Preliminary Investigation (PI-0074)

Caltrans Division of Research, Innovation and System Information

Assessing Permanent Shading Impacts on Riparian Plant and Aquatic Species and Habitat

Requested by
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Executive Summary

Background

Caltrans regularly faces conflicting professional opinions when assessing the ecological impacts associated with roadway improvements. Roadway projects often involve work adjacent to and within waterways, riparian habitat and wetlands. Differing opinions and a lack of clearly defined regulatory codes complicate the decisions that must be made to remove or add shading structures (trees, shrubs, piers, bridges and viaducts).

With the passage of California Senate Bill 1, the Road Repair and Accountability Act of 2017, numerous bridges are scheduled to be replaced, repaired or updated to meet current Caltrans standards. Accurately accounting for shading impacts on the aquatic and riparian environment and obtaining consistent opinions from all agencies will aid in project delivery.

The results of this Preliminary Investigation are expected to serve as a first step in developing a toolkit for planners, engineers and biologists to facilitate more efficient and successful project permitting.

Summary of Findings

A targeted literature search produced a number of resources that address plant, animal and ecological responses to shade. In addition, practices, guidelines and procedures for assessing the impacts of shade as part of transportation construction projects were also identified. Below is a summary of the publications that are described in detail in the body of this report.

Shade Tolerance

The publications in this section provide a broad understanding of light (in terms of both quantity and quality of solar radiation) that is needed for plant species to conduct photosynthesis, propagate and survive. Research describing plant physiology related to photosynthesis is noted for both natural and artificial light conditions. A 2013 journal article describes methods for measuring and estimating the below-canopy light environment in a forest. While upper-canopy trees are the vectors for creating the shade in that case, they can be thought of as analogous to bridges and other transportation infrastructure when measuring shade impacts to riparian environments.

Influence of Shading on Riparian Water Temperature

Additional research describes the impact of shade on water temperature and on the ecological and microclimatic nature of streams. Described in this research are human influences affecting in-stream photosynthesis, aquatic insect production and fish productivity. In addition, a 2015 journal article documents a historical rise in the stream temperature of river catchments in the UK as a result of climate change. The article suggests that shade may actually have some benefit in offsetting these increases in stream temperature because it allows time for ecosystems to adapt. Other research indicates that allowing light to enter the stream increases the ability of plants to photosynthesize and increases aquatic insect production and fish productivity.

Shade Impacts on Plant Species

Information from the U.S. Department of Agriculture's PLANTS Database provides information about the shade tolerance of California native plants that are of interest to Caltrans. Other resources describe how plants that live above and below the surface of streams are impacted by shade, including a North Carolina Department of Transportation (DOT) study that focuses on the impacts of bridge shading on submerged aquatic vegetation.

Shade Impacts on Aquatic Animal Species

This section documents the impacts of shade on animals and their habitat. General biological processes influenced by fluctuation in stream temperatures are described, as are the nature and magnitude of impacts to fish species and fish habitat. A 2010 Washington State DOT study examines the use of fiber-optic light as a technique for mitigating the impacts of dock shading on juvenile salmon behavior.

Practices and Guidelines

A relatively small number of practices and guidelines for assessing and mitigating shade impacts were found. A comprehensive set of white papers compiled by the Washington Department of Fish and Wildlife in 2009 provides specific information about shade impacts from bridge projects and other improvements, as well as detailed information about mitigation techniques in both freshwater and marine environments. A 2016 study by the agency provides a brief set of guidelines for minimizing the footprint of residential docks and using light-penetrable grating to allow natural light to filter through; these guidelines may have some applicability to bridges.

Gaps in Findings

The majority of research in this area describes the effects of shade in relation to plant and animal physiology and reproduction, and does not address specific practices that planners and engineers could undertake to assess and mitigate construction impacts from shading to biological communities and aquatic habitat.

We were unable to locate additional information about SHADE2, a shade model developed by researchers affiliated with the University of Georgia's Warnell School of Forestry and Natural Resources. The journal article describing this model and its application is cited on page 15 of this report.

Next Steps

Moving forward, Caltrans could consider:

- Following up with the Washington Department of Fish and Wildlife to find out how its procedures and guidelines could be used to assess shading impacts from transportation infrastructure, including impacts to aquatic animal life.
- Contacting North Carolina DOT for more information about its study of bridge shading impacts on submerged vegetation.
- Contacting University of Georgia's Warnell School of Forestry and Natural Resources to learn more about the riparian shade model SHADE2 and possible follow-up research.

- Consulting with professional ecologists who focus on riparian environments to gain a better understanding of the interaction of shade with water temperature and its impact on the ecological processes of plant and animal communities.
- Conducting a survey of state DOTs to learn about agency efforts to mitigate the impacts of shade in connection with transportation construction projects.

Detailed Findings

The results of a literature search that examined plant, animal and ecological responses to shade are summarized below in the following topic areas:

- Shade tolerance.
- Influence of shading on riparian water temperature.
- Shade impacts on plant and aquatic animal species.
- Practices and guidelines.

Shade Tolerance

The publications below provide a broad understanding of the quantity and quality of solar radiation that plants need to conduct photosynthesis, propagate and survive.

"Comparing Shade Tolerance Measures of Woody Forest Species," Jiayi Feng, Kangning Zhao, Dong He, Suqin Fan, TienMing Lee, Chengjin Chu and Fangliang He, *PeerJ*, October 2018.
https://peerj.com/articles/5736/
To provide guidance for choosing appropriate shade tolerance indices in future studies, researchers compared five measures of shade tolerance of understory wood species:

- Low-light abundance.
- Sapling ratio.
- Mortality.
- Light environment.
- Leaf light compensation point (LCP) measurement.

All the shade tolerance measures except the low-light abundance index performed poorly in distinguishing and ranking shade tolerance of the tested species. Researchers concluded that low-light abundance is the most objective and practical of the five most commonly used indices for measuring and ranking shade tolerance of understory wood species. The low-light abundance method measures shade tolerance showing abundance distribution along a light gradient. Examples include measuring the ratio of saplings growing in low light environment over the total abundance of the species, or measuring the number (abundance) of stems in a low light environment of the target species to infer shade tolerance.

Follow-up research may help determine whether this method could be used effectively in connection with bridges and other improvements. Researchers noted that the simplicity of the method should "greatly facilitate the assessment of light niche differentiation between species and thus contribute to understanding coexistence of tree species in forests." This may also be analogous to understanding light niche differentiation of shaded plants in riparian environments.

"Shade Factors for 149 Taxa of In-Leaf Urban Trees in the USA," E. Gregory McPherson, Qingfu Xiao, Natalie van Doorn, Nels Johnson, Shannon Albers and Paula Peper, *Urban Forestry and Urban Greening*, Vol. 31, pages 204-211, 2018.
https://www.fs.fed.us/psw/publications/mcpherson/psw_2018_mcpherson002.pdf
From the abstract:

> Shade factors, defined as the percentage of sky covered by foliage and branches within the perimeter of individual tree crowns, have been used to model the effects of trees on air pollutant uptake, building energy use and rainfall interception. For the past 30 years the primary source of shade factors was a database containing values from 47 species. In most cases, values were obtained from measurements on a single tree in one location. To expand this database 11,024 shade factors were obtained for 149 urban tree species through a photometric process applied to the predominant species in 17 U.S. cities. Two digital images were taken of each tree, crowns were isolated, silhouette area defined and shade factors calculated as the ratio of shaded (i.e., foliage and woody material) pixels to total pixels within the crown silhouette area. The highly nonlinear relationship between both age and diameter at breast height (DBH), and shade factor was captured using generalized additive mixed models.
>
> We found that shade factors increased with age until trees reached about 20 years or 30 cm DBH. Using a single shade factor from a mature tree for a young tree can overestimate actual crown density. Also, in many cases, shade factors were found to vary considerably for the same species growing in different climate zones. We provide a set of tables that contain the necessary values to compute shade factors from DBH or age with species and climate effects accounted for. This new information expands the scope of urban species with measured shade factors and allows researchers and urban foresters to more accurately predict their values across time and space.

Researchers examined the following species occurring in California:

- *Acacia melanoxylon* R. Br. (black acacia).
- *Acer palmatum* Thunb. (Japanese maple).
- *Acer saccharinum* L. (silver maple).
- *Betula pendula* Roth (European white birch).
- *Brachychiton populneus* (Schott & Endl.) R. Br. (kurrajong).
- *Callistemon citrinus* (Curtis) Skeels (lemon bottlebrush).
- *Cedrus deodara* (Roxb. ex D. Don) G. Don (deodar cedar).
- *Celtis sinensis* Pers. (Chinese hackberry).
- *Cinnamomum camphora* (L.) J. Presi (camphor tree).
- *Magnolia grandiflora* L. (southern magnolia).
- *Metrosideros excelsa* Sol. ex Gaertn. (New Zealand Christmas tree).
- *Melaleuca quinquenervia* (Cav.) S.T. Blake (punk tree).
- *Phoenix canariensis* Chabaud (Canary Island date palm).
- *Pinus brutia* Ten. (Turkish pine).
- *Pinus canariensis* C. Sm. (Canary Island pine).
- *Pistacia chinensis* Bunge (Chinese pistache).
- *Pinus radiata* D. Don (Monterey pine).
- *Pinus thunbergii* Parl. (Japanese black pine).
- *Pittosporum undulatum* Vent. (Victorian

box).

- *Cupaniopsis anacardioides* (A. Rich.) Radlk. (carrotwood).
- *Eucalyptus globulus* Labill. (blue gum eucalyptus).
- *Eucalyptus sideroxylon* A. Cunn. ex Woolls (red ironbark).
- *Ficus thonningii* Blume (figueira benjamin).
- *Fraxinus angustifolia* 'Raywood' Vahl (Raywood ash).
- *Fraxinus excelsior* 'Hessei' L. (Hesse ash).
- *Fraxinus holotricha* Koehne (Moraine ash).
- *Fraxinus pennsylvanica* Marshall (green ash).
- *Fraxinus uhdei* (Wenz.) Lingelsh. (evergreen ash).
- *Fraxinus velutina* Torr. (velvet ash).
- *Ginkgo biloba* L. (gingko).
- *Gleditsia triacanthos* L. (honeylocust).
- *Jacaranda mimosifolia* D. Don (jacaranda).
- *Koelreuteria paniculata* Laxm. (goldenrain tree).
- *Lagerstroemia indica* L. (common crapemyrtle).
- *Liquidambar styraciflua* L. (sweetgum).
- *Liriodendron tulipifera* L. (tulip tree).
- *Platanus × acerifolia* (Aiton) Willd (London planetree).
- *Platanus racemosa* Nutt. (California sycamore).
- *Podocarpus macrophyllus* (Thunb.) Sweet (yew podocarpus).
- *Prunus caroliniana* (Mill.) Aiton (Carolina laurelcherry).
- *Prunus cerasifera* Ehrh. (cherry plum).
- *Pyrus calleryana* Decne (Callery pear).
- *Pyrus kawakamii* Hayata (evergreen pear).
- *Quercus agrifolia* Née (California live oak).
- *Quercus ilex* L. (holly oak).
- *Schinus molle* L. (California peppertree).
- *Schinus terebinthifolius* Raddi (Brazilian peppertree).
- *Sequoia sempervirens* (Lamb. ex D. Don) Endl. (coast redwood).
- *Ulmus americana* L. (American elm).
- *Ulmus parvifolia* Jacq. (Chinese elm).
- *Washingtonia robusta* H. Wendl. (Mexican fan palm).
- *Zelkova serrata* (Thunb.) Makino (Japanese zelkova).

Figures 5 and 6 on page 210 provide an overall view of the relationships between shade factor and diameter at breast height (DBH) and shade factor and age. In the abstract section, the authors note that the relationship is highly nonlinear for both variables.

Supplementary material provided by the authors (see https://data.mendeley.com/datasets/wz8fd94288/1) includes a set of tables that contain the values needed to compute shade factors. The computation uses a multistep process, described as follows:

> Ideally, the user will have a DBH [value], as the best model relies on DBH. The user will select a DBH value from Table S1 and then add to it the corresponding species/climate value from Table S2. If the user does not have a DBH value, but has an age value, she can proceed with the same process using Tables S3 and S4. Table S5 contains the species-

> climate combinations associated with each shade density class and Table S6 provides the species code for each taxon. Table S7 provides the codes for each climate zone.

"Measuring and Estimating the Below-Canopy Light Environment in a Forest: A Review," Alvaro Promis, *Revista Chapingo, Serie Ciencias Forestales y del Ambiente*, Vol. 19, No. 1, pages 139-146, May 2013.
https://www.researchgate.net/publication/236789716_Measuring_and_estimating_the_below-canopy_light_environment_in_a_forest_a_review
This article describes the instruments, techniques and methods used to measure or estimate below-canopy solar radiation. While upper-canopy trees are the vectors for creating the shade, they can be thought of as analogous to bridges and other transportation infrastructure when measuring shade impacts to riparian environments. *From the article's conclusion*:

> There are several methods, techniques and instruments that have different properties to measure or estimate the light environment within a forest. However, it is impossible to decide which one is better. The decision of selecting a particular method will depend on the question to be answered, the nature of the problem and the desired accuracy of the measurement or estimation. For example, for trends on general aspects it would be appropriate to have an understanding of the canopy cover, but if one wants to specifically study the survival or growth of regeneration plants, methods, techniques and instruments providing greater accuracy in estimating the light environment would be required. Therefore, it becomes necessary to review existing information before buying or purchasing the equipment. Thus, an informed decision can be taken on what wavelength, method, technique and instrument can best meet the research requirements.

"Photoreceptor Signaling Networks in Plant Responses to Shade," Jorge Casal, *Annual Review of Plant Biology*, Vol. 64, pages 403-427, April 2013.
Citation at https://www.annualreviews.org/doi/abs/10.1146/annurev-arplant-050312-120221
This article examines how the quality of light, or wavelength, is critical to understanding shade tolerance as light spectra can vary depending on the time of day or season of the year. *From the abstract*:

> The dynamic light environment of vegetation canopies is perceived by phytochromes, cryptochromes, phototropins, and UV RESISTANCE LOCUS 8 (UVR8). These receptors control avoidance responses to preclude exposure to limiting or excessive light and acclimation responses to cope with conditions that cannot be avoided. The low-red/far-red ratios of shade light reduce phytochrome B activity, which allows phytochrome-interacting factors (PIFs) to directly activate the transcription of auxin-synthesis genes, leading to shade-avoidance responses. Direct PIF interaction with DELLA proteins links gibberellin and brassinosteroid signaling to shade avoidance. Shade avoidance also requires constitutive photomorphogenesis 1 (COP1), a target of cryptochromes, phytochromes, and UVR8. Multiple regulatory loops and the input of the circadian clock create a complex network able to respond even to subtle threats of competition with neighbors while still compensating for major environmental fluctuations such as the day-night cycles.

"Shade Tolerance, a Key Plant Feature of Complex Nature and Consequences," Fernando Valladares and Ülo Niinemets, *Annual Review of Ecology, Evolution and Systematics*, Vol. 39, pages 237-257, December 2008.
Citation at https://doi.org/10.1146/annurev.ecolsys.39.110707.173506
From the abstract: Light gradients are ubiquitous in nature, so all plants are exposed to some degree of shade during their lifetime. The minimum light required for survival, shade tolerance, is a crucial life-history trait that plays a major role in plant community dynamics. There is

consensus on the suites of traits that influence shade tolerance, but debate over the relative importance of traits maximizing photosynthetic carbon gain in low light versus those minimizing losses. Shade tolerance is influenced by plant ontogeny and by numerous biotic and abiotic factors. Although phenotypic plasticity tends to be low in shade-tolerant species (e.g., scant elongation in low light), plasticity for certain traits, particularly for morphological features optimizing light capture, can be high. Understanding differential competitive potentials among co-occurring species mediated by shade tolerance is critical to predict ecosystem responses to global change drivers such as elevated CO_2, climate change and the spread of invasive species.

"Plant Productivity in Response to LED Lighting," Gioia Massa, Hyeon-Hye Kim, Raymond Wheeler and Cary Mitchell, *HortScience*, Vol. 43, No. 7, pages 1951-1956, December 2008.
http://hortsci.ashspublications.org/content/43/7/1951.full.pdf+html
This article suggests a possible approach to investigating whether artificial lighting from LED light sources could be used as a mitigative measure for shade impacts. While this study focuses on crops, the examination of light requirements (including wavelength specificity) essential for plant growth could inform mitigation practices associated with transportation improvements.
From the abstract:

> Light-emitting diodes (LEDs) have tremendous potential as supplemental or sole-source lighting systems for crop production both on and off earth. Their small size, durability, long operating lifetime, wavelength specificity, relatively cool emitting surfaces, and linear photon output with electrical input current make these solid-state light sources ideal for use in plant lighting designs. Because the output waveband of LEDs (single color, nonphosphor-coated) is much narrower than that of traditional sources of electric lighting used for plant growth, one challenge in designing an optimum plant lighting system is to determine wavelengths essential for specific crops. Work at NASA's Kennedy Space Center has focused on the proportion of blue light required for normal plant growth as well as the optimum wavelength of red and the red/far-red ratio. The addition of green wavelengths for improved plant growth as well as for visual monitoring of plant status has been addressed.

Influence of Shading on Riparian Water Temperature

The following resources examine the negative and positive impacts of shade on water temperature. These impacts include the reduction of photosynthesis in stream plants, which affects fish habitat and insect productivity. Research suggests that creating shade can have a positive effect by preserving cold water habitat for fish, particularly for streams with temperatures that are increasing due to climate change. Blocking light can also prevent stream eutrophication (such as algal blooms), which may reduce oxygen levels for fish and other species.

"Regulating Riparian Forests for Aquatic Productivity in the Pacific Northwest, USA: Addressing a Paradox," Michael Newton and George Ice, *Environmental Science and Pollution Research,* Vol. 23, pages 1149-1157, 2016.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4713451/pdf/11356_2015_Article_5814.pdf
In this article, investigators discuss the negative effects that shading has on riparian water temperature. Researchers question the current practice in Oregon that limits the harvesting of forest trees in riparian areas to reduce sunlight to the stream, thereby warming the stream and impacting salmon that live in colder water. They argue that opening up forest cover to allow some light to streams helps increase in-stream photosynthesis, aquatic insect production and fish productivity. Lower light levels may maintain colder temperature but reduce productivity. Although bridges are not discussed in this article, the shade impacts from tree canopies could be considered analogous. *From page 1155 of the article (page 7 of the PDF)*:

> Contemporary forest practices have greatly reduced immediate negative impacts, including large water temperature increases observed as a result of historic timber harvesting and management activities. Consideration of how to provide for both productive forests and fisheries is part of both harvesting of timber and fisheries management. There is strong evidence that openings and disturbance in riparian areas can boost cold-water fish production in forest streams. Considering the site-specific conditions of forest reaches, some riparian management, such as creating canopy gaps for enhancement of primary production in cold streams, should be allowed to provide for increased fish food production, and to achieve the long-term silvicultural goals for riparian corridors.

"Seeing the Landscape for the Trees: Metrics to Guide Riparian Shade Management in River Catchments," Matthew Johnson and Robert Wilby, *Water Resources Research*, Vol. 51, No. 5, pages 3754-3769, May 2015.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014WR016802
From the abstract: Rising water temperature (Tw) due to anthropogenic climate change may have serious consequences for river ecosystems. Conservation and/or expansion of riparian shade could counter warming and buy time for ecosystems to adapt. However, sensitivity of river reaches to direct solar radiation is highly heterogeneous in space and time, so benefits of shading are also expected to be site specific. We use a network of high-resolution temperature measurements from two upland rivers in the UK, in conjunction with topographic shade modeling, to assess the relative significance of landscape and riparian shade to the thermal behavior of river reaches. Trees occupy 7 percent of the study catchments (comparable with the UK national average) yet shade covers 52 percent of the area and is concentrated along river corridors. Riparian shade is most beneficial for managing Tw at distances 5–20 km downstream from the source of the rivers where discharge is modest, flow is dominated by near-surface hydrological pathways, there is a wide floodplain with little landscape shade, and where cumulative solar exposure times are sufficient to affect Tw. For the rivers studied, we find that approximately 0.5 km of complete shade is necessary to offset Tw by 1°C during July (the

month with peak Tw) at a headwater site[,] whereas 1.1 km of shade is required 25 km downstream. Further research is needed to assess the integrated effect of future changes in air temperature, sunshine duration, direct solar radiation, and downward diffuse radiation on Tw to help tree planting schemes achieve intended outcomes.

"Rising Stream and River Temperatures in the United States," Sujay Kaushal, Gene Likens, Norbert Jaworski, Michael Pace, Ashley Sides, David Seekell, Kenneth Belt, David Secor and Rebecca Wingate, *Frontiers in Ecology and the Environment*, Vol. 8, No. 9, pages 461-466, November 2010.
Citation at https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/090037
From the abstract: Water temperatures are increasing in many streams and rivers throughout the US. We analyzed historical records from 40 sites and found that 20 major streams and rivers have shown statistically significant, long-term warming. Annual mean water temperatures increased by 0.009–0.077°C yr^{-1}, and rates of warming were most rapid in, but not confined to, urbanizing areas. Long-term increases in stream water temperatures were typically correlated with increases in air temperatures. If stream temperatures were to continue to increase at current rates, due to global warming and urbanization, this could have important effects on eutrophication, ecosystem processes such as biological productivity and stream metabolism, contaminant toxicity, and loss of aquatic biodiversity.

"Model-Based Assessment of Shading Effect by Riparian Vegetation on River Water Quality," Andrea Ghermandi, Veronique Vandenberghe, Lorenzo Benedetti, Willy Bauwens and Peter Vanrolleghem, *Ecological Engineering*, Vol. 35, No. 1, pages 92-104, January 2009.
Citation at https://www.sciencedirect.com/science/article/pii/S0925857408002127
From the abstract: A simulation study was carried out to evaluate the effect of shading on six water quality variables in a moderate-size Belgian river stretch. A dynamic modeling approach making use of the River Water Quality Model No. 1 was chosen to represent the system. The scenarios developed indicate that shading may be an effective tool in controlling stream eutrophication (44 percent reduction in phytoplankton productivity in the simulated stretch) but has a limited effect on dissolved oxygen, chemical oxygen demand, nitrates, ammonium nitrogen, and phosphates. Results suggest that shading can effectively be implemented as a direct management strategy to improve water quality conditions in small and moderate-size watercourses that are exposed to excessive algal growth during summer periods.

Heat Exchange Functions, Chapter 3, *Scientific Literature Review of Forest Management Effects on Riparian Functions for Anadromous Salmonids*, California State Board of Forestry and Fire Protection, September 2008.
See Attachment A.
As the executive summary indicates, this publication produced by Sound Watershed Consulting presents a "comprehensive review of 34 scientific literature articles provided by the Board of Forestry to address a series of Key Questions relevant to riparian management for the protection of threatened and impaired watersheds in State and private forestlands in California."

The executive summary (beginning on page 1 of the report, page 5 of the PDF) highlights key findings:

- [S]hade provided by riparian vegetation is a key factor controlling heat input to streams, even though in-stream water temperatures are governed by a host of other complex physical factors that control heat transfer between air, water, and the streambed.

- There is no single, fixed-width buffer or canopy closure prescription that will provide the desired heat regulation objectives for salmon in all cases. [...]
- The science on heat exchange indicates that water temperature protection could be provided by varying the riparian shade requirements in relation to stream temperature sensitivity. This report provides some examples of approaches tha[t] can be used, and key variables to consider when designing strategies to manage shade in different settings.
- In fish-bearing waters that are directly downstream of headwater streams, the literature indicates that temperature could be positively influenced by providing shaded conditions on headwater stream segments that extend from 500 to 650 ft (150 to 200 m) upstream from the confluence with fish-bearing streams. This distance is based on research findings outside of California, therefore this distance may need to be validated with studies in various California ecoregions.
- The authors' interpretation of the reviewed literature suggests that managing to protect salmonid habitat conditions would require that targets be set for desired stream temperature, and that shade requirements vary in relation to the stream's specific sensitivity to shade as a thermal influence on temperature. The literature indicates that stream temperature is a major factor influencing population performance.

Key information gaps are highlighted on page 32 of the report (page 36 of the PDF). They include establishing criteria for patch treatments such as canopy openings; developing GIS maps for classifying stream temperature sensitivity at the reach/watershed and site scales; assessing the effect of shade provided by shrub cover and understory vegetation; and identifying potential factors influencing the relative sensitivity of water temperature to microclimate variables.

Note: The document cited above was provided by Cajun James, principal research scientist for Sierra Pacific Industries and a member of the technical advisory committee overseeing the research effort that produced the report. James is conducting long-term watershed research studies in the Sierra Nevada and Southern Cascades to determine the effectiveness of different riparian buffer characteristics on biological diversity, near-stream microclimate and water quality.

James noted that the modified Brown's equation discussed in the document (and further described in the 1990 *Watercourse Temperature Evaluation Guide* cited below) would not be as relevant to the small section of a stream impacted by a new or modified bridge. According to the guide, Brown's equation was developed in 1969 as a "simple predictive model for the change in stream temperature if an area was clearcut and the watercourse was left with no buffer strip." James said that the three factors affecting stream temperature—how much water is in the stream, the time of travel of the water in the stream, and the surface area of the stream exposed to solar radiation—are most relevant to large sections of stream frontage and not the relatively short spans impacted by a bridge or other structure.

Contact: Cajun James, Research and Monitoring Manager, Sierra Pacific Industries, 530-378-8151, cjames@spi-ind.com.

Related Resource:

Watercourse Temperature Evaluation Guide, Peter Cafferata, California Department of Forestry and Fire Protection, 1990.
File available for download at
https://www.researchgate.net/publication/272090813_Watercourse_Temperature_Evaluation_Guide/download
From the introduction:

> Despite the significance of streamside shade in the protection of water quality, the factors which affect stream temperatures are poorly understood, and the amount and quality of riparian vegetation which will be left after logging are rarely quantified in the field (Amaranthus 1984). This guide book should help foresters in California assess the impact of management activities on stream temperature. It consists of three parts. First, the physical parameters which affect the amount of solar radiation reaching streams are explained. Second, an effective method to measure shade canopy is presented. Next, a simple predictive model for stream temperature is given. Finally, an example of how the model works is shown.

See page 9 of the PDF for a description of Brown's model; page 10 of the PDF presents a field procedure for using a modified version of Brown's model.

"Recent Advances in Stream and River Temperature Research," Bruce Webb, David Hannah, R. Dan Moore, Lee Brown and Franz Nobilis, *Hydrological Processes*, Vol. 22, No. 7, pages 902-918, March 2008.
Citation at https://onlinelibrary.wiley.com/doi/abs/10.1002/hyp.6994
From the abstract: Research on stream and river temperatures is reviewed with particular attention being given to advances in understanding gained since 1990 and on investigations of fundamental controls on thermal behavior, thermal heterogeneity at different spatial scales, the influences of human impacts, and the nature of past and future trends.

"Keeping It Cool: Unraveling the Influences on Stream Temperature," Jonathan Thompson, *PNW Science Findings*, Issue 73, June 2005.
https://www.fs.fed.us/pnw/sciencef/scifi73.pdf
From the summary: Researchers at the PNW [Pacific Northwest Research] Station have recently conducted experiments and calculated heat budgets that itemize the relative influence of several factors on the water temperature of mountain streams in western Oregon. New technologies allow more detailed measurements of heat fluxes and more accurate determination of the factors affecting stream temperature, allowing management practices to be tailored to minimize their influence on stream ecosystems. Direct solar radiation is the primary contributor to daily fluctuations in water temperature. Managing for shade by maintaining streamside vegetation is an effective way to reduce heat flux. In addition, the type of substrate and the length of time that stream water spends below the stream channel is an important predictor of daily temperature variations. Much remains to be learned about how these factors vary across the landscape.

Shade Impacts on Plant and Aquatic Animal Species

Shade Impacts on Plant Species

The publications in this section address shade impacts to plant species in two topic areas:

- Subsurface vegetation.
- Above-surface vegetation.

Subsurface Vegetation

Influence of Shading on Submerged Aquatic Vegetation from Bridge Structures, Kevin Stallings, Robert Richardson, Brett Hartis, Steve Hoyle, North Carolina Department of Transportation, November 2014.
https://connect.ncdot.gov/projects/research/RNAProjDocs/2012-18FinalReport.pdf
From the abstract: [T]his project was initiated to draft a thorough literature review and to quantify the impact of bridge shading on SAV [submerged aquatic vegetation]. The main objective was to determine if North Carolina Coastal Plain bridges impair SAV growth and presence through shading. A primary vegetation survey indicated that within the study area for all bridges, only a small amount of SAV was detected near bridges or outside the bridge footprint. No SAV was found in the study area around 13 of the 16 bridge sites evaluated. Due to the limited SAV found, secondary surveys were conducted outside of the bridge study areas and these also found minimal SAV in these river systems. No significant differences were observed with regards to bridge orientation; however, as bridge height increased, so did light availability. This suggests that bridges constructed located closer to the water's surface may have greater impacts as reduced light availability could lead to reduced SAV growth within the bridge footprint. Future research should survey larger areas of these river systems to determine the overall abundance and distribution of SAV as SAV appears to be limited in eastern NC [North Carolina] rivers. It may be possible to direct future bridge construction to areas with no SAV and poor SAV habitat thus reducing potential impact.

"Light Requirements for Growth and Survival of Eelgrass (*Zostera marina* L.) in Pacific Northwest (USA) Estuaries," Ronald Thom, Susan Southard, Amy Borde and Peter Stoltz, *Estuaries and Coasts*, Vol. 31, No. 5, pages 969-980, November 2008.
Citation at https://link.springer.com/article/10.1007/s12237-008-9082-3
From the abstract: We developed light requirements for eelgrass in the Pacific Northwest, USA, to evaluate the effects of short- and long-term reductions in irradiance reaching eelgrass, especially related to turbidity and overwater structures. Photosynthesis-irradiance experiments and depth distribution field studies indicated that eelgrass productivity was maximum at a photosynthetic photon flux density (PPFD) of about 350–550 μmol quanta $m^{-2}\ s^{-1}$. Winter plants had approximately threefold greater net apparent primary productivity rate at the same irradiance as summer plants. Growth studies using artificial shading as well as field monitoring of light and eelgrass growth indicated that long-term survival required at least 3 mol quanta m^{-2} day^{-1} on average during spring and summer (i.e., May-September), and that growth was saturated above about 7 mol quanta $m^{-2}\ day^{-1}$. We conclude that non-light-limited growth of eelgrass in the Pacific Northwest requires an average of at least 7 mol quanta $m^{-2}\ day^{-1}$ during spring and summer and that long-term survival requires a minimum average of 3 mol quanta $m^{-2}\ day^{-1}$.

Above-Surface Vegetation

"Modeled Riparian Stream Shading: Agreement with Field Measurements and Sensitivity to Riparian Conditions," Guoyuan Li, C. Rhett Jackson and Kristin Kraseski, *Journal of Hydrology*, Vols. 428-429, pages 142-151, February 2012.
http://coweeta.uga.edu/publications/10673.pdf
Researchers developed models for shade measurement in riparian situations that may have some application to or could be modified to examine shading from transportation improvements such as bridges. As the researchers noted, "SHADE2 is similar to several shade models documented in the literature including SHADE by Chen et al. (1998) and that of DeWalle (2008, 2010)." (See *Related Resources* below for citations to these publications.) They further noted that "the success of SHADE2 implies that these other models also provide accurate time series of instantaneous shade." *From the article's summary*:

> Shading by riparian vegetation and streambanks reduces incident solar radiation on channels, and accurate estimation of riparian shading through the sun's daily arc is a critical aspect of water temperature and dissolved oxygen modeling. However, riparian trees exhibit complex shapes, often leaning and growing branches preferentially over channels to utilize the light resource. As a result, riparian vegetation cast complex shadows with significant variability at the scale of meters. Water quality models necessarily simplify factors affecting shading at the expense of accuracy. All models must make simplifying assumptions about tree geometry. Reach-based models must average channel azimuth and riparian conditions over each reach, and GIS models must also accept errors in the channel-riparian relationships caused by the DEM grid detail. We detail minor improvements to existing shade models and create a model (SHADE2) that calculates shading ratio (%) by riparian canopy at any time and location for given stream characteristics including stream azimuth, stream width, canopy height, canopy overhang, and height of maximum canopy overhang. Sensitivity of simulated shade to these variables is explored. We also present a new field photographic technique for quantifying shade and use this technique to provide data to test the SHADE2 algorithm. Twenty-four independent shade measurements were made in eight channels with mature hardwood riparian trees at different times of the summer and at different times of the day. Agreement between measured and modeled shade was excellent, with r^2 of 0.90.

Related Resources:

> **"Modeling Stream Shade: Riparian Buffer Height and Density as Important as Buffer Width,"** David R. DeWalle, *Journal of the American Water Resources Association*, Vol. 46, No. 2, pages 323-333, April 2010.
> https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2010.00423.x
> *From the abstract*: A theoretical model was developed to explore impacts of varying buffer zone characteristics on shading of small streams using a path-length form of Beer's law to represent the transmission of direct beam solar radiation through vegetation. Impacts of varying buffer zone height, width, and radiation extinction coefficients (surrogate for buffer density) on shading were determined for E-W and N-S stream azimuths in infinitely long stream sections at 40°N on the summer solstice. Increases in buffer width produced little additional shading beyond buffer widths of 6-7 m for E-W streams due to shifts in solar beam pathway from the sides to the tops of the buffers. Buffers on the north bank of E-W streams produced 30% of daily shade, while the south-bank buffer produced 70% of total daily shade. For N-S streams an optimum buffer width was less-clearly defined, but a buffer width of about 18-20 m produced about 85-90% of total predicted shade. The model results supported past field studies showing buffer widths of 9-11 m were sufficient for stream

temperature control. Regardless of stream azimuth, increases in buffer height and extinction coefficient (buffer density) were found to substantially increase shading up to the maximum tree height and stand density likely encountered in the field. Model results suggest that at least 80% shade on small streams up to 6-m wide can be achieved in mid-latitudes with relatively narrow 12-m wide buffers, regardless of stream azimuth, as long as buffers are tall (≈30 m) and dense (leaf area index ≈6). Although wide buffers may be preferred to provide other benefits, results suggest that increasing buffer widths beyond about 12 m will have a limited effect on stream shade at mid-latitudes and that greater emphasis should be placed on the creation of dense, tall buffers to maximize stream shading.

"Guidelines for Riparian Vegetative Shade Restoration Based Upon a Theoretical Shaded-Stream Model," David R. DeWalle, *Journal of the American Water Resources Association*, Vol. 44, No. 6, pages 1372-1387, December 2008.
https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2008.00230.x
From the abstract: Guidelines for riparian vegetative shade restoration were developed using a theoretical model of total daily radiation received by a shaded stream. The model assumed stream shading by nontransmitting, vertical or overhanging, solid vegetation planes in infinitely long reaches. Radiation components considered in the model were direct beam shortwave on the stream centerline, diffuse atmospheric shortwave, shortwave reflected by vegetation, atmospheric longwave, and longwave emitted by vegetation. Potential or extraterrestrial shortwave irradiation theory was used to compute beam shortwave radiation received at the stream centerline, and view factor theory was used to compute diffuse radiation exchange among stream, vegetation, and atmospheric planes. Model shade effects under clear skies were dominated by reductions in receipt of direct beam shortwave radiation. Model shade effects with cloudy skies were dominated by the "view factor effect" or the decreases in diffuse shortwave and longwave radiation from the atmosphere balanced against increases in longwave radiation from vegetation. Model shade effects on shortwave radiation reflected by vegetation were found to be negligible. The model was used to determine the vegetation height (H) to stream width (W) ratios needed to achieve 50, 75, and 90 % shade restoration for mid-latitude conditions on clear and cloudy days. Ratios of vegetation height to stream width, for dense nontransmitting vegetation, generally ranged from 1.4 to 2.3 for 75% shade restoration at a mid-latitude site (40°N). The model was used to show H/W needed for E-W vs. N-S stream azimuths, varying stream latitudes between 30° and 50°N, channels with overhanging vegetation, channels undergoing width changes, as well as the limits to shade restoration on very wide channels.

"Stream Temperature Simulation of Forested Riparian Areas: I. Watershed-Scale Model Development," Yongqin David Chen, Robert F. Carsel, Steven Mccutcheon and Wade L. Nutter, *Journal of Environmental Engineering*, Vol. 124, No. 4, pages 304-315, April 1998.
https://www.researchgate.net/profile/Steven_Mccutcheon/publication/245300016_Stream_Temperature_Simulation_of_Forested_Riparian_Areas_I_Watershed-Scale_Model_Development/links/0f317537cc3ae94b26000000/Stream-Temperature-Simulation-of-Forested-Riparian-Areas-I-Watershed-Scale-Model-Development.pdf
From the abstract: To simulate stream temperatures on a watershed scale, shading dynamics of topography and riparian vegetation must be computed for estimating the amount of solar radiation that is actually absorbed by water for each stream reach. A series of computational procedures identifying the geometric relationships among the sun position, stream location and orientation, and riparian shading characteristics were used to develop a computer program called SHADE. The SHADE-generated solar radiation data are used by the Hydrologic Simulation Program-FORTRAN (HSPF) to simulate hourly stream

temperatures. A methodology for computing the heat flux between water and streambed was selected, evaluated, and implemented in the HSPF code. This work advances the state of the art in watershed analysis by providing a quantitative tool for relating riparian forest management to stream temperature, which is a vital component of aquatic habitat. This paper describes the modeling strategies, the SHADE program in terms of algorithms and procedures, the integration of SHADE with HSPF, and the algorithms and evaluation of the bed conduction of heat. A companion paper presents an application of the SHADE-HSPF modeling system for the Upper Grande Ronde watershed in northeast Oregon.

Note: The citations and table below provide information about the shade tolerance of the California native plants of interest to Caltrans.

PLANTS Database, Natural Resources Conservation Service, U.S. Department of Agriculture, December 2018.
https://plants.sc.egov.usda.gov/java/
From the web site: The PLANTS Database provides standardized information about the vascular plants, mosses, liverworts, hornworts and lichens of the U.S. and its territories.

Calscape, California Native Plant Society, 2018.
https://www.calscape.org/
This web site allows users to enter an address or click on a map to identify the plants native to that location. The site describes each plant and its natural setting, and offers landscaping information. The Advanced Search tool allows users to search for plants suitable for part or full shade.

Shade Tolerance and General Characteristics of California Tree Species[1]

Plant Species	Shade Tolerance	General Description	Characteristics
Arroyo willow (*Salix lasiolepis*)	Intolerant	https://plants.sc.egov.usda.gov/core/profile?symbol=SALA6	https://plants.usda.gov/java/charProfile?symbol=SALA6
Sandbar (narrowleaf) willow (*Salix exigua*)	Intermediate	https://plants.sc.egov.usda.gov/core/profile?symbol=SAEX	https://plants.sc.egov.usda.gov/java/charProfile?symbol=SAEX
Goodding's willow (*Salix gooddingii*)	Intolerant	https://plants.sc.egov.usda.gov/core/profile?symbol=SAGO	https://plants.sc.egov.usda.gov/java/charProfile?symbol=SAGO
Pacific willow (*Salix lucida* Muhl. ssp. *lasiandra*)	Intolerant	https://plants.usda.gov/core/profile?symbol=SALUL	https://plants.usda.gov/java/charProfile?symbol=SALUL
White alder (*Alnus rhombifolia*)	Tolerant	https://plants.usda.gov/core/profile?symbol=ALRH2	https://plants.usda.gov/java/charProfile?symbol=ALRH2

Shade Tolerance and General Characteristics of California Tree Species[1]			
Plant Species	**Shade Tolerance**	**General Description**	**Characteristics**
Boxelder (*Acer negundo*)	Tolerant	https://plants.sc.egov.usda.gov/core/profile?symbol=ACNE2	https://plants.sc.egov.usda.gov/java/charProfile?symbol=ACNE2
Valley oak (*Quercus lobata*)	Intolerant	https://plants.sc.egov.usda.gov/core/profile?symbol=QULO	https://plants.sc.egov.usda.gov/java/charProfile?symbol=QULO
Fremont cottonwood (*Populus fremontii*)	Intolerant	https://plants.usda.gov/core/profile?symbol=POFR2	https://plants.usda.gov/java/charProfile?symbol=POFR2
Black cottonwood (*Populus balsalmifera* L. ssp. *trichocarpa*)	Intolerant	https://plants.usda.gov/core/profile?symbol=POBAT	https://plants.usda.gov/java/charProfile?symbol=POBAT
Buttonbush (*Cephalanthus occidentalis*)	Tolerant	https://plants.usda.gov/core/profile?symbol=CEOC2	https://plants.usda.gov/java/charProfile?symbol=CEOC2

1 The links in this table are taken from the PLANTS Database provided by the Natural Resources Conservation Service.

Shade Impacts on Aquatic Animal Species

Research addressing the shade impacts to aquatic animal species and their habitat is presented below. See also **Influence of Shading on Riparian Water Temperature** (page 7 of this report) for publications that examine water temperature impacts on fish and fish habitat.

Nearshore Habitat: How Bank Armoring and Overwater Structures Shape the Health of Pacific Salmon and Steelhead, National Oceanic and Atmospheric Administration, Spring 2012.
http://www.westcoast.fisheries.noaa.gov/publications/habitat/fact_sheets/nearshore_habitat.pdf
This document provides links to other resources that describe how bank armoring and overwater structures affect the health of nearshore habitat.

“Human Impacts to River Temperature and Their Effects on Biological Processes: A Quantitative Synthesis,” Erich Hester and Martin Doyle, *Journal of the American Water Resources Association,* Vol. 47, No. 3, pages 571-587, June 2011.
Citation at https://doi.org/10.1111/j.1752-1688.2011.00525.x
From the abstract: Land-use change and water resources management increasingly impact stream and river temperatures and therefore aquatic organisms. Efforts at thermal mitigation are expected to grow in future decades. Yet the biological consequences of both human thermal impacts and proposed mitigation options are poorly quantified. This study provides such context for river thermal management in two ways. First, we summarize the full spectrum of human thermal impacts to help thermal managers consider the relative magnitudes of all impacts and mitigation options. Second, we synthesize biological sensitivity to river temperature shifts using thermal performance curves, which relate organism-level biological processes to temperature.

This approach supplements the popular use of thermal thresholds by directly estimating the impact of temperature shifts on the rates of key biological processes (e.g., growth). Our results quantify a diverse array of human thermal impacts, revealing that human actions tend to increase more than decrease river temperatures. Our results also provide a practical framework in which to quantify the sensitivity of river organisms to such impacts and related mitigation options. Finally, among the data and studies we synthesized, river organisms appear to be more sensitive to temperature above than below their thermal maxima, and fish are more sensitive to temperature change than invertebrates.

Assessing and Mitigating Dock Shading Impacts on the Behavior of Juvenile Pacific Salmon (*Oncorhynchus* spp.): Can Artificial Light Mitigate the Effects?, Kotaro Ono, Charles Simenstad, Jason Toft, Susan Southard, Kathryn Sobocinski and Amy Borde, Washington State Department of Transportation, July 2010.
https://www.wsdot.wa.gov/research/reports/fullreports/755.1.pdf
Researchers conducted this study at Port Townsend Ferry Terminal, which is located in an area where Puget Sound narrows before opening into the Strait of Juan de Fuca. This area "is a convergence place for many juvenile salmon species and populations that originate from Puget Sound and Hood Canal." Figure 3, Depth Profile at Port Townsend Ferry Terminal (m), on page 18 of the report (page 32 of the PDF) provides a visual description of the overwater structure studied in this project. *From the abstract*:

> The shadows from large over-water structures built on nearshore habitats in the Puget Sound can reduce prey abundance and disrupt juvenile Pacific salmon (*Oncorhynchus* spp.) migratory behavior with potential consequences on survival rates. As part of an ongoing project to reduce the effects of ferry terminals on juvenile salmon, this study looked at the effectiveness of a fiber optic lighting system at mitigating dock shading impacts on juvenile salmon behavior. We conducted intensive visual observations, snorkel surveys, and video filming surveys … to test whether migrating salmon reacted to changes in light beneath the terminal and whether evident reactions by the salmon were moderated by the fiber optic lighting system.
>
> We found that during high tides shoals of juvenile salmon (primarily pink salmon *O. gorbuscha*) were reluctant to swim under the dock and also under the shaded areas. … As a consequence of this dock avoidance behavior, ferry terminals likely delay migration for some juvenile salmon (pink salmon) by several hours per dock encounter, during high tide periods, daylight hours and on sunny days.
>
> Our results also indicated that light transmitted or installed under some old and new terminals could mitigate dock shading impacts on juvenile salmon. However, our experience testing both fiber optic-transmitted natural and in situ artificial (halogen) light suggests that such light mitigation systems will need to (1) be more powerful, (2) be regulated to light only shaded areas, (3) operate on a natural light spectrum, and (4) distribute light over a wide area. … The use of artificial light is a promising mitigation method because fish appeared to respond at a low light level. However, our results were not sufficient to determine whether artificial light could completely mitigate the effects of the dock and eliminate juvenile salmon avoidance behaviors.

Overwater Structures and Non-Structural Piling, Washington Department of Fish and Wildlife, December 2006.
https://wdfw.wa.gov/publications/00995/wdfw00995.pdf
From the executive summary:

> The literature review conducted for this white paper identified 12 impact mechanisms [including shading] associated with the construction and operation of overwater structures and non-structural piling that could potentially affect aquatic species being considered for coverage under the HCP [Habitat Conservation Plan] ("potentially covered species"). … Following a brief description of overwater structures and non-structural piling activities and potential impact mechanisms, the 52 aquatic species being considered for coverage under the HCP are described. Based on this information, the risks of direct and indirect impacts to the potentially covered species or their habitats are discussed. In addition, the potential for cumulative impacts is discussed, and the risks for incidental take of potentially covered species is qualitatively estimated. The white paper then identifies data gaps (i.e., instances in which the data or literature are insufficient to allow conclusions on the risk of take). The white paper concludes by providing habitat protection, conservation, mitigation and management strategies consisting of actions that could be taken to avoid or minimize the impacts of overwater structures and non-structural piling.

Beginning on page 11-1 of the report (page 146 of the PDF), the researchers present guidelines and strategies to address shade impacts that appeared in previous research in this topic area, including:

- Increase the height of overwater structures to allow light transmission under the structures.
- Decrease structure width to decrease the shade footprint.
- Align the structure in a north-south orientation to allow the arc of the sun to cross perpendicular to the structure, which reduces the duration of light limitation each day.
- Use the smallest number of pilings possible, allowing more light beneath the structure.
- Use grated surfaces or include openings in the deck surface to pass light, as opposed to prisms.
- Design and construct overwater structures to allow incidental light to penetrate as far under as possible, while still providing the necessary capacity and safety considerations necessary to support their intended function.
- Experiment with technologies and designs that can soften the light-dark edge to minimize potential temporary inhibition of movement.
- Decrease the dark-edge effect as much as possible to encourage daytime movement under terminals and other overwater structures.
- Investigate fish feeding behavior during temporary delays of movement.
- Avoid a net increase in overwater coverage in a lake system.
- Restrict new and replacement piers to a 3.5-foot-wide cantilever bridge that spans the nearshore area to a narrow moorage structure of the minimum size necessary to moor a boat.
- Grate cantilever bridge structures and construct them as high off the water as practicable.

- Construct moorage structures with no less than 24 inches above the ordinary high water line.
- Remove floating structures after boating season.
- Study prisms and grating to determine their efficacy at providing sufficient ambient light for macrophyte production under piers. (A macrophyte is defined as a plant, especially an aquatic plant, large enough to be seen by the naked eye.)

Practices and Guidelines

The following resources illustrate how state and local agencies are using mitigation plans and guidelines to address the impacts of shading. The most comprehensive document—a 2009 resource from the Washington Department of Fish and Wildlife—provides information about mitigation techniques for use in both freshwater and marine environments.

"How to Effectively Assess Bridge Shading Impacts," Dudek, February 20, 2018.
http://dudek.com/effectively-assess-bridge-shading-impacts/
From the blog post:

> The Edinger Street Bridge replacement project in Huntington Beach required the Orange County Public Works Department to confront the prospect of mitigating for permanent impacts to tidal salt marsh habitat. The [c]ounty's first site assessment identified permanent shade impacts outside of the bridge footprint. After performing a second assessment of the site conditions, our habitat restoration experts concluded that natural regrowth was highly likely.
>
> We successfully negotiated a mitigation plan with the California Coastal Commission that recognized temporary impacts previously thought to be permanent and allowed for passive restoration of temporary impact areas with appropriate monitoring and potential adaptive measures. Thus, the project significantly reduced the acreage of off-site wetlands establishment in the coastal zone.

Related Resources:

Addendum to Coastal Development Permit No. 5-15-0148: Habitat Mitigation and Monitoring Plan (HMMP) for the Edinger Bridge Replacement Project, California Coastal Commission, July 7, 2015.
https://documents.coastal.ca.gov/reports/2015/7/th20c-7-2015.pdf
Pages 1 through 4 of this addendum address modifications to the June 2014 Habitat Mitigation and Monitoring Plan for the Edinger Bridge Replacement Project. (The plan does not appear to be publicly available.)

2017 Annual Report: Nature Reserve of Orange County, Natural Communities Coalition, 2017.
https://occonservation.org/wp-content/uploads/mdocs/Draft%202017%20Annual%20Report%20v2%20reduced%20size.pdf
Table 3 of Section 8.3 (page 43 of Section 8.3, page 181 of the PDF) provides information about the 2017 installation of the Edinger Bridge over Bolsa Chica Channel:

Description of the Mitigation: Creation of 1.26 acres of Salt Marsh and 0.10 acres of Transitional Brackish Marsh.

Installation Date: December 2017.

Performance Standards Summary by Year 5:

- 80% minimum container plant survival.
- 5% maximum non-native plant cover.
- 65% native plant cover.

Performance Standards Status: To be determined after first year of monitoring is complete.

Current Status: Initial site grading in December 2017; planting has not occurred yet.

Residential Dock Guidelines, Oregon Department of Fish and Wildlife, February 2016.
https://www.dfw.state.or.us/lands/docs/Dock_Guidlines.pdf
Oregon Department of Fish and Wildlife developed guidelines for residential docks to reduce the adverse effects of these structures on Oregon's waterways and minimize potential impacts to fish, wildlife and habitat resources. The references section (beginning on page 5) lists publications that address the impacts of overwater structures.

SR 520, I-5 to Medina: Bridge Replacement and HOV [High-Occupancy Vehicle] Project, Conceptual Wetland Mitigation Report, Washington State Department of Transportation, February 2011.
https://www.wsdot.wa.gov/sites/default/files/2018/06/19/SR520ReportFEISConceptualWetlandsMitigationPlan022011.pdf
This plan addresses mitigation efforts associated with the riparian vegetation community. Highlighted below are sections of the report that may be of particular interest:

From *5.3.7, Mitigation Site Design* on page 100 of the report (page 116 of the PDF):

> WSDOT proposes a total of 3.46 acres of riparian enhancement at the Arboretum Creek Mitigation Site. This enhancement will include mitigation actions in both wetland and upland habitats along Arboretum Creek and the associated hillside seeps. Specific construction activities may include minor grading/contouring, replanting native wetland and upland plant species, and control of non-native species on the site. The proposed mitigation will be developed in consultation with the Arboretum and Botanical Garden Committee (ABGC) and will be consistent with the Arboretum's goals and master plan (Seattle Parks and Recreation 2001). Figure 7 illustrates the mitigation concept for the Arboretum Creek site.

See Table 16 on page 105 (page 121 of the PDF) for a description of the enhanced riparian buffers.

From *5.5.7, Mitigation Site Design* on page 131 of the report (page 147 of the PDF):

> At this site, WSDOT proposes to establish 2.47 acres of forested, scrub-shrub, and emergent wetland and to enhance 2.02 acres of forested riparian buffer along the Cedar River. Specific construction activities may include setback of the existing levees, excavation to construct a blind channel on the north side of the Cedar River, excavation/grading/contouring to establish a surface consistent with wetland hydrology, replanting native wetland and upland plant species, and control of non-native species on

the site. Wetland would be established within the proposed levee setback area, and the remaining areas of the site would be revegetated with appropriate forested upland vegetation. Figure 9 illustrates the mitigation concept for the site.

Mitigation Monitoring and Reporting Program for the Chula Vista Bayfront Master Plan, San Diego Unified Port District, May 2010.
https://www.chulavistaca.gov/home/showdocument?id=12355
[Plan begins on page 93 of the PDF.]
See page 156 of the PDF for a discussion of mitigation measures (MM) 4.8-14 and MM 4.8-15 that address mitigation for permanent direct and indirect impacts from bridge shading. Each mitigation measure includes a reference to Table 4.8-8, which provides a breakdown of the required mitigation acreages for all California Department of Fish and Game impacts within the Port's jurisdiction. See *Related Resource* below for the publication containing Table 4.8-8 and additional information about the two mitigation measures (MM 4.8-14 and MM 4.8-15).

Related Resource:

Volume 3: Final Environmental Impact Report, Chula Vista Bayfront Master Plan and Port Master Plan Amendment, San Diego Unified Port District, April 2010.
https://pantheonstorage.blob.core.windows.net/ceqa/Final-Environmental-Impact-Report-EIR-for-the-Chula-Vista-Bayfront-Master-Plan-and-Port-Master-Plan-Amendment-Volume-3.pdf
See page 185 of the PDF for Table 4.8-8, Mitigation Requirements for Proposed Impacts to Jurisdictional Wetland Resources — Port Lands (acres). See also the following detailed descriptions of the two mitigation measures highlighted in the preceding publication:

- *Mitigation Measure 4.8-14* (page 188 of the PDF). Mitigation Measure 4.8-14 shall be implemented to reduce the indirect and direct impacts to CCC wetlands from circulation road/bridge construction and improvement during Phase I within both the Port's and City's jurisdiction (see Significant Impacts 4.8-22, 4.8-23, 4.8-32, and 4.8-33) to a level of less than significant.
- *Mitigation Measure 4.8-15* (page 189 of the PDF). Mitigation Measure 4.8-15 shall be implemented to reduce the direct permanent and temporary impacts to CCC wetlands during program-level phases within the Port's jurisdiction (see Significant Impacts 4.8-24 through 4.8-26) to a level of less than significant.

Compiled White Papers for Hydraulic Project Approval Habitat Conservation Plan (HCP), Washington Department of Fish and Wildlife, March 2009.
https://wdfw.wa.gov/publications/00803/wdfw00803.pdf
These white papers prepared in connection with a programmatic multispecies Habitat Conservation Plan provide specific information on shading impacts from bridge projects and other improvements, as well as detailed information on mitigation techniques in both freshwater and marine environments. Below are report elements specific to riparian vegetation:

- Page 7-3 of the report (page 120 of the PDF) for shade impacts to fish and fish habitat.
- Page 7-11 of the report (page 128 of the PDF) for nonfood shade effects.
- Page 7-49 of the report (page 166 of the PDF) for ambient light and shade.
- Page 7-53 of the report (page 170 of the PDF) for shade in freshwater systems.
- Page 7-55 of the report (page 172 of the PDF) for shade in marine environments.

- Page 7-170 of the report (page 287 of the PDF) for riparian vegetation and large woody debris modifications.
- Page 8-9 of the report (page 387 of the PDF) for cumulative impacts of permitted structures on riparian vegetation.
- Page 8-13 of the report (page 391 of the PDF) for cumulative impacts of riparian vegetation modification.
- Pages 9-8 and 9-42 of the report (pages 412 and 446 of the PDF) for general risk of take from riparian vegetation and large woody debris modifications.
- Page 10-12 of the report (page 648 of the PDF) for riparian vegetation modifications data gaps.
- Page 11-14 of the report (page 686 of the PDF) for recommended habitat protection, conservation and mitigation strategies for riparian and shoreline vegetation.