments. *Plant Ecology* 147:21-35.
- Gergel, S.E., M.G. Turner, J.R. Miller, J.M. Melack, and E.H. Stanley. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences* 64:118-128.
- Gibbons, J.W. 2003. Terrestrial habitat: a vital component for herpetofauna of isolated wetlands. *Wetlands* 23:630-635.
- Gibbs, J.P., and W.G. Shriver. 2005. Can road mortality limit populations of pool-breeding amphibians? *Wetlands Ecology and Management* 13:281-289.
- Gilliom, R.J. 2007. Pesticides in U.S. streams and groundwater. *Environmental Science and Technology* 41:3407-3413.



- Ginetz, R.M., and Larkin P.A. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). *Journal of Fisheries Research Board of Canada* 33:19-24.
- Glista, D.J., T.L. DeValt, and J.A. DeWoody. 2008. Vertebrate road mortality predominately impacts amphibians. *Herpetological Conservation and Biology* 3:77-87.
- Golec, C., T. LaBanca, and G. Leppig. 2007. Conservation of sensitive plants on private redwood timberlands in northern California. pages 169-184 in: Standiford, R.B., Giusti, G.A., Valachovic, Y., Zielinski, W.J., and Furniss, M.J., (eds.) *Proceedings of the Redwood Region Science Symposium: What Does the Future Hold?* Gen. Tech. Rep. PSW-GTR-194. Pacific Southwest Research Station, USDA Forest Service, Albany, CA.
- Grindal, S.D., J.L. Morissette, and R.M. Brigham. 1999. Concentration of bat activity in riparian habitats over an elevational gradient. *Canadian Journal of Zoology* 77:972-977.
- Guo, L., C.E. Nordmark, F.C. Spurlock, B.R. Johnson, L. Li, J.M. Lee, and K.S. Goh. 2004. Characterizing dependence of pesticide load in surface water on precipitation and pesticide use for the Sacramento River Watershed. *Environmental Science and Technology* 38:3842-3852.
- Halpern, C.B., D. McKenzie, S.A. Evans, and D.A. Maguire. 2005. Initial responses of forest understories to varying levels and patterns of green-tree retention. *Ecological Applications* 15:175-195.
- Hannon, S.J., A. Cynthia, S.B. Paszkowski, J. DeGroot, S.E. Macdonald, M. Wheatley, and B.R. Eaton. 2002. Abundance and species composition of amphibians, small mammals, and songbirds in riparian forest buffer strips of varying widths in the boreal mixedwood of Alberta. *Canadian Journal of Forest Research* 32:1784-1800.
- Hansen, A.J., R.L. Knight, J.M. Marzluff, S. Powell, K. Brown, P.A. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity patterns, mechanisms, and research needs. *Ecological Applications* 15:1893-1905.
- Harper, K.A., S.E. MacDonald, P.J. Burton, J. Chen, K.D. Brososfske, S.C. Saunders, E.S. Euskirchen, D. Roberts, M.S. Jaiteth, and P.A. Esseen. 2005. Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology* 19:768-782.
- Harmel, R.D., A. Fallon, and M.D. Smolen. Undated. Riparian buffer systems for Oklahoma. Oklahoma Cooperative Extension Service, BAE-1517, Oklahoma State University, Stillwater, OK.
- Harper, E.B., T.A.G. Rittenhouse, and R.D. Semlitsch. 2008. Demographic consequences of terrestrial habitat loss for pool-breeding amphibians: predicting extinction risks associated with inadequate size of buffer zones. *Conservation Biology* 22:1205-1215.

- Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville. 2004. Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences of the United States of America* 101:12422–12427.
- Hilty, J. and A. Merelender. 2002. Wildlife activity along creek corridors. *Practical Winery and Vineyard*, Nov/Dec. pages 6-11.
- Houlahan, J.E., and C.S. Findlay. 2003. The effects of adjacent land use on wetland amphibian species richness and community composition. *Canadian Journal of Fisheries and Aquatic Sciences* 60:1078–1094.
- Incardona, J.P., T.K. Collier, and N.L. Scholz. 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicology and Applied Pharmacology* 196:191-205.
- Incardona, J.P., M.G. Carls, H. Teraoka, K.A. Sloan, T.K. Collier, and N.L. Scholz. 2005. Aryl hydrocarbon-receptor independent toxicity of weathered crude oil during fish development. *Environmental Health Perspectives* 113:1755-1762.
- Interagency Flood Management Review Committee 1994. *Sharing the Challenge: Interagency Floodplain Management into the 21st Century*. Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force. Washington, D.C.
- Johnson, P.A., D.L. Mock, E.J. Teachout, and A. McMillan. 2000. Washington State wetland mitigation evaluation study, Phase 1: Compliance. Washington State Department of Ecology, Olympia, WA.
- Johnson, C.W. and S. Buffler. 2008. Riparian buffer design guidelines for water quality and wildlife habitat functions on agricultural landscapes in the Intermountain West case study. General Technical Report RMRS-GTR-203. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO.
- Johnston, D., G. Tatarian, and E. Pierson. 2004. California bat mitigation techniques, solutions, and effectiveness. Prepared by H.T. Harvey and Associates for the California Department of Transportation, Sacramento, CA. Project No. 2394-01.
- Johnston, E.A., and M.W. Klemens. 2005a. The impacts of sprawl on biodiversity. pages 18-53 in: E.A. Johnson and Klemens (eds.) *Nature in fragments*. Columbia University Press, New York, NY.
- Johnston, E.A., and M.W. Klemens. 2005b. (eds.) *Nature in fragments*. Columbia University Press, New York, NY.
- Joyal, L.A., M. McCollough, and M.L. Hunter, Jr. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. *Conservation Biology* 15:1755-1762.
- Jules, E.S., and B.J. Rathcke. 1999. Mechanisms of reduced *Trillium* recruitment along edges of old-growth forest fragments. *Conservation Biology* 13:784-793.
- Katibah, E.F. 1984. A brief history of riparian forests in the Central Valley of California. pages 23-29 in: R.E. Warner and K.M. Hendrix (eds) *California riparian systems: ecology, conservation and productive management*. University of California Press, Berkeley, CA.

- Katz, J., P.B. Moyle, R.M Quiñones, J. Israel, and S. Purdy. 2013. Impending extinction of salmon, steelhead and trout (Salmonidae) in California. *Environmental Biology of Fishes* 96:1169-1186.
- Kelsey K.A., and S.D. West. 1998. Riparian wildlife. pages 235–258 in: Naiman R.J., R.E. Bilby (eds.) *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*. Springer-Verlag, New York, N.Y.
- Kiffney, P.M., J.S. Richardson, and J.P. Bull. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology* 40:1060-1076.
- Kihlsinger, R.L. 2008. Success of wetland mitigation projects. *National Wetland Newsletter* 30:14-16.
- Kinley, T.A., and N.J. Newhouse. 1997. Relationship of riparian reserve width to bird density and diversity in southwestern British Columbia. *Northwest Science* 71:75-86.
- Kim, J., T. Kim, R.W. Arritt, and N.L. Miller. 2002. Impacts of increased CO<sup>2</sup> on the hydroclimate of the western United States. *Journal of Climate* 15:1926-1942.
- Kim, J. 2005. A projection of the effects of the climate change induced by increased CO<sup>2</sup> on extreme hydrologic events in the western U.S. *Climate Change* 68:153-168.
- Knowles, N., and D.R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters* 29(18):38(1-4).
- Koopman, M.E., R.S. Nauman, B.R Barr, S.J. Vynne, and G.R Hamilton. 2009. Projected future conditions in the Klamath Basin of southern Oregon and northern California. *National Center for Conservation Science and Policy*, Ashland, CA.
- Kunkel, K.E. 2003. North American trends in extreme precipitation. *Natural Hazards* 29:291–305.
- Laetz, C.A., D.H. Baldwin, T.K. Collier, V. Herbert, J.D. Stark and N.L. Scholz. 2009. The synergistic toxicity of pesticide mixtures: implications of risk assessment and the conservation of endangered Pacific salmon. *Environmental Health Perspectives* 117:348-353.
- Lannoo, M. (ed.) 2005. *Amphibian Declines*. University of California Press, Berkeley, CA.
- Laurance, W.F., L.V. Ferreira, J.M. Rankin-De Merona, S.G. Laurance, R.W. Hutchings, and T.E. Lovejoy. 1998. Effects of forest fragmentation on recruitment patterns in Amazonian tree communities. *Conservation Biology* 12:460–464.
- Leppig, G. 2004. Rare plants of northern California coastal peatlands: patterns of endemism and phytogeography. pages 43-50 in: M.B. Brooks, S.K. Carothers, & T. LaBanca (eds.) *The ecology and management of rare plants of northwestern California: proceedings from a 2002 Symposium of the North Coast Chapter of the California Native Plant Society*. California Native Plant Society, Sacramento, CA.
- Linbo, T.L., C.M. Stehr, J.P. Incardona, and N.L. Scholz. 2006. Dissolved copper triggers cell death in the peripheral mechanosensory system of larval fish. *Environmental Toxicology and Chemistry* 25:597–603.

- Lohse, K.A., D.A. Newburn, J.J. Opperman, and A.M. Merenlender. 2008. Forecasting relative impacts of land use on anadromous fish habitat to guide conservation planning. *Ecological Applications* 18:467-482.
- Longcore, T., and C. Rich. 2004. Ecological light pollution. *Frontiers in Ecology and the Environment* 2:191-198.
- Lovejoy, T.E., R.O. Bierregaard, Jr., A.B. Rylands, J.R. Malcolm, C.E. Quintela, L.H. Harper, K.S. Brown, Jr., A.H. Powell, G.V.N. Powell, H.O.R. Schubart, and M. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. pages 257-285 in: M. Soulé, (ed.) *Conservation Biology*. Sinauer Associates, Inc, Sunderland, MA.
- Lunde, R.E., and A.S. Harestad. 1986. Activity of little brown bats in coastal forests. *Northwest Science* 60:206-209.
- Luginbuhl, J.M., J.M. Marzluff, J.E. Bradley, M.G. Raphael, and D.E. Varland. 2001. Corvid survey techniques and the relationship between corvid relative abundance and nest predation. *Journal of Field Ornithology* 72:556-572.
- Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran. 1998. Status and trends of the nation's biological resources. 2 vols. U.S. Department of the Interior, U.S. Geological Survey, Reston, Va. [www.nwrc.usgs.gov/sandt/SNT.pdf](http://www.nwrc.usgs.gov/sandt/SNT.pdf)
- Machtans, C.S., M. Villard, and S.J. Hannon. 1996. Use of riparian buffer strips as movement corridors by forest birds. *Conservation Biology* 10:1366-1379.
- Mack, R.N., and W.M. Lonsdale. 2001. Humans as global plant dispersers: getting more than we bargained for. *BioScience* 51:95-102.
- Maestas, J.D., R.L. Knight, R.L. Gilgert, and C. Wendell. 2001. Biodiversity and land-use change in the American mountain west. *Geographical Review Geographical Review* 91:509-525.
- Malcolm, J.R. 1994. Edge effects in Central Amazonian forest fragments. *Ecology* 75:2438-2445.
- Malo, J.E., F. Suarez, and A. Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology* 41:701-710.
- Mannshardt-Shamseldin, E.C., R.L. Smith, S.R. Sain, L. O. Mearns, and D. Cooley 2010. Downscaling extremes: a comparison of extreme value distributions in point-source and gridded precipitation data. *The Annals of Applied Statistics* 4:484-502.
- Marzluff, J.M. 2001. Worldwide increase in urbanization and its effects on birds. pages 19-44 in: J.M. Marzluff, R. Bowman, and R. Donnelly (eds.) *Avian Ecology and Conservation in an Urbanizing World*. Kluwer Academic, Norwell, CA.
- Marzluff, J.M., and E. Neatherlin. 2006. Corvid response to human settlements and campgrounds: causes, consequences, and challenges for conservation. *Biological Conservation* 130:301-314.
- Mayer, P.M., S.K. Reynolds, M.D. McCutchen, and T.J. Canfield. 2006. Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: A review of current science and regulations. EPA/600/R-05/118. U.S. Environmental Protection Agency. Cincinnati, OH.
- Mayer, T.D., and S.W. Naman. 2011. Streamflow response to climate as influenced by geology and elevation. *Journal of the American Water Resources Association* 47:724-738.

- McCarthy, S.G., J. Incardona, N.L. Scholz. 2008. Coastal storms, toxic turnoff, and the sustainable conservation of fish and fisheries. *American Fisheries Society Symposium* 64:7-27.
- McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. *Journal of Fisheries Research Board of Canada* 17:655-676.
- McIntyre, J.K., D.H. Baldwin, J.P. Meador, and N.L. Scholz. 2008. Chemosensory deprivation in juvenile coho salmon exposed to dissolved copper under varying water chemistry conditions. *Environmental Science and Technology* 42:1352–1358.
- Meine, C.D., and G.W. Archibald. (eds). 1996. *The cranes: status survey and conservation action plan*. IUCN, Gland, Switzerland, and Cambridge, U.K. Northern Prairie Wildlife Research Center Online.  
<http://www.npwrc.usgs.gov/resource/birds/cranes/index.htm>
- Michalak, J., and J. Lerner. 2007. Linking conservation and land use planning: using the state wildlife action plans to protect wildlife from urbanization. *Defenders of Wildlife*. Washington, D.C.
- Miller, N.L., K.E. Bashford, and E. Strem. 2003. Potential impacts of climate change on California hydrology. *Journal of American Water Resources Association* 39:771-784.
- Miller, M.W. 2006. Apparent effects of light pollution on singing behavior of American robins. *The Condor* 108:130-139.
- Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of North American fishes during the past century. *Fisheries* 14:22-38.
- Mitsch, W.J., and J.G. Gosselink. 2000. *Wetlands, Third Edition*. Wiley and Sons. New York, N.Y.
- Miyashita, T., A. Shinkai, and C. Takafumi. 1998. The effects of forest fragmentation on web spider communities in urban areas. *Biological Conservation* 86:357-364.
- Moen, J., and B.G. Jonsson. 2003. Edge effects on liverworts and lichens in forest patches in a mosaic of boreal forest and wetland. *Conservation Biology* 17:380–388.
- Mohseni, O., H.G. Stefan, and J.G. Eaton. 2003. Global warming and potential changes to fish habitat in U.S. Streams. *Climate Change* 59:389-409.
- Moore, A.A., and M.A. Palmer. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. *Ecological Applications* 15:1169-1177.
- Moore, R.D., D.L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. *Journal of the American Water Resources Association* 41:813-834.
- Mount, J.F. 1995. *California Rivers and Streams: the Conflict Between Fluvial Processes and Land Use*. University of California Press, Berkeley, CA.
- Moyle, P.B. 2002. *Inland Fishes of California*. University of California Press, Berkeley, CA.
- Moyle P.B., and J.E. Williams. 1990. Biodiversity loss in the temperate zone: decline of the native fish faunal of California. *Conservation Biology* 4:275-284.

- Moyle, P.B., J.D. Kiernan, P.K. Crain, R.M. Quiñones. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. *PLOS ONE* 8:1-12.
- Naiman, R.J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3:209-212.
- Naiman, R.J., R.E. Bilby, and P.A. Bisson. 2000. Riparian ecology and management in the Pacific coastal rain forest. *BioScience* 50:996-1011.
- National Academy of Sciences. 2012. Sea Level Rise for the Coasts of California, Oregon, and Washington: Past Present, and Future. Committee on sea level rise for the coasts of California Oregon and Washington. National Research Council of the National Academies. National Academies Press. Washington, D.C.
- National Research Council. 1992. Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academies Press. Washington D.C. <http://www.nap.edu/catalog/1807.html>.
- National Research Council. 2001. Compensating for wetland losses under the Clean Water Act. National Academies Press. Washington D.C. <http://www.nap.edu/catalog/1807.html>.
- National Research Council. 2002. Riparian Areas: Functions and Strategies for management. National Academies Press. Washington D.C. <http://www.nap.edu/catalog/1807.html>.
- Natural Resource Conservation Service. 2004. Planning and Design Manual for the Control of Erosion, Sediment, and Stormwater. US Department of Agriculture. <http://www.abe.msstate.edu/csd/p-dm/>.
- Nelson, C.R., and C.B. Halpern. 2005a. Edge-related responses of understory species to aggregated retention harvest in the Pacific Northwest. *Ecological Applications* 15:196-209.
- Nelson, C.R., and C.B. Halpern. 2005b. Short-term responses of vascular plants and bryophytes in forest patches retained during structural retention harvests. pages 366-368 in: C.E. Peterson and D.A. Maguire, (eds.) *Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry*. Proceedings of a conference. USDA Forest Service General Technical Report PNW-GTR-635. Pacific Northwest Research Station. Portland, OR.
- Nicholls, R.J., F.M.J. Hoozemans, and M. Marchand. 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analysis. *Global Environmental Change* 9:S69-S87.
- Ober, H.K., and J.P. Hayes. 2008. Influence of vegetation on bat use of riparian areas at multiple spatial scales. *Journal of Wildlife Management* 72:396-404.
- Odell, E.A., D.M. Theobald, and R.L. Knight. 2003. Incorporating ecology into land use planning. *Journal of the American Planning Association* 69:72-82.
- Office of Planning and Research. 2009. CEQA and low impact development stormwater design: preserving stormwater quality and stream integrity through California Environmental Quality Act (CEQA) review. Technical Advisory Aug. 5, 2009. Governor's Office of Planning and Research. Sacramento, CA.

- Olson, D.H., P.D. Anderson, C.A., Frissell, H.H. Welsh, Jr., and D.F. Bradford. 2007. Biodiversity management approaches for stream-riparian areas: perspectives for Pacific Northwest headwater forests, microclimates, and amphibians. *Forest Ecology and Management* 246:81-107.
- O'Neal, K. 2002. Effects of global warming on trout and salmon in U.S. streams. Defenders of Wildlife and National Resources Defense Council. New York, NY.
- Oregon Climate Change Research Institute. 2010. Oregon Climate Assessment Report. K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon. Accessed on: January 25, 2011. Available at: <http://occri.net/ocar>.
- Ozanne, C.M.P., A. Foggo, C. Hambler and M.R. Speight. 1997. The significance of edge-effects in the management of forests for invertebrate biodiversity, pages 534-550 in: N. Stork, J. Adis and R. Didham, (eds.) *Canopy Arthropods*. Chapman and Hall, London, U.K.
- Ozanne, C.M.P., M.R. Speight, C. Hambler, and H.F. Evans. 2000. Isolated trees and forest patches: patterns in canopy arthropod abundance and diversity in *Pinus sylvestris* (scots pine). *Forest Ecology and Management* 137:53-63.
- Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics* 37:637-669.
- Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37-42.
- Patten, B. 1971. Increased predation by the torrent sculpin, *Cottus rhotheus*, on coho salmon fry, *Oncorhynchus kisutch*, during moonlight nights. *Journal of Fisheries Research Board of Canada* 28:1352-1354.
- Paul, M.J., and J.L. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics* 32:333-365.
- Peters, R.J., B.R. Missildine, and D.L. Low. 2008. Seasonal fish densities near river banks stabilized with various stabilization methods. First year report of the Flood Technical Assistance Project. U.S. Fish and Wildlife Service. Lacey, WA.
- Petranka, J.W., M.E. Eldridge, and K.E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. *Conservation Biology* 7:363-370.
- Pew Oceans Commission. 2003. America's living oceans: charting a course for sea change. Pew Oceans Commission. Arlington, VA.
- Pierson, E.D. 1998. Tall trees, deep holes and scarred landscapes: conservation biology of North American bats. pages 309-325 in: T.H. Kunz and P.A. Racey (eds.) *Bat Biology and Conservation*. Smithsonian Institution Press, Washington, D.C.
- Pierson, E.D., W.E. Rainey, and C. Corben. 2006. Distribution and status of red bats (*Lasiurus blossevillii*) in California. Contract Report. Species Conservation and Recovery Program, Habitat Conservation Planning Branch, California Department of Fish and Game, Sacramento, CA.
- Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. *BioScience* 47:769-784.
- Poff, N.L., M.M. Brinson, and D.W. Jay. 2002. Aquatic ecosystems and global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Pew Center on Global Climate Change, Arlington, VA.

- Point Reyes Bird Observatory Conservation Science. 2011. Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife. Version 1.0. <http://data.prbo.org/apps/bssc/climatechange>.
- Pringle, C. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. *Ecological Applications* 11:981–998.
- Racey, P.A., and A.C. Entwistle. 2008. Conservation ecology of bats. pages 680-743 in: T.H. Kunz and M.B. Fenton (eds.) *Bat Ecology*. University of Chicago Press, Chicago, IL.
- Raedeke, K.J., R.D. Taber, and D.K. Paige. 1988. Ecology of large mammals in riparian systems of Pacific Northwest forests. pages 113-132 in: K. Raedeke, (ed.) *Streamside Management: riparian wildlife and forestry interactions*. Contribution Number 59, Institute of Forest Resources, University of Washington, Seattle, WA.
- Rahmstorf, S. 2007. A Semi-empirical approach to projecting future sea-level rise. *Science* 315:368-370.
- Rambo, T.R., and M.P. North. 2008. Spatial and temporal variability of canopy microclimate in a Sierra Nevada riparian forest. *Northwest Science* 82:259-268.
- Reclamation. 2011. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water. Prepared for United States Congress, U.S. Bureau of Reclamation, Technical Service Center, Denver, CO.
- Reese, D.A., and H.H. Welsh, Jr. 1998. Habitat use by western pond turtles in the Trinity River. *California Journal of Wildlife Management* 62:842-853.
- Reichard, S.H., and P. White. 2001. Horticulture as a pathway of invasive plant introductions in the United States. *BioScience* 51:103-113.
- Relyea, R.A. 2005. The impact of insecticides and pesticides on the biodiversity of aquatic communities. *Ecological Applications* 15:618-627.
- Rich, C., and T. Longcore, 2006. *Ecological consequences of artificial night lighting*. Island Press, Washington, D.C.
- Richardson, J.S. R.J. Naiman, F.J. Swanson, and D.E. Hibbs. 2005. Riparian communities associated with Pacific Northwest headwaters streams: assemblages, processes, and uniqueness. *Journal of American Water Resources Association* 41:935-947.
- Ricketts, T.H., E.O. Dinerstein, D.M. Loucks, and J. Colby. 1999. *Terrestrial Ecoregions of North America: a conservation assessment*. World Wildlife Fund, Washington, D.C.
- Ridley, S.P.D., G.T. Busteed, L.B. Kats, T.L. Vandergon, L.F.S. Lee, R.G. Dagit, J.L. Kerby, R.N. Fischer, and R.M. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams. *Conservation Biology* 19:1894-1907.
- Riparian Habitat Joint Venture. 2004. Version 2.0. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight. <http://www.prbo.org/calpif/pdfs/riparian.v-2.pdf>. Sacramento, CA.
- Rittenhouse, T.A.G., and R.D. Semlitsch. 2007. Distribution of amphibians in terrestrial habitat surrounding wetlands. *Wetlands* 27:153-161.



- Robinson, C.T., K. Tockner, and J.V. Ward. 2002. The fauna of dynamic riverine landscapes. *Freshwater Biology* 47:661–677.
- Rodewald, A.D., and M.H. Bakermans. 2006. What is the appropriate paradigm for riparian forest conservation? *Biological Conservation* 128:193-200.
- Rodgers, J.A., Jr., and H.T. Smith. 1997. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. *Wildlife Society Bulletin* 25:139-145.
- Roe, J.H., and A. Georges. 2007. Heterogeneous wetland complexes, buffer zones, and travel corridors: Landscape management for freshwater reptiles. *Biological Conservation* 135:67-76.
- Rosen, P.C., and C.H. Lowe. 1994. Highway mortality of snakes in the Sonoran desert of southern Arizona. *Biological Conservation* 68:143-148.
- Rottenborn, S.C. 1999. Predicting the impacts of urbanization on riparian bird communities. *Biological Conservation* 88:289-299.
- Russell, W.H., and C. Jones. 2002. The effects of timber harvesting on the structure and composition of adjacent old-growth coast redwood forest. *Landscape Ecology* 16:731-741.
- Russell, W., and S. Terada. 2009. The effects of revetment on streamside vegetation in *Sequoia sempervirens* (Taxodiaceae) forests. *Madroño* 56:71-80.
- Sandahl, J.F., D.H. Baldwin, J.J. Jenkins, and N.L. Scholz. 2004. Odor-evoked field potentials as indicators of sublethal neurotoxicity in juvenile coho salmon exposed to copper, chlorpyrifos, or esfenvalerate. *Canadian Journal of Fisheries and Aquatic Sciences* 61:404-413.
- Sandahl, J.F., D.H. Baldwin, J.J. Jenkins, and N.L. Scholz. 2005. Comparative thresholds for acetylcholinesterase inhibition and behavioral impairment in coho salmon exposed to chlorpyrifos. *Environmental Toxicology and Chemistry* 24:136-145.
- Sandahl, J.F., D.H., Baldwin, J.J. Jenkins, and N.L. Scholz. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. *Environmental Science and Technology* 41:2998-3004.
- Semlitsch, R.D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. *Conservation Biology* 12:1113-1119.
- Semlitsch, R.D., and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17:1219-1228.
- Semlitsch, R.D., and J.B. Jensen 2001. Core habitat, not buffer zone. *National Wetlands Newsletter* 23:5-6,11.
- Schlenker, W.W., M. Hanemann, and A.C. Fisher. 2007. Water availability, degree days, and the potential impact of climate change on irrigated agriculture in California. *Climatic Change* 81:19–38.
- Scholz, N.L., N.K. Truelove, J.S. Labenia, D.H. Baldwin, and T.K. Collier. 2006. Dose-additive inhibition of Chinook salmon acetylcholinesterase activities by mixtures of organophosphate and carbamate insecticides. *Environmental Toxicology and Chemistry* 25:1200–1207.
- Seidman, M.V., and C.J. Zabel. 2001. Bat activity along intermittent streams in northwestern California. *Journal of Mammalogy* 82:738-747.

- Shisler, J.K., R.A. Jordan, and R.N. Wargo. 1987. Coastal wetland buffer delineation. New Jersey Department of Environmental Protection, Division of Coastal Resources, Trenton, N.J.
- Shuford, W.D., and T. Gardali (eds.) 2008. California bird species of special concern. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, CA. and California Department of Fish and Game, Sacramento, CA.
- Snow, L.A. 2010. State of the state's wetlands report. Memorandum to wetlands conservation community from Lester A. Snow Secretary for Natural Resources. October 18, 2010. California Natural Resources Agency, Sacramento, CA.
- Snyder, C.D., J.A. Young, R. Vilella, and D.P. Lemarie. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. *Landscape Ecology* 18:647-664.
- Snyder, M.A., J.L. Bell, and L.C. Sloan. 2002. Climate responses to doubling of atmospheric carbon dioxide for a climatically vulnerable region. *Geophysical Research Letters* 29:9-1 to 9-4.
- Sparling, D.W., G.M. Fellers, and L.L. McConnell. 2001. Pesticide and amphibian population declines in California, USA. *Environmental Toxicology and Chemistry* 20:1591-1595.
- Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. *BioScience* 45:168-182.
- Sparling, D.W., and G.M. Fellers. 2007. Comparative toxicity of chlorpyrifos, diazinon, malathion and their oxon derivatives to larval *Rana boylei*. *Environmental Pollution* 147:535-539.
- Sparling, D.W., and G.M. Fellers. 2009. Toxicity of two insecticides to California, USA, anurans and its relevance to declining amphibian populations. *Environmental Toxicology and Chemistry* 28:1696-1703.
- Spence, B.C., G.A. Lomnický, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.
- Stein, S.M., I. Ronald, E. McRoberts, R.J. Alig, M.D. Nelson, D.M. Theobald, M. Eley, M. Dechter, and M. Carr. 2005. Forests on the edge housing development on America's private forests. General Technical Report PNW-GTR-636. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. Portland, OR.
- SWRCB. 2002. State Water Resources Control Board. 2002 CWA Section 303(d) List of Water Quality Limited Segment. Approved by the US Environmental Protection Agency, July 2003.  
[http://www.waterboards.ca.gov/water\\_issues/programs/tmdl/303d\\_lists.shtml](http://www.waterboards.ca.gov/water_issues/programs/tmdl/303d_lists.shtml)
- SWRCB. 2008. Requiring sustainable water resources management. Resolution No. 2008-0030. State Water Resources Control Board. Sacramento, CA.
- SWRCB. 2012a. California Wetland and Riparian Area Protection Policy, Technical Advisory Team, Technical Memorandum No. 2: Wetland Definition, 25 June 2009, revised September 1, 2012, State Water Resources Control Board. Sacramento, CA.  
[http://www.swrcb.ca.gov/water\\_issues/programs/cwa401/wrapp.shtml#technical](http://www.swrcb.ca.gov/water_issues/programs/cwa401/wrapp.shtml#technical)

- SWRCB. 2012b. California Wetland and Riparian Area Protection Policy, Technical Advisory Team, Technical Memorandum No. 3: Landscape Framework for Wetlands and Other Aquatic Areas. October 20, 2009, Revised September 1, 2012. State Water Resources Control Board. Sacramento, CA.  
[http://www.swrcb.ca.gov/water\\_issues/programs/cwa401/wrapp.shtml#technical](http://www.swrcb.ca.gov/water_issues/programs/cwa401/wrapp.shtml#technical)
- Tabor, R.A., Brown G.S., and Luiting V.T. 2004. The effect of light intensity on sockeye salmon fry migratory behavior and predation by cottids in the Cedar River, Washington. *North American Journal of Fisheries Management* 24:128-145.
- Tallmon, D.A., E.S. Jules, N.J. Radke, and L.S. Mills. 2003. Of mice and men and *Trillium*: cascading effects of forest fragmentation. *Ecological Applications* 13:1193-1203.
- Thomas, D.W. 1988. The distribution of bats in different ages of Douglas-fir forests. *Journal of Wildlife Management* 52:619-626.
- Trenham, P.C., and H.B. Shaffer. 2005. Amphibian upland habitat use and its consequences for population viability. *Ecological Applications* 15:1158-1168.
- Tockner, K., S.E. Bunn, C. Gordon, R.J. Naiman, G.P. Quinn, and J.A. Stanford. 2008. Flood plains: critically threatened ecosystems. pages 45–61 in: N. Polunin (ed.) *Aquatic Ecosystems: Trends and Global Prospects*. Cambridge University Press, Cambridge, U.K.
- Trombulak, S.C., and C.A. Frissell. 2000. Review of the ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.
- U.S. Commission on Ocean Policy. 2004. An ocean blueprint for the 21st Century: Final Report of the U.S. Commission on Ocean Policy—Pre-Publication Copy. Washington, D.C.: U.S. Commission on Ocean Policy. Available:  
[http://www.oceancommission.gov/documents/full\\_color\\_rpt/wel-come.html](http://www.oceancommission.gov/documents/full_color_rpt/wel-come.html)  
[accessed 26 October 2005]. Urban Areas. National Academy Press, Washington, D.C.
- USDA. 2000. Conservation buffers to reduce pesticide losses. United States Department of Agriculture, Natural Resources Conservation Service. Washington, D.C.
- USEPA. 1988. Greenhouse effect sea level rise and coastal wetlands. J.G. Titus (ed.) U.S. Environmental Protection Agency. EPA-230-05-86-013. Washington, D.C.
- USEPA. 1999. Preliminary data summary of urban stormwater best management practices. U.S. Environmental Protection Agency, EPA-821-R-99-012. Washington, D.C.
- USEPA. 2000. Low Impact Development (LID) a literature review. U.S. Environmental Protection Agency, EPA-841-B-00-005. Washington, D.C.
- USEPA, USACE. 2008. Compensatory Mitigation for Losses of Aquatic Resources; Final Rule. 33 CFR Parts 325 and 332 (Department of the Army, Corps of Engineers) 40 CFR Part 230 (Environmental Protection Agency (73 Fed. Reg. 70, Pp. 19594-19705) April 10, 2008.
- USFWS. 2000. Impacts of riprapping to ecosystem functioning, Lower Sacramento River, California. U.S. Fish and Wildlife Service. Sacramento, CA.
- USFWS. 2004. Impacts of riprapping to aquatic organisms and aquatic functioning, Lower Sacramento River, California. U.S. Fish and Wildlife Service. Sacramento, CA.

- USGCRP, 2009. Global climate change impacts in the United States. U.S. Global Change Research Program. T.R. Karl, J.M. Melillo, and T.C. Peterson (eds.) Cambridge University Press, New York, N.Y.
- Van Metre, P.C., and B.J. Mahler. 2003. The contribution of particles washed from rooftops to contaminant loading to urban streams. *Chemosphere* 52:1727–1741.
- Vanrheenen, N.T., A.W. Wood, R.N. Palmer, and D.P. Lettenmaier. 2004. Potential implications of PCM climate change scenarios for Sacramento-San Joaquin River Basin hydrology and water resources. *Climate Change* 62:257-281.
- Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences* 106:21527–21532.
- Voelz, J. 2006. The characteristics and benefits of green roofs in urban environments. University of California, Davis Extension. Davis, CA.
- Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann, and P.M. Davies. 2010. Global threats to human water security and river biodiversity. *Nature* 467:555-561.
- Wake, D.B., and V.T. Vrendenburg. 2008. Are we in the midst of a sixth mass extinction? A view from the world of amphibians. *Proceedings of the National Academy of Sciences* 105:11466-11473.
- Watershed Protection Research. 2003. Impacts of impervious cover on aquatic ecosystems. Monograph No. 1. Center for Watershed Protection. Ellicott City, MD.
- Watkins, Z., J. Chen, J. Pickens, and K. Brosofske. 2003. Effects of forest roads on understory plants in a managed hardwood landscape. *Conservation Biology* 17:411-419.
- Welsh, H.H., G.R. Hodgson, and N.E. Karraker. 2005. Influences of the vegetation mosaic on riparian and stream environments in a mixed forest-grassland landscape in “Mediterranean” northwestern California. *Ecogeography* 28:537-551.
- Wenger, S., and L. Fowler. 2000. Conservation subdivision ordinances. UGA Institute of Ecology Office of Public Services, The University of Georgia. Athens, GA.
- Wilcove, D.S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66:1211-1214.
- Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Assessing the relative importance of habitat destruction, alien species, pollution, overexploitation, and disease. *BioScience* 48:607-615.
- Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister and J.E. Deacon. 1989. Fishes of North America: endangered, threatened, or of special concern. *Fisheries* 14:2-22.
- Winter, L., and G.E. Wallace. 2006. Impacts of feral and free-ranging cats on bird species of conservation concern: a five state review of New York, New Jersey, Florida, California and Hawaii. American Bird Conservancy. Washington, D.C.
- Woods, M., R.A. McDonald, and S. Harris. 2003. Predation of wildlife by domestic cats *Felis catus* in Great Britain. *Mammal Review* 33:174-188.
- Wunder, L., and A.B. Carey. 1996. Use of forest canopy by bats. *Northwest Science* 70:79-85.

- Yates, D., H. Galgrath, D. Purkey, A. Huber-Lee, J. Sieber, J. West, S. Herrod-Julius, and B. Joyce. 2008. Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. *Climatic Change* 91:335-350.
- Young, A., and N. Mitchell. 1994. Microclimate and vegetation edge effects in a fragmented podocarp-broadleaf forest in New Zealand. *Biological Conservation* 67:63-72.
- Zedler, J.B. 2004. Compensating for wetland losses in the United States. *Ibis* 146:92-100 (Suppl. 1).
- Ziemer, R.R. and T.E. Lisle. 1998. Hydrology. pages 43-68 in: R.J. Naiman and R.E. Bilby (eds.) *River Ecology and Management*. Springer. New York, N.Y.
- Zhang, D., J. Chen, B. Song, M. Xu, P. Sneed, and R. Jensen. 2000. Effects of silvicultural treatments on forest microclimate in southeastern Missouri Ozarks. *Climate Research* 15:45-59.
- Zwiers, F.W., and V.V. Kharin. 1998. Changes in the extremes of the climate simulated by CCC GCM2 under CO<sup>2</sup> doubling. *Journal of Climate* 11:2200-2222.