TACCIMO Template for Assessing Climate Change Impacts and Management Options

TACCIMO Literature Report

Management Options Literature Report – Annotated Bibliography Format
Report Date: May 29, 2013

Content Selections:
FACTORS – Freshwater Ecosystems, Animal Communities
CATEGORIES – Fish, Freshwater Wetlands, Lakes & Ponds, Riparian Areas, Interactions with other Factors
REGIONS – National, West, R5: Pacific Southwest

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest & Western Wildland Environmental Threat Assessment Centers, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

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Management Options by Source

Wednesday, May 29, 2013

RESOURCE AREA (FACTOR): FRESHWATER ECOSYSTEMS

GENERAL IMPACTS

R5: PACIFIC SOUTHWEST

Viers, J. H. & Rheinheimer, D. E. (2011). Freshwater conservation options for a changing climate in California's Sierra Nevada. Marine and Freshwater Research, 62,

"There is a need to identify areas (major rivers and catchments) where expropriation and development can be prioritised over biodiversity and vice versa (Rheinheimer et al. 2007). One approach proposed by Moyle (1996) is the concept of Aquatic Diversity Management Area, which is a formally identified catchment high in freshwater biodiversity, but placed within a larger resource management framework (Moyle and Yoshiyama 1994). A different approach is to focus on flow-regime prioritization (e.g. native fish populations; Williams 2006b), wherein regulated catchments would have one of the following management priorities: (1) natural flow regime to maintain viable populations; (2) adaptive and experimental management of in-stream flows to enhance recovery; and (3) status quo flow regulation, where population recovery is difficult and the other beneficial uses of water, such as hydropower and water supply, are highly desired. Such spatial optimisation of development of rivers (e.g. multiple dams on a single tributary as opposed to single dams on multiple tributaries) allows for a more coherent ecological and hydrological approach to conservation purposes (Richter et al. 2010)."

"Catchment specialisation, a type of triage, is an extreme prioritisation for multiple demands over large areas. This could produce improved freshwater biodiversity protection by systematically selecting for representation, viability and resilience; however, it would require regulatory and legal changes. The focus would be on high-priority catchments specialised for biodiversity and ecosystem value. In the Sierra Nevada, the Feather River could be managed for its water-delivery potential, the American River for its hydropower development and the Yuba River restored for anadromous salmonid recovery and persistence. There may also be niche environments with unique assemblages in developed rivers that must be aggressively managed for their ecological value (e.g. meadow complexes of Feather River headwaters). A regional vision is required, developed by all potential stakeholders and involving most, if not all, major basins and their downstream constituents, 38 million residents of California, well beyond the current IRWMP [Integrated Regional Water Management Plans] context."

"For hydropower, there are potential operational improvements that would favour aquatic ecosystems (Rheinheimer et al. 2007; Viers 2011). This includes regionalisation of hydropower management, through coordination of mitigation and relicensing efforts, integration of adaptive management (Pahl-Wostl 2007; Pittock and Hartmann 2011) into operational requirements within FERC [Federal Energy Regulatory Commission] licenses and improved simulation and optimisation models for scenario analyses. There is also a need for parallel licensing, where there is explicit coordination of licensing dams within a large catchment, including coordination of inter-basin transfers. Currently, licencees can avoid consideration of cumulative or large-scale spatial effects, because they are considered outside the legal framework. Regional coordination would impose management for conservation, and optimise energy production for the power grid. The latter issue becomes even more critical with non-stationary hydrology, as is expected with climate warming, and managing water and power for uncertain futures (Pahl-Wostl 2007; Milly et al. 2008)."

"Also, aging of a dam or reassessment of its utility may warrant a decommissioning (Pittock 2010; Pittock and Hartmann 2011) or, at minimum, the construction of fish passage if required. Installation of outlet works to draw from different depths (Rheinheimer et al. 2007) would allow dam operators to release water optimally at desired temperatures to benefit downstream aquatic life avoiding unseasonal temperatures caused by thermal stratification. Other physical options include new pumped-storage facilities that pump water to hydropower-storage reservoirs during low demand to be released later when demand is high. Physical improvements or changes in dam operation can reduce the need for additional development (Richter et al. 2010), saving money and presumably improving environmental outcomes (Watts et al. 2010)."

"One mechanism to change resource management behaviours is to explicitly recognise the economic benefit downstream water users receive from upstream catchment stewardship and provide payments for ecosystem services (Chan et al. 2006). Antiquated notions of water rights and beneficial uses in the western United States have precluded any implementation of such payments, such as mitigation banking (i.e. a deeded land exchange for adverse environmental impacts incurred elsewhere) and environmental uses of water (Bricker and Filippi 2000). There is a move to embed payments for ecosystem services through the restoration of montane meadows of the Sierra Nevada, which are intended to dampen peaks of upstream hydrographs and elevate base flows, minimizing downstream flooding and increasing dry-season water supply while also improving wildlife habitat (National Fish and Wildlife Foundation 2009). The National Fish and Wildlife Foundation will fund US$10 million to various organisations over 10 years to implement and monitor ecological and hydrological benefits of meadow restoration (National Fish and Wildlife Foundation 2009). Although this incentive may not prompt downstream stakeholders to pay for improved ecosystem services, it is a welcome development."

"Protection of freshwater resources could be improved by providing mechanisms for volitional passage over barriers (e.g. fish ladders), and targeting management of regulated flows for ecosystems. Maintaining the natural features of the flow regime for endemic species is paramount to any successful management strategy intended to conserve freshwater biodiversity. Regulated river systems should be evaluated for the presence and condition of endemic-species assemblages or life-history traits that can be supported by regulated flows that mimic the natural flow regime or maintain downstream thermal regimes. Hydrologically connected rivers and streams with unimpaired flows should also be identified and prioritised for their resilience to hydrologic alteration from climate warming (Pittock and Finlayson 2011). When combined, this collection should form the basis for catchments prioritised for climate-warming resilience (see Pittock et al. 2008). Practical flow management should be adaptive (e.g. Watts et al. 2010), with formal hypotheses and actions as experiments, for established priority issues and areas, identified from a catchment assessment."

FRESHWATER WETLANDS

NATIONAL

Burkett, V. & Kusler, J. (2000). Climate change: Potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association, 36 (2), 313-320.

"Increased protection for existing wetlands and removal of stresses (e.g., water pollution) may not only reduce the sensitivity of plants and animals to small changes in temperature or precipitation but also achieve broader wetland protection and restoration goals. Other measures for achieving broader objectives and reducing climate change impacts include development setbacks for coastal and estuarine wetlands, sediment diversions for dams, linking presently fragmented wetlands and waterways to provide the corndors needed for plant and animal migration, using water control structures for some wetlands to enhance particular functions and address decreased precipitation andlor increased evaporation, long-term securement of water resources for wetland conservation, increasing management programs for exotic species, and implementing various wetland restoration measures."

Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. Wetlands Ecology and Management, 17(1), 71-84. doi:10.1007/s11273-008-9119-1

"Given the diversity of wetland types and their individual characteristics, the impacts resulting from climate change will be somewhat customized and so will the restoration remedies. It will be critically important to determine specific expected future changes in climate by region and conduct adequate monitoring to ascertain how actual conditions track with the specific climate change model for a region."

"An important management strategy to ensure wetland sustainability is the prevention or reduction of additional stress that can reduce the ability of wetlands to respond to climate change. Maintaining hydrology, reducing pollution, controlling exotic vegetation, and protecting wetland biological diversity and integrity are important activities to maintain and improve the resiliency of wetland ecosystems so that they continue to provide important services under changed climatic conditions (Kusler et al. 1999; Ferrati et al. 2005)."

"Cultivation has been suggested to be the most important factor in soil carbon loss (Lal et al. 2004). However, the restoration of wetland hydrology (e.g., plugging drains) also is a critical component of restoration. The fact that carbon storage is enhanced under anoxic conditions is important because flooded wetlands provide optimal conditions for accretion of organic matter (Euliss et al. 2006)."

"Wetland restoration and management must incorporate known climatic oscillations. Short-term periodic weather phenomena, such as El Niño, should be closely monitored and predictable. By understanding effects of periodic oscillations on habitats and wildlife, management options can be fine-tuned. For example, restoration of native plants during the wet phase of oscillations, avoiding the drought phase, could make the difference between success and failure."

Sorenson, L. G., Goldberg, R., Root, T. L. & Anderson, M. G. (1998). Potential effects of global warming on waterfowl populations in the northern Great Plains. Climatic Change, 40, 343 – 369.

"Current conservation investments, particularly for long-term securement, should be targeted to less drought-prone portions of the PPR [Prairie Pothole Region]. Wetland areas likely to be impacted by expanding agriculture should also receive attention now before they are extensively drained or altered."

WEST

Sorenson, L. G., Goldberg, R., Root, T. L. & Anderson, M. G. (1998). Potential effects of global warming on waterfowl populations in the northern Great Plains. Climatic Change, 40, 343 – 369.

"More protections should be provided for wetlands, such as enhancing long-term legal securement of water for managed wetlands where possible. Preservation of existing wetlands through policy initiatives such as the Conservation Reserve Program and Wetlands Reserve Program in the U.S. should be continued and expanded. This will allow society to a) retain options in the future under any climate change scenario, and b) respond appropriately to developments such as unanticipated geographic heterogeneity in drought severity. Moreover, it would reduce direct impacts on wetlands now that are likely only to compound the negative effects of global climate change."

LAKES AND PONDS

R5: PACIFIC SOUTHWEST

Sahoo, G. B. & Schladow, S. G. (2008). Impacts of climate change on lakes and reservoirs dynamics and restoration policies. Sustainability Science, 3, 189 – 199.

"External nutrient sources such as fertilizer use, pet wastes, stormwater runoff, septic system effluents, waterfowl, agriculture, and even rainfall can contribute nutrients to a lake [such as Lake Tahoe]. Lake management removes or modifies as many of these nutrient sources as possible, especially those sources shown to be contributing the greatest nutrient load to the water body. In-lake restoration techniques are necessary and they should be followed by, or occur simultaneously with, appropriate long-term management actions to control sediments, nutrients, and toxic inputs. A successful lake restoration program should strive to manage both external and internal nutrient sources. Many of them, particularly the internal action alternatives, are best applied, and in some cases can only be applied, to small lakes or on a local scale."

"Hypolimnetic aeration/oxygenation, which can be achieved by pure oxygen injection, or air injection (see McGinnis et al. 2004; Sahoo and Luketina 2006; Singleton et al. 2007), is an effective means of improving DO concentration in the water column. In the specific case of Lake Tahoe, however, injection of air or oxygen would be difficult due to the compression needs in overcoming the lake's great depth."

RIPARIAN AREAS

NATIONAL

Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S. L., Richter, B. & Warner, R. (2009). Climate change and river ecosystems: Protection and adaptation options. Environmental Management, 44, 1053 – 1068. DOI 10.1007/s00267-009-9329-1

"For rivers in regions expected to experience hot, dry periods, establishment of drought-tolerant varieties of plants may help protect the riparian corridor from erosion. A focus on increasing genetic diversity and population size through plantings or via stocking fish may increase the adaptive capacity of species. Aquatic fauna may benefit from an increase in physical habitat heterogeneity in the channel (Brown 2003), and replanting or widening any degraded riparian buffers may protect river fauna in many ways including providing more shade and maintaining sources of allochthonous input (Palmer and others 2005)."

Seavy, N. E., Gardali, T., Golet, G. H., Griggs, F. T., Howell, C. A., Kelsey, R., … & Weigand, J. F. (2009). Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecological Restoration, 27(3), 330-338. doi: 10.3368/er.27.3.330

"Restoration programs that reestablish appropriate hydrological processes, actively intervene with horticultural techniques to propagate and establish native vegetation where necessary, and manage for genetic diversity to facilitate evolutionary processes can build upon the natural resilience of riparian systems."

"Restoring riparian habitats and hydrological function recreates or increases connectivity between habitats and across elevational zones, thus providing avenues for species movements in response to climate change."

"Restoring riparian habitat will strengthen linkages between aquatic and terrestrial systems, making both more resilient and resistant to the stresses imposed by climate change. "

"Restoring [riparian] vegetation and protecting groundwater resources will enhance thermal refugia that will be increasingly important as air temperature rises."

"Restoring riparian ecosystems may also reduce the impacts of extreme flood events. Levees, especially those nearest the river channel, may increase flood stage and flow velocity during floods (Gergel et al. 2002). Riparian restoration to reconnect the river channel with its floodplain by moving back or breaching levees can benefit ecosystem function and nonstructural food control for urban or agricultural areas (Poff 2002, Golet et al. 2006)."

"By recharging groundwater and reducing flood damage, riparian restoration will strengthen ecosystem resistance against extreme floods and altered surface flows anticipated from climate change."

"Novel conditions created by climate change will require that [riparian] restoration proceeds within the framework of adaptive management, in which specific hypotheses are tested and monitoring is used to verify that desired outcomes are achieved (O'Donnell and Galat 2008)."

"Some horticultural restoration techniques can enhance riparian ecosystem resilience. Techniques under investigation include using ecological genetics to prepare for unexpected conditions (e.g., by deliberately increasing genetic variability) and also planting early seral colonizers adapted to flooding together with late seral species that may be less tolerant of flooding but grow better on drier sites."

"When the climate is changing rapidly, planting only local genetic material may not be the most appropriate strategy (Rice and Emery 2003, Bower and Aitken 2008). Collecting seed from within a watershed but across a range of elevations may better facilitate evolutionary adaptation to climate change [in riparian restoration projects]."

"Planting species [in riparian areas] that are associated with both ends of the hydrologic spectrum may provide some insurance against unexpected future conditions. Incorporating strategies that address uncertainty into horticultural restoration has the potential to both increase the odds of short-term restoration success and provide long-term maintenance of critical evolutionary processes."

Spittlehouse, D. L. (2005). Integrating climate change adaptation into forest management. The Forestry Chronicle, 81(5), 691-695. doi: 10.5558/tfc81691-5

"In some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation will become the highest priority. Forest harvesting and road building may have to mitigate the impacts of changes in the timing of peak flow and volume in streams on infrastructure, fish habitat, and potable water supplies (Mote et al. 2003). Warmer and drier summer conditions will increase the need to maintain cool stream temperatures by maintaining riparian cover for streams in harvested areas (Moore et al. 2005)."

WEST

Littell, J. S., Peterson, D. L., Millar, C. I. & O'Halloran, K. A. (2011). U.S. National Forests adapt to climate change through Science – Management partnerships. Climatic Change, DOI 10.1007/s10584-011-0066-0

"Protect riparian areas, which have disproportionately high value for biodiversity. New policies for riparian and watershed management limit road construction across perennial streams. Helicopters are used for logging where roads cannot be built. This maintains riparian reserves of biodiversity and reduces fragmentation and erosion."

Perry, L. G., Anderson, D. C., Reynolds, L. V., Nelson, S. M., & Shafroth, P. B. (2012). Vulnerability of riparian ecosystems to elevated CO2 and climate change in arid and semiarid western North America. Global Change Biology, 18, 821 - 842. doi: 10.1111/j.1365-2486.2011.02588.x

"A global assessment of major river basins identified three in SAWNA [semiarid and arid western North America] (Columbia, Sacramento, and Colorado) that are almost certain to need management intervention to mitigate climate-change impacts (Palmer et al., 2008). Along highly regulated mainstem reaches of these rivers, intensively managed and site-specific approaches will be necessary, such as active revegetation along the lower Colorado River (Briggs & Cornelius, 1998). Along reaches that might still receive high flows from unregulated tributaries, measures such as levee breaching could enhance floodplain connectivity (Florsheim & Mount, 2002). "

"Furthermore, efforts to de-armor bends and reconnect abandoned channels isolated by land conversion could increase opportunities for rivers to meander and create new surfaces for pioneer forest establishment. Along individual tributaries, more adaptation options are possible. In the lower Colorado River basin, where water management has already severely altered the main stem and virtually all tributaries, proactive management efforts are ongoing, including securing water rights, establishing protected area corridors, and institutionalizing environmental flows along the San Pedro (Stromberg & Tellman, 2009), Bill Williams (Shafroth et al., 2010), and Verde rivers (Haney et al., 2008)."

R5: PACIFIC SOUTHWEST

Lawler, J. J., Tear, T. H., Pyke, C., Shaw, M. R., Gonzalez, P., Kareiva,P., Hansen, L., Hannah, L., Klausmeyer, K., Aldous, A., Bienz, C., & Pearsall, S. (2010). Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment, 8(1), 35-43.

"The outcomes of translocations are especially uncertain. First, translocations are inherently unpredictable. Even when detailed habitat assessments have been conducted, the success of a translocation project tends to be highly uncertain. This is compounded by the uncertainties in projected future climates and the responses of the ecological systems that will affect the suitability of translocation sites. In contrast, strategies that are designed to increase connectivity or remove other stressors, such as the dam removal and restoration of riparian vegetation being carried out at the Sycan Marsh, are likely to be more robust to the uncertainties of climate change."

INTERACTIONS WITH OTHER FACTORS

R5: PACIFIC SOUTHWEST

Seavy, N. E., Gardali, T., Golet, G. H., Griggs, F. T., Howell, C. A., Kelsey, R., … & Weigand, J. F. (2009). Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecological Restoration, 27(3), 330-338. doi: 10.3368/er.27.3.330

"In California, the importance of linkages between aquatic and terrestrial systems is exemplified by the Yolo Bypass, an engineered floodplain on the Sacramento River. When the Yolo Bypass foods, 24,000 ha of agricultural land, wetlands, and riparian and upland vegetation are covered with shallow water.

Flooding provides important benefits to aquatic, wetland, and terrestrial taxa, including fish and birds (Sommer et al. 2001)."

RESOURCE AREA (FACTOR): ANIMAL COMMUNITIES

FISH

NATIONAL

Bernazzani, P., Bradley, B., and Opperman, J. (2012). Integrating climate change into habitat conservation plans under the U.S. Endangered Species Act. Environmental Management, 49(6), 1103-1114. doi:10.1007/s00267-012-9853-2

"For example, the Ecosystem Diagnosis and Treatment (EDT) tool can model the relative abundance and habitat capacity for anadramous fish in response to various scenarios, including those that specifically incorporate climate change, and predict effects on covered fish species [under the Endangered Species Act] (Lestelle and others 2004)."

Dunwiddie, P. W., Hall, S. A., Ingraham, M. W., Bakker, J. D., Nelson, K. S., Fuller, R. , & Gray, E. (2009). Rethinking conservation practice in light of climate change. Ecological Rest., 27, 320-329.

"To understand how projects are affecting ecosystem resilience, monitoring must be focused on resilience indicators, rather than short-term structural outcomes such as acres restored or number of fish present."

Olson, D., & Burnett, K. (2009). Design and management of linkage areas across headwater drainages to conserve biodiversity in forest ecosystems. Forest Ecology and Management, 258, 117-126.

"River basins with no freshwater connectivity would need higher densities of linkage areas because there is no chance of incidental dispersal along downstream connected riparian corridors. Hence, we propose higher densities of linkage areas across ridgelines of 4th- and 5th-code HUs than across ridgelines between 6th-code HUs that are contained entirely within a single 5th-code HU."

Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S. L., Richter, B. & Warner, R. (2009). Climate change and river ecosystems: Protection and adaptation options. Environmental Management, 44, 1053 – 1068. DOI 10.1007/s00267-009-9329-1

"In regions with higher temperatures and less precipitation, reactive projects might include fish passage projects to allow stranded populations to move between isolated river reaches during drought times, replanting of native riparian vegetation with drought resistant vegetation, or removal of undesirable non-native species that take hold. If dams are present, flow releases during the summer could be used to sustain flora and fauna in downstream river reaches that are drying up."

Rahel, F. J., Bierwagen, B., & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology, 22(3), 551-561.

"To ameliorate the effects of climate change, managers may need to manipulate habitats in ways that favor native species. For example, the effects of warmer air temperatures can be countered by planting riparian vegetation to shade streams and reduce solar inputs. Shadinghelps maintain cool water temperatures needed by native species that might otherwise be replaced by invasive warmwater species."

"Translocating imperiled trout species to higher elevations to escape climate warming wouldcause problems for native amphibians that are themselves species of conservation concern (Vredenburg 2004). We need better understandings of which non-native species are likely to become invasive and which species of conservation concern could cause problems if translocated to environments outside their historical range."

Rieman, B. E., Hessburg, P. F., Luce, C., & Dare, M. R. (2010). Wildfire and management of forests and native fishes: Conflict or opportunity for convergent solutions? BioScience, 60 (6), 460-468.

"Aquatic managers may wish to avoid any activity that would continue the disruption of watershed or stream conditions (Rhodes and Baker 2008), anticipating conflict in any further terrestrial work. But in some cases, additional ground disturbance linked to forest thinning and fuels management could be minor relative to past effects of fragmentation or watershed disruption. It could be opportune to use existing road networks to support forest restoration in one area, while restoring hydrologic and biological connectivity through road obliteration and barrier removal in another (Rieman et al. 2000, Brown et al. 2004). If efforts to restore one system could simultaneously encourage interest or leverage capacity to restore the other (e.g., by sharing limited planning or capital resources), benefits could be greater than those realized working alone."

"Many headwater streams are prone to large floods or debris flows triggered by wildfire and storms that follow. Large habitat networks can often absorb and benefit ecologically from such events (Reeves et al. 1995), but small, isolated systems will be more vulnerable (Dunham et al. 2003, Rieman et al. 2003). Aquatic management objectives may tend toward control in the latter case (e.g., Brown et al. 2001). When these conditions overlap with an interest in controlling fire for other reasons (e.g., near urban areas; lower left cell, table 1), aggressive fuels management or fire suppression to mitigate the extent of severe fire effects (Reinhardt et al. 2008) could reflect a convergence in management objectives."

Xenopoulos, M. A., & Lodge, D. M. (2006). Going with the flow: using species-discharge relationships to forecast losses in fish biodiversity. Ecology, 87(8), 1907-1914. doi:10.1890/0012-9658(2006)87[1907:GWTFUS]2.0.CO;2

"The lag times between reductions in flow and species extinctions provide an opportunity for biologists to offer advice on how to target conservation efforts to slow or prevent the loss of freshwater [fish] species."

WEST

Bisson, P. A., Dunham, J. B. & Reeves, G. H. (2009). Freshwater ecosystems and resilience of Pacific salmon: habitat management based on natural variability. Ecology and Society, 14 (1), 1 - 18. http://www.ecologyandsociety.org/vol14/iss1/art45/

"Climate change poses a long list of challenges for maintaining the resilience of Pacific salmon [Oncorhynchus spp] (e.g., ISAB 2007). Perhaps the most obvious management strategy to strengthen resilience in the face of climate change is to maintain as much water as possible in streams and lakes during periods of low flow. Decreased summer low flows may diminish the network of perennial streams, requiring fish to occupy smaller and less diverse habitats (Battin et al. 2006). Lower stream flows during summer may also result in stressful maximum temperatures for Pacific salmon, including migrating adults prior to spawning. The maintenance or restoration of natural processes that moderate stream temperatures, such as promoting the recovery of natural riparian vegetation or eliminating water withdrawals from hyporheic channels (Beschta et al. 1987), may counter some of the undesirable influences of climate change. "

"During the winter, increased flooding may create societal pressure to prevent damage to homes and infrastructure and isolate rivers from their floodplains, but such actions often run counter to the objective of maintaining floodplain processes and aquatic habitat diversity [for Pacific salmon, Oncorhynchus spp.] (Greene et al. 2005). Accordingly, assessments to determine where flooding can be allowed in a watershed and, in particular, where flooding will reconnect the river with floodplain habitats are of direct importance to salmon [Oncorhynchus spp] (Hulse and Gregory 2004)."

"Management of the freshwater habitat of Pacific salmon [Oncorhynchus spp.] should focus on natural processes and variability rather than attempt to maintain or engineer a desired set of conditions through time (Lugo et al. 1999, Dale et al. 2000). This does not imply that we should attempt to re-create or reestablish completely pristine conditions everywhere, which would simply not be possible. When applied to the management of aquatic ecosystems, the concept of resilience requires us to abandon the idea that any water body not conforming to an idealized notion of optimum habitat needs to be fixed. From this new perspective, resource managers must examine variability in current aquatic conditions and establish the large-scale spatial and temporal context of a watershed, historical changes in the system, and potential threats and expectations. The fundamental idea is to characterize variation in natural processes within stream networks and ask where we are, where we want to go, and how we get there in the context of restoring a natural range of habitat conditions for Pacific salmon."

"The first step in developing such strategies [managing freshwater habitat of Pacific salmon, Oncorhynchus spp.] will be to establish environmental targets that are compatible with natural disturbance and recovery processes. This will include a careful examination of long-term environmental data from nearby areas that are relatively pristine or have been minimally developed, because this information will help set the constraints on what will be possible from a habitat recovery standpoint. The second step will be to assess the current and potential threats to the reestablishment of complex natural habitats. Some of these threats may be addressed by restoration programs, but others, for various reasons, will not, and these will also constrain what is possible. The third step will be to determine if the planning area is sufficiently large to achieve the three criteria for habitat resilience: (1) the capacity to recover from disturbances without intervention, (2) a full range of habitats to support multiple salmon life histories, and (3) ecological connectivity; if so, it will also be necessary to determine when and where restoration techniques should be applied to help maintain these criteria."

Dunham, J., Rieman, B. & Chandler, G. (2003). Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. North American Journal of Fisheries Management, 23, 894 – 904.

"Managers often question how cold water needs to be to support bull trout [Salvelinus confluentus]. The answer is not a single number, but rather a continuum of values associated with the expected probability of occurrence. Risk-averse strategies to protect this threatened species may adopt a more or less conservative approach to choosing an acceptable temperature for management purposes. For example, such an approach would entail protecting the full range of the habitats that bull trout might use (e.g.,<26°C; Figure 2). Another approach would be to target restoration of water temperatures that bull trout are most likely to use (e.g., ≤12°C; Figure 2). The point estimates of the probability of occurrence from the models are not precise, and the uncertainty in model predictions could be an important consideration in choosing management criteria for temperature (Poole et al. 2001)."

"Coldwater alone is not enough to support populations of bull trout [Salvelinus confluentus], as is suggested by research linking the occurrence of local populations to the amount and distribution of potentially suitable thermal habitat on landscapes (e.g., Rieman and Dunham 2000; Dunham et al. 2002b). Our work shows that large, isolated, and undisturbed coldwater habitats are more likely to support local populations of bull trout. Conservation efforts to benefit bull trout would be more effective if existing areas with these characteristics were identified, along with areas where restoration could provide these conditions."

Williams, J. E., Haak, A. L., Neville, H. M. & Colyer, W. T. (2009). Potential consequences of climate change to persistence of cutthroat populations. North American Journal of Fisheries Management, 29, 533 – 548. DOI: 10.1577/M08-072.1.

"A primary strategy [for cutthroat trout (Oncorhynchus clarkii)] should focus on expanding small, isolated populations to achieve an effective population size of at least 500 (e.g., Hilderbrand and Kershner 2000) by increasing available habitat and improving existing habitat quality. Trout will have a much better chance of persisting in the face of increasing environmental threats if they have access to heterogeneous habitat and refugia, both seasonally and during disturbance (Dunham et al. 2003). Secondly, ecological and life history diversity could potentially be restored by providing instream flows and reconnecting stream systems to allow access to migratory habitats by removing instream barriers. Finally, existing habitat stressors (such as livestock grazing, road development, and water withdrawals) should be curtailed."

"In habitats [for cutthroat trout (Oncorhynchus clarkii)] where conditions are predicted to be suitable in the future, these restoration activities may provide opportunities for reintroductions, allowing for expansion of populations across more of the historic distribution of these species and providing a stronger foundation for the maintenance and evolution of future diversity. Many of these actions may necessitate control or elimination of nonnative species, which is one of the principal threats facing native trout in the western United States (Fausch et al. 2006)."

Rieman, B. E., Isaak, D., Adams, S., Horan, D., Nagel, D., … & Myers, D. (2007). Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. Transactions of the American Fisheries Society, 136, 1552 – 1565. DOI: 10.1577/T07-028.1

"Our results suggest moderate to high risks will extend across the [Columbia River] basin with even modest warming. Consideration of ecological and evolutionary significance, as well as risk related to climate change, could highlight areas as regional priorities (Allendorf et al. 1997). For example, by virtue of their extended isolation from other bull trout [Salvelinus confluentus] populations and location on the extreme margins of the species' range, both the Jarbidge and Klamath subregions could represent distinct and thus evolutionarily important populations (Leary et al. 1993; Lesica and Allendorf 1995; Rieman et al. 1997) worthy of extraordinary efforts."

"Extensive investment may be pointless if climate change is expected to eliminate most suitable habitat [for bull trout, Salvelinus confluentus in the Columbia River basin] (Halpin 1997). Alternatively, land use management and habitat restoration in areas with already degraded habitats may become critical if remnant populations are to retain enough resilience to persist under the challenges posed by even modest climate change."

Rieman, B., Lee, D., Burns, D., Gresswell, R., Young, M., Stowell, R., … & Howell, P. (2003). Status of native fishes in the western United States and issues for fire and fuels management. Forest Ecology and Management, 178, 197 – 211.

"For restoration to succeed it may be necessary to address more than the local conditions of habitats and individual populations. The geometry and interconnection of habitats may be particularly important to the dynamics, productivity and persistence of many populations (Rieman and Dunham, 2000; Dunham et al., this issue). Declines in anadromous salmonids associated with dams and other changes in the Pacific Northwest have reduced the influx of nutrients to streams (Gresh et al., 2001), which may further constrain the survival and resilience of remnant populations (Zabel and Williams, 2002) and have cascading effects on whole communities and ecosystems (Willson and Halupka, 1995; Gresh et al., 2001; Helfield and Naiman, 2001). "

"In parts of the interior Columbia River basin and coastal systems of the Pacific Northwest, for example, large interconnected networks of stream habitats remain. Some species (e.g. bull trout), although depressed, still occur across the majority of their historical range (Rieman et al., 1997). Populations of bull trout [Salvelinus confluentus], cutthroat trout [Oncorhynchus clarkii], steelhead [Oncorhynchus mykiss], and salmon in some basins still migrate to and through large rivers, lakes, and the ocean. In other basins reconnection of larger networks of habitat is still possible (Lee et al., 1997). Many of these populations will persist and could even flourish if the constraints on important habitat forming and biological processes are addressed (e.g. Beechie and Bolton, 1999; Roni et al., 2002)."

"By contrast, in some watersheds in the Pacific Northwest and throughout much of the interior west and southwest, [fish] habitat loss and fragmentation is pronounced and some watersheds and aquatic communities may be irreversibly altered. Reconnecting large networks of habitat and restoring the natural processes maintaining these systems is unlikely at present. Thus, conservation management may require more intensive and direct intervention and manipulation of habitats, populations, and communities (Young and Harig, 2001; Harig and Fausch, 2002)."

"Where [fish] populations can still express the full range of life histories and remain connected to a range of habitats, even large fires may pose little threat (Dunham et al., this issue). Indeed, fire could even be critical to the long-term maintenance of important habitats. In contrast, where populations have been constrained by habitat loss, fragmentation, and the expansion of exotic species, the probability for local extinctions linked to any disturbance has probably increased. If changes in fire patterns lead to larger, more severe disturbances than characteristic of at least the more recent evolutionary past for these species, the risks are compounded (i.e. fragmentation interacting with larger disturbances) (Dunham et al., this issue). Where these conditions coincide the mitigation of extreme fires and their effects might benefit native fishes (Brown et al., 2001)."

"For example, large fires can affect watershed processes dramatically. The loss of vegetation and creation of hydrophobic soils can increase the potential for flooding and surface and mass erosion leading to dramatic increases in sedimentation, debris flows, or even complete channel reorganization (Rieman and Clayton, 1997; Meyer et al., 2001). The loss of riparian shading and changes in flow volume may produce more extreme temperatures (McMahon and deCalista, 1990). Large fires threaten a negative influence on the quality of habitats for fishes and other aquatic organisms. Arguably, we should minimize the potential for large fires to minimize those risks."

"Alternatively, logging and thinning intended to remove fuels or to replace fire may ultimately remove a legacy of materials that would structure aquatic habitats in the future. Management intended to replace or mimic the effects of fire may look nothing like those fires from a watershed perspective (Reeves et al., 1995). Because management often involves repeated entry and the maintenance of an infrastructure including roads, the negative effects of management can be chronic or persistent compared to the acute and periodic effect of fire (Rieman and Clayton, 1997). Species that evolved in variable environments may be adapted to the periodic or pulsed events, but not the chronic ones (Poff and Ward, 1990)."

Wenger, S. J., Isaak, D. J., Luce, C. H., Neville, H. M., Fausch, K. D., Dunham, J. B., Dauwalter, D. C., Young, M. K., Elsner, M. M., Rieman, B. E., Hamlet, A. F., & Williams, J. E. (2011). Flow regime, temperture, and biotic interactions drive differential declines of trout species under climate change. Proceedings of the National Academy of Sciences, 108 (34), 14175-14180.

"In contrast, stream temperature is often influenced by anthropogenic activity and future increases can be offset by restoration measures such as maintenance of stream flows and reforestation (Isaak 2010). Thus, managers interested in conserving cutthroat trout [Oncorhynchus clarkii] or rainbow trout [Oncorhynchus mykiss] habitat may wish to focus on such restoration activities, which are likely to provide some benefits regardless of the precise climate trajectory. In selecting actions, managers should consider local conditions; for example, the response of cutthroat trout depends substantially on which nonnative species are present, and this varies from region to region. Overall, we argue that considering biotic interactions and variables other than temperature not only gives us a richer understanding of species-climate relationship, but also can inspire a more strategic portfolio of management alternatives."

"For example, there is little that can be done to influence the predicted increase in winter high flows, so some declines in fall-spawning species (e.g., brook trout [Salvelinus fontinalis] and brown trout [Salmo trutta]) may be inevitable in regions where flows are likely to shift."

Wenger, S. J., Isaak, D. J., Dunham, J. B., Fausch, K. D., Luce, C. H., … & Chandler, G. L. (2011). Role of climate and invasive species in structuring trout distributions in the interior Columbia River Basin, USA. Canadian Journal of Fisheries and Aquatic Sciences, 68, 988 – 1008. doi:10.1139/F2011-034

"Our results [from analyzing a fish occurrence database assembled from fish data collections in Idaho, Montana, and Wyoming] have several implications for management. The first is that in locations that (i) support both cutthroat trout [Oncorhynchus clarkii] and brook trout [Salvelinus fontinalis] but (ii) are warmer than optimal for brook trout and (iii) have high flows in the winter, brook trout control efforts may be highly feasible and provide significant benefits to cutthroat trout. Second, preventing brook trout from accessing uninvaded UVBs [unconfined valley bottoms] may be important for protecting habitat for native trout, as removal of established populations of brook trout from UVBs is unlikely to be effective (e.g., Meyer et al. 2006). Third, areas where brook trout currently dominate over cutthroat trout still have conservation value, because these locations may become less hospitable to brook trout and more so to cutthroat trout in the future."

"An important intermediate management step in these locations [areas where brook trout, Salvelinus fontinalis, currently dominate over cutthroat trout, Oncorhynchus clarkii] may be to guard against the invasion of warm-water species, perhaps using barriers to upstream migration (Fausch et al. 2009) and through the application of distributional monitoring protocols (Isaak et al. 2009) that facilitate the early detection of invasions and increase the chances of population eradication. Finally, our results reinforce those of other researchers (e.g., Rieman et al. 2007; Isaak et al. 2010) that suggest effective long-term management for bull trout in the face of climate change will require prioritization to ensure that resources are allocated to those locations with the coldest temperatures that offer the greatest long-term potential to sustain the species."

R5: PACIFIC SOUTHWEST

Katz, J., Moyle, P. B., Quinones, R. M., Israel, J. & Purdy, S. (2012). Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes, DOI 10.1007/s10641-012-9974-8

"Connectivity among habitats is becoming increasingly important as temperatures climb. In particular, seasonal access to cold water areas, especially smaller streams at higher elevations, is becoming more important to salmonids seeking coldwater refuges (Crozier et al. 2008). Under these conditions, mainstem rivers such as the Klamath River will be available primarily as seasonal migration corridors (Quiñones and Moyle in press). Habitat connectivity becomes as important as habitat quantity and quality when populations decrease and habitat is fragmented (Isaak et al. 2007). Consequently, removing physical (e.g., dams, shallow water) and physiological (e.g., warm water temperatures) barriers to upstream migration and behavioral thermoregulation will become an increasingly important conservation strategy."

"Because diverse habitats are necessary for expression of life history variation, decreases in habitat diversity can lead to reductions in life history diversity and to diminished resilience of salmon populations (Waples et al. 2009). Therefore, restoration and protection of physical habitat diversity is essential to maintaining genetic diversity and fostering resilience to both climate change and human population pressure in salmonid stocks (Hilborn et al. 2003; Rogers and Schindler 2008; Schindler et al. 2008; Carlson et al. 2011)."

"Because habitat diversity is essential to maintaining life history diversity, conservation strategies that restore and improve physical habitat quality, extent, and connectivity are essential tools in improving the odds of salmonid persistence (Greene et al. 2010). This general action must go hand in hand with changing hatchery operations, that reduce the adaptive potential of wild populations via introgression with domesticated hatchery genomes."

"Provide immediate additional protection to 'salmon strongholds' where salmonid diversity is high and habitat conditions are still reasonably good, such as the Smith River and the Blue Creek watershed of the Klamath Basin. This means reducing the human footprint on stronghold watersheds as much as possible by managing the watersheds first and foremost for native fish."

"Restore connectivity between river channels and seasonal habitat such as oxbows, riparian terraces, and floodplains wherever possible. Protect and restore cold water habitats, especially streams with groundwater inputs, the mouths of tributaries where hyporheic flows may provide thermal refuges, and watersheds that lie within the coastal fog belt. In regulated streams, reserve as much cold water in reservoirs as possible for providing suitable flows for native salmonids. Remove artificial migration barriers (including small and large dams, low flow and warm water barriers) to provide salmonids access to a wider range of habitats, comparable to historic ranges."

"Protect and restore riparian buffers alongside lower order streams (1st–3rd) where riparian vegetation can provide significant protection from solar radiation and maintain cooler water temperatures, as well as reduce sediment input. Reduce fine sediment delivery to streams to prevent streams from becoming shallower and thus more likely to become warmer, by improved watershed management (e.g., reducing effectsfrom high road density, logging, and mining)."

"Reform statewide [California] hatchery policy so that the overarching goal of hatcheries is protection of wild populations of fish, rather than enhancing fisheries. End gene flow between hatchery strays and naturally reproducing spawning groups. This is essential for recovery of naturally reproducing stocks. Segregation of hatchery and naturally reproducing gene pools may be achieved in two ways: 1) physical segregation via active sorting at weirs or dams whereby only non-hatchery fish are passed upstream above the barrier, 2) use of hatchery brood stocks that are divergent from local genomes so that when hybridization between naturally produced individuals and hatchery strays inevitably occurs the hybrid progeny inherit a genome unfit for local conditions, experience high mortality in the wild and are rapidly culled from the naturally produced gene pool. "

"Mark all hatchery fish with external marks so targeted management is possible. Relocate salmon and steelhead [Oncorhynchus mykiss] production hatcheries closer to river mouths in order to reduce mixing of wild and hatchery stocks. Relocate at least some harvest from the ocean to rivers and estuaries to allow targeting populations best able to sustain fishing pressure, especially hatchery stocks, while protecting imperiled naturally reproduced anadromous runs from overfishing. Close hatcheries where adverse impacts outweigh benefits."

Kiernan, J. D., Moyle, P. B. & Crain, P. K. (2012). Restoring native fish assemblages to a regulated California stream using the natural flow regime concept. Ecological Applications, 22 (5), 1472 – 1482.

"Native fish assemblages in Putah Creek, and elsewhere in California, evolved under a Mediterranean-type hydrologic regime, with rain delivered in winter and spring followed by summer droughts with little or no precipitation. Consequently, most native species spawn in mid-February through mid-April and require hydrologic cues such as increased stream flow or floodplain inundation to initiate spawning behavior (Moyle 2002). The new flow regime was explicitly designed to provide an initial pulse flow (3 days) in early spring, followed by 30 consecutive days of elevated flows and a gradual ramping of flows down to the minimum flows scheduled for that month. Further, it ensured sufficient water to provide cool (<22°C) lotic (flowing) conditions throughout most of the lower creek during the warmest times of

"Here we provide a rigorous example of how targeted changes to the flow regime successfully reestablished native fishes and reduced abundances of alien fishes throughout much of a regulated California stream. This favorable outcome was achieved by manipulating stream flows at key times of the year and only required a small increase in the total volume of water delivered downstream (i.e., not diverted) during most water years (Moyle et al. 1998). Our study supports a growing body of literature that shows the natural flow regime can be a powerful tool for restoring native fish populations."

Lawler, J. J., Tear, T. H., Pyke, C., Shaw, M. R., Gonzalez, P., Kareiva,P., Hansen, L., Hannah, L., Klausmeyer, K., Aldous, A., Bienz, C., & Pearsall, S. (2010). Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment, 8(1), 35-43.

"Several current restoration activities to improve bull trout (Salvelinus confluentus) habitat and to address some of the effects of climate change on the Sycan Marsh preserve take both a longer term and larger spatial perspective. For example, preserve managers are increasing connectivity within the stream network by removing barriers to dispersal, thereby allowing fish to move in response to changes in stream temperature. Managers are also restoring the historic hydrologic regime by removing water-control structures. These removals will allow the stream to expand, contract, and move through its floodplain, potentially buffering the impacts of projected changes in future stream flow. Other management activities include increasing riparian vegetation to reduce channel width and improve in-stream habitat conditions, and restoring hardwoods in riparian areas to provide microhabitats that reduce the effects of irradiance. However, managers also recognize that, as a result of climate change, water temperatures may rise above the bull trout's viability threshold, no matter how much restoration is accomplished in the watershed. In this case, bull trout protection and restoration efforts will need to shift to higher elevations. Determining when restoration efforts need to shift upstream, or whether fish need to be moved, will require targeted monitoring and active adaptive management. "

Marchetti, M. P. & Moyle, P. B. (2001). Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications, 11 (2), 530-539.

" This study provides a clear demonstration of how native fishes in streams of the western United States exhibit different habitat requirements and respond to temporal variation in flow in a different manner than nonnative fishes. It supports the concept that restoration of natural flow regimes, in company with other restoration measures, is necessary if the continued downward decline of native fish populations in the western United States is to be reversed."

"In years where large natural flows occur [in California] (1997, 1998), little water would have to be released from storage beyond what is required to maintain summer base flows for native species. During years with very little flow (1994, 1995), however, maintenance of native fishes may require augmenting base flows and occasionally releasing large pulse flows in winter (Moyle et al. 1998). "

"Fortunately, the native fishes [in California] are adapted for surviving multiyear periods of adverse flow conditions (Moyle et al. 1982) so they can persist through an extended drought, provided the alien fishes are kept at bay or that suitable habitat refuges exist for the native fishes. Thus, an adaptive management scheme focused on native fish assemblages would necessarily include consideration of other environmental variables in addition to streamflow. One such management option might include increasing riparian vegetation along the lower portions of the creek. This would create more shaded aquatic habitat and would cool water temperatures, favoring native fishes, perhaps reducing water costs during periods of drought."

Moyle, P. B., Kiernan, J. D., Crain, P. K. & Quicones, R. M. (2012). Projected effects of future climates on freshwater fishes of California. California Energy Commission. Publication number: CEC-500-2012-028.

"The studies of Martis, Sagehen, and Putah creeks [in California] indicate that different species respond in different ways to variability in flow, which is likely to increase with climate change (Kiernan and Moyle 2012; Kiernan et al. 2012). Declining trends may be hard to detect without long-term monitoring as a consequence. The success of reestablishing native fishes in Putah Creek indicates that managing flow regimes in regulated streams may be a powerful tool to counter the negative effects of climate change, as may the establishment of cool-water refuges for fish, even in urban areas such as streams in the San Francisco Bay region."

Null, S. E., Viers, J. H., Deas, M. L., Tanaka, S. K. & Mount, J. F. (2012). Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change, DOI 10.1007/s10584-012-0459-8

"To maintain coldwater habitat with climate warming in California, it will likely be necessary to operate dams for thermal management, improve passage around dams, or remove some dams. While dams have fundamentally altered the natural flow regime in California and threatened some anadromous salmonids in the state, they also provide benefits for controlling the temperature of reservoir releases and may provide a critical coldwater supply to maintain habitat for coldwater species with climate warming (Yates et al. 2008). Thermal stratification in large reservoirs isolates the hypolimnion, often maintaining a coldwater pool through summer and into fall. Adapting reservoir operations to incorporate coldwater releases from the hypolimnion of large reservoirs may offset some of the thermal effects of climate warming and enhance thermal refugia in downstream locations for coldwater fish species, such as Chinook salmon [Oncoryhnchus tshawytscha] and steelhead trout [Oncorhynchus mykiss]."