APPENDIX G: COMMENT LETTERS RECEIVED

Awan, Afifa@SLC

From: Katherine Perez <canutes@verizon.net>
Sent: Tuesday, June 16, 2015 8:49 PM
To: Awan, Afifa@SLC
Subject: Re: Notice of Intent to Adopt A Mitigated Negative Declaration for the Georgia Pacific Gypsum Antioch Wharf Upgrade Project

Afifa Awan,

It is the recommendation of the tribe to have the propose project (Georgia Pacific Gypsum Antioch Wharf Upgrade project) monitored by both a qualified archaeological firm and native american monitor.

Katherine Perez
MLD
Nototomne Cultural Preservation
cell: (209) 649-8972 or
office: (209) 887-3415
canutes@verizon.net

On Tuesday, June 16, 2015 4:46 PM, "Awan, Afifa@SLC" <Afifa.Awan@slc.ca.gov> wrote:

To All Interested Parties,

Please find attached the Notice of Intent to Adopt A Mitigated Negative Declaration (MND) for the Georgia Pacific Gypsum Antioch Wharf Upgrade Project. The MND can be downloaded from http://www.slc.ca.gov/Division_Pages/DEPM/Reports/Antioch_Wharf/Antioch_Wharf.html. This notice provides the date of the California State Lands Commission meeting that will consider the subject Project.

Sincerely,

Afifa Awan
Environmental Scientist
California State Lands Commission
100 Howe Avenue, Suite 100-South
Sacramento, CA 95825-8202
Desk: (916) 574-1891
afifa.awan@slc.ca.gov

Central Valley Regional Water Quality Control Board

8 July 2015

Afifa Awan
California State Lands Commission
100 Howe Avenue, Suite 100 South
Sacramento, CA 95825

CERTIFIED MAIL
7014 2870 0000 7535 4296

COMMENTS TO REQUEST FOR REVIEW FOR THE MITIGATED NEGATIVE DECLARATION, GEORGIA PACIFIC GYPSUM ANTIOCH WHARF UPGRADE PROJECT, SCH# 2015062045, CONTRA COSTA COUNTY

Pursuant to the State Clearinghouse's 16 June 2015 request, the Central Valley Regional Water Quality Control Board (Central Valley Water Board) has reviewed the *Request for Review for the Mitigated Negative Declaration* for the Georgia Pacific Gypsum Antioch Wharf Upgrade Project, located in Contra Costa County.

Our agency is delegated with the responsibility of protecting the quality of surface and groundwaters of the state; therefore our comments will address concerns surrounding those issues.

<u>Construction Storm Water General Permit</u>

Dischargers whose project disturb one or more acres of soil or where projects disturb less than one acre but are part of a larger common plan of development that in total disturbs one or more acres, are required to obtain coverage under the General Permit for Storm Water Discharges Associated with Construction Activities (Construction General Permit), Construction General Permit Order No. 2009-009-DWQ. Construction activity subject to this permit includes clearing, grading, grubbing, disturbances to the ground, such as stockpiling, or excavation, but does not include regular maintenance activities performed to restore the original line, grade, or capacity of the facility. The Construction General Permit requires the development and implementation of a Storm Water Pollution Prevention Plan (SWPPP).

For more information on the Construction General Permit, visit the State Water Resources Control Board website at:
http://www.waterboards.ca.gov/water_issues/programs/stormwater/constpermits.shtml.

Phase I and II Municipal Separate Storm Sewer System (MS4) Permits[1]

The Phase I and II MS4 permits require the Permittees reduce pollutants and runoff flows from new development and redevelopment using Best Management Practices (BMPs) to the maximum extent practicable (MEP). MS4 Permittees have their own development standards, also known as Low Impact Development (LID)/post-construction standards that include a hydromodification component. The MS4 permits also require specific design concepts for LID/post-construction BMPs in the early stages of a project during the entitlement and CEQA process and the development plan review process.

For more information on which Phase I MS4 Permit this project applies to, visit the Central Valley Water Board website at:
http://www.waterboards.ca.gov/centralvalley/water_issues/storm_water/municipal_permits/.

For more information on the Phase II MS4 permit and who it applies to, visit the State Water Resources Control Board at:
http://www.waterboards.ca.gov/water_issues/programs/stormwater/phase_ii_municipal.shtml

Industrial Storm Water General Permit

Storm water discharges associated with industrial sites must comply with the regulations contained in the Industrial Storm Water General Permit Order No. 97-03-DWQ.

For more information on the Industrial Storm Water General Permit, visit the Central Valley Water Board website at:
http://www.waterboards.ca.gov/centralvalley/water_issues/storm_water/industrial_general_permits/index.shtml.

Clean Water Act Section 404 Permit

If the project will involve the discharge of dredged or fill material in navigable waters or wetlands, a permit pursuant to Section 404 of the Clean Water Act may be needed from the United States Army Corps of Engineers (USACOE). If a Section 404 permit is required by the USACOE, the Central Valley Water Board will review the permit application to ensure that discharge will not violate water quality standards. If the project requires surface water drainage realignment, the applicant is advised to contact the Department of Fish and Game for information on Streambed Alteration Permit requirements.

If you have any questions regarding the Clean Water Act Section 404 permits, please contact the Regulatory Division of the Sacramento District of USACOE at (916) 557-5250.

---

[1] Municipal Permits = The Phase I Municipal Separate Storm Water System (MS4) Permit covers medium sized Municipalities (serving between 100,000 and 250,000 people) and large sized municipalities (serving over 250,000 people). The Phase II MS4 provides coverage for small municipalities, including non-traditional Small MS4s, which include military bases, public campuses, prisons and hospitals.

Clean Water Act Section 401 Permit – Water Quality Certification

If an USACOE permit (e.g., Non-Reporting Nationwide Permit, Nationwide Permit, Letter of Permission, Individual Permit, Regional General Permit, Programmatic General Permit), or any other federal permit (e.g., Section 9 from the United States Coast Guard), is required for this project due to the disturbance of waters of the United States (such as streams and wetlands), then a Water Quality Certification must be obtained from the Central Valley Water Board prior to initiation of project activities. There are no waivers for 401 Water Quality Certifications.

Waste Discharge Requirements

If USACOE determines that only non-jurisdictional waters of the State (i.e., "non-federal" waters of the State) are present in the proposed project area, the proposed project will require a Waste Discharge Requirement (WDR) permit to be issued by Central Valley Water Board. Under the California Porter-Cologne Water Quality Control Act, discharges to all waters of the State, including all wetlands and other waters of the State including, but not limited to, isolated wetlands, are subject to State regulation.

For more information on the Water Quality Certification and WDR processes, visit the Central Valley Water Board website at:
http://www.waterboards.ca.gov/centralvalley/help/business_help/permit2.shtml.

Regulatory Compliance for Commercially Irrigated Agriculture

If the property will be used for commercial irrigated agricultural, the discharger will be required to obtain regulatory coverage under the Irrigated Lands Regulatory Program.
There are two options to comply:

1. **Obtain Coverage Under a Coalition Group.** Join the local Coalition Group that supports land owners with the implementation of the Irrigated Lands Regulatory Program. The Coalition Group conducts water quality monitoring and reporting to the Central Valley Water Board on behalf of its growers. The Coalition Groups charge an annual membership fee, which varies by Coalition Group. To find the Coalition Group in your area, visit the Central Valley Water Board's website at: http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/app_approval/index.shtml; or contact water board staff at (916) 464-4611 or via email at IrrLands@waterboards.ca.gov.

2. **Obtain Coverage Under the General Waste Discharge Requirements for Individual Growers, General Order R5-2013-0100**. Dischargers not participating in a third-party group (Coalition) are regulated individually. Depending on the specific site conditions, growers may be required to monitor runoff from their property, install monitoring wells, and submit a notice of intent, farm plan, and other action plans regarding their actions to comply with their General Order. Yearly costs would include State administrative fees (for example, annual fees for farm sizes from 10-100 acres are currently $1,084 + $6.70/Acre); the cost to prepare annual monitoring reports; and water quality monitoring costs. To enroll as an Individual Discharger under the Irrigated Lands Regulatory

Program, call the Central Valley Water Board phone line at (916) 464-4611 or e-mail board staff at IrrLands@waterboards.ca.gov.

Low or Limited Threat General NPDES Permit

If the proposed project includes construction dewatering and it is necessary to discharge the groundwater to waters of the United States, the proposed project will require coverage under a National Pollutant Discharge Elimination System (NPDES) permit. Dewatering discharges are typically considered a low or limited threat to water quality and may be covered under the General Order for *Dewatering and Other Low Threat Discharges to Surface Waters* (Low Threat General Order) or the General Order for *Limited Threat Discharges of Treated/Untreated Groundwater from Cleanup Sites, Wastewater from Superchlorination Projects, and Other Limited Threat Wastewaters to Surface Water* (Limited Threat General Order). A complete application must be submitted to the Central Valley Water Board to obtain coverage under these General NPDES permits.

For more information regarding the Low Threat General Order and the application process, visit the Central Valley Water Board website at:
http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2013-0074.pdf

For more information regarding the Limited Threat General Order and the application process, visit the Central Valley Water Board website at:
http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2013-0073.pdf

If you have questions regarding these comments, please contact me at (916) 464-4684 or tcleak@waterboards.ca.gov.

Trevor Cleak
Environmental Scientist

cc: State Clearinghouse unit, Governor's Office of Planning and Research, Sacramento

Awan, Afifa@SLC

From: Rene Urbina <rene.urbina@pw.cccounty.us>
Sent: Wednesday, July 15, 2015 4:25 PM
To: Comments, CEQA@SLC
Cc: Teri Rie
Subject: Georgia Pacifica Gypsum Antioch Wharf Upgrade Project - SCH#2015062045, CSLC File Ref: MND #778; PRC 1589.1; W30204

Hello Afifa Awan,

We received the Notice of Public Review to Adopt a Mitigated Negative Declaration for the Georgia Pacific Gypsum Antioch Wharf Upgrade Project. The project is on the San Joaquin River, offshore from 801 Minaker Drive, City of Antioch. We understand that the project consists of doing some upgrades to the Antioch Wharf on the San Joaquin River. The upgrades consist of removal of some timber breasting and mooring dolphins and wooden walkways, install four steel monopiles below the mudline, and repair one timber piling and twelve stringers on the wharf.

At this time we do not have any comments to submit, since this is a project in the City of Antioch, in an unformed drainage area, and the project would not have a significant impact to the drainage area.

We appreciate the opportunity to comment on this project in regards to drainage matters. If you should have any further questions, you may contact me at (925) 313-2308 or by e-mail at rurbi@pw.cccounty.us.

Thank you,

Rene Urbina, PE
Civil Engineer
Contra Costa County Flood Control & Water Conservation District
Phone: (925) 313-2308
e-mail: rene.urbina@pw.cccounty.us

STOEL RIVES LLP
ATTORNEYS AT LAW

500 Capitol Mall, Suite 1600
Sacramento, California 95814
main 916.447.0700
fax 916.447.4781
www.stoel.com

TIMOTHY M. TAYLOR
tim.taylor@stoel.com

July 15, 2015

VIA FEDERAL EXPRESS

Ms. Afifa Awan
Environmental Scientist
California State Lands Commission
100 Howe Avenue, Suite 100-South
Sacramento, CA 95825-8202

Re: Georgia-Pacific Gypsum Antioch Wharf Upgrade Project Mitigated Negative Declaration, June 2015

Dear Ms. Awan:

The following comments are submitted on behalf of the project applicant, Georgia-Pacific Gypsum LLC (GP) with respect to the above-referenced Mitigated Negative Declaration (MND). GP greatly appreciates the extensive efforts undertaken by State Lands Commission staff to prepare a thorough MND and to bring forward the Wharf Upgrade Project (the Project) for consideration.

In submitting these comments, GP primarily seeks to clarify and expand upon existing points addressed in the MND. In some cases, minor corrections are offered by the applicant or its expert consultants. It is important to note the comments below do not raise new environmental issues or identify any new impacts beyond those covered in the MND. Additionally, the comments do not suggest any changes in the level of significance of previously identified environmental effects, either before or following mitigation.

The comments that follow are presented sequentially, consistent with the issues covered in the MND. All comments are identified by page and line number, as set forth in the left margin.

Attached as Exhibit "A" is the updated "Section 7 Biological Assessment, Antioch Wharf Breasting Dolphin Replacement" (ACOE Project Reference: SPK-2011 00039) (rev. June 2015), prepared by WRA Environmental Consultants on behalf of GP. Exhibit "A" is submitted for inclusion in the record of proceedings, and supplants in full Appendix "D" to the MND.

The applicant offers the following comments:

EXECUTIVE SUMMARY

ES-1:33 to 37 - The text provides that "GP Gypsum proposes to structurally upgrade several wharf components at the existing wharf/ship terminal and meet California Building Code berthing requirements for Marine Oil Terminals, commonly and herein referred to as the Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS)."

It is important to clarify that the GP Gypsum terminal is not a marine oil terminal and is not regulated as a marine oil terminal. The design team elected to use some of the applicable berthing and mooring portions of MOTEMS in the design criteria as MOTEMS is generally considered to be a state of the art marine terminal design code.

ES-1:16 to 19 - GP confirms that all in-water project work will be completed no later than November 30, 2015.

ES-6:1 to 2 - The first sentence should be amended to read, "The proposed upgrades will not result in any changes in the volume of gypsum rock off-loaded at the facility, changes to the terminal capacity, delivery schedules, or onshore Plant capacity or operations."

ES-6:13 - Change "clamshell buck", to "clamshell bucket".

ES-6:12 to 16 - Last sentence - GP will make every effort to completely remove existing piles during project construction. As discussed at our meeting with State Lands permitting and environmental staff on April 15, 2015, however, on occasion during removal operations, the existing piles will break due to age, deterioration, or brittleness. When this occurs, further removal will be attempted by grasping the remaining pile stump with a clamshell bucket. Although GP will attempt to remove all piles in their entirety - at a minimum they will be removed to 3 feet below the mudline. Should a pile break below 3 feet from the mudline, the remaining pile will be left buried in place in order to avoid further disturbance and sediment disruption.

ES-7:14 to 22 - GP believes that the MND slightly overstates the condition of portions of the wharf. While GP is fully committed to upgrading the facility via this project action, the facility is not "so deteriorated that [it] must be repaired". Rather, the facility continues to be operational at this time.

PROJECT DESCRIPTION

2-19:10 to 30 - At line 11 change October to November.

AIR QUALITY

3-22:14 to 3-23:4 - The applicant wishes to clarify this paragraph by re-stating that there will be no potentially significant project-specific impacts to air quality.

3-22:18 to 3-23:4 - The language is unclear. The MND should expressly state that the project is consistent with the City of Antioch General Plan. This consistency determination has been made and is set forth in the MND's land use analysis at page 3-100, section 3.10.3.

Additionally, the Bay Area Air Quality Management District's 2010 Clean Air Plan fully accounts for local land uses, including the existing project, within the cumulative environment. The basin plan assumes construction that does not exceed its daily thresholds.

3-23:2 to 4 - The MND's quantitative assessment of project emissions shows that daily emissions from construction would fall below the daily threshold. That threshold is designed to reduce cumulative impacts to a less-than-significant level. Compliance with the threshold limits assures that the project would not contribute in a cumulatively considerable manner to regional emissions of criteria pollutants.

3-24:4 to 5 - The reference to reaching "the nearest receptor", should be changed to "the nearest sensitive receptor." (See page 3-23, distance to nearest "sensitive" receptor is 1,800 feet.)

BIOLOGICAL RESOURCES

3-30:29 to 3-31:2 - Essential Fish Habitat (EFH) – The Project Area also includes EFH for West Coast Groundfish and Coastal Pelagic Species. The analysis and mitigation provided for impacts to fish habitat and the aquatic environment would mitigate impacts to a less than significant level. No additional mitigation would be necessary for West Coast Groundfish or Coastal Pelagic Species EFH.

3-31:3 to 17; 3-41:17 to 28 - The Project Area does not contain critical habitat for spring-run Chinook salmon. The Project will have no impact to spring-run Chinook salmon critical habitat. An excerpt from the Federal Register that identifies spring-run Chinook salmon critical habitat closest to the Project Area is attached as Exhibit "B."

3-38:8 to 30 - The following point of clarification addresses Lange's metalmark butterfly (LMB) and Project design features that avoid impacts to the species. LMB is addressed in the document, and the following comment is intended to clarify why the Project, as designed and proposed, will have a less than significant impact on LMB.

The Project will avoid impact pile driving during the LMB adult flight season, which ranges from August 1st to September 29th. (Johnson et al. 2007, USFWS 2014, USFWS 2015.) There are no thresholds or standards identified for acoustic impacts to LMB, and acoustic impacts are not identified as a threat to the species. (Richmond et al. 2015.) There is no available science on what effect, if any, above ambient acoustic levels would have on the species life history or physiology. Despite this absence of data, the Project will avoid impact hammer driving during this period so there will be no impact from the Project to adult breeding, feeding, or sheltering.

The proposed period when impact pile driving would occur for the Project is October 1st through November 30th. During this period, the only LMB life stage anticipated to occur within or adjacent to Antioch Dunes National Wildlife Refuge (ADNWR) would be eggs, which remain dormant until the rainy season. (USFWS 2014.) The adult flight season would be over, and larvae generally hatch out in February and the larvae reared in the captive breeding program are not released back to ADNWR until around late June. (USFWS 2012.) Potential Project acoustic levels are not anticipated to affect eggs, as any wind and associated movement of the buckwheat would be much greater than the any potential minor vibrations in air pressure from sound resulting from impact hammer driving. Furthermore, any eggs present would be scattered around the host plants and would therefore receive additional acoustic sheltering from the physical structure of the plants. Thus, the project is anticipated to have a less than significant impact on eggs or larvae.

This Project design feature incorporates measures to protect LMB from potential acoustic effects of impact hammer driving. The Project will not result in the direct loss or modification of habitat for LMB, as all work occurs outside of LMB habitat. Therefore, the Project will have a less than significant impact on LMB.

3-49: Table 3.4-1, top line - Change "The NMFS", to "The MMPA".

3-45:22 to 37 - Sacramento Perch – This species is considered extirpated from its native range, and is only known to persist in small lakes and reservoirs. This species is unlikely to occur in the Project Area and does not require an analysis of potential Project impacts. See the attached paper from Crain and Moyle (2011), regarding Sacramento perch distribution information, attached as Exhibit "C."

3-59:16 to 17 - The project window of August 1 – November 30 does fall within the typical breeding bird window, which runs from February 1 – August 31. The time frame should be clarified that proposed work may occur during the breeding, nesting, and rearing season which extends until August 31 for the area. The mitigation measures identified in MM BIO-9 address this potential impact to breeding birds and mitigates the impact to a less than significant level.

As noted above, the Biological Assessment has been slightly revised, and is attached as Exhibit "A."

MITIGATION MONITORING PROGRAM

5.1:16 to 19 - The following language is overstated and erroneous: "The Project Applicant is responsible for the successful implementation of and compliance with the MMs identified in this MMP. This includes all field personnel and contractors working for the Applicant." The Applicant does not have sole implementation and compliance authority over portions of several mitigation measures, as identified below with emphasis:

The applicant is responsible for seeking all necessary permits/ authorizations needed to comply with the Mitigation Measures imposed and the associated reporting requirements. Other agencies requirements must also be adhered to as part of the MMs.

5-4:MM BIO-3 - "...the Project proponent shall obtain *the California Department of Fish and Wildlife's written approval for a designated Project Biologist.*"

5-8:MM BIO-9 - "The buffer zone may be reduced after *consultation and with concurrence from the California Department of Fish and Wildlife and/or the U.S. Fish and Wildlife Service Division of Migratory Bird Management.*"

5-9:MM CUL-1 - "The final disposition of archaeological, historical, and paleontological resources recovered on State lands under the jurisdiction of the CSLC *must be approved by the Commission.*"

5-9 to 5-10:MM CUL-2 - "[A] qualified Cultural Resources Specialist must be contacted immediately, *who shall consult with the County Coroner*...If human remains are of Native American origin, *the County Coroner shall notify the Native American Heritage Commission within 24 hours of this determination and a Most Likely Descendent shall be identified. No work is to proceed in the discovery area until consultation is complete and procedures to avoid and/or recover the remains have been implemented.*"

For each of the above mitigation measures, implementation and compliance responsibilities are shared amongst the applicant and the other identified entities.

Once again, GP appreciates the opportunity to share these comments with the State Lands Commission. This particular MND has proven to be a complex undertaking, and GP shares with State Lands the desire to provide a comprehensive and thorough assessment of the environmental issues, and appropriate mitigation for all potentially significant impacts. Should there be any questions regarding the above comments, or an interest in further dialogue with the applicant, GP stands ready to do so.

Very truly yours,

Timothy M. Taylor

TMT:eay
Enclosures (Exhs. "A" through "C")

cc: Jennifer DeLeon
Vicki Caldwell
Richard Grassetti

EXHIBIT A

Section 7 Biological Assessment

ACOE Project Reference: SPK-2011 00039
Antioch Wharf Breasting Dolphin Replacement
Georgia-Pacific Gypsum, LLC.
Antioch, Contra Costa County, California

Applicant:

Georgia-Pacific Gypsum LLC
801 Minaker Drive
Antioch, CA 94509

Contact:

Dan Chase
Associate Biologist
chase@wra-ca.com

Original Date:

January, 2015

Revised Dates:

June, 2015

and

May, 2015

ENVIRONMENTAL CONSULTANTS

This page intentionally left blank.

TABLE OF CONTENTS

1.0 INTRODUCTION 1
  1.1 Federally Listed Species Considered (Including Candidate Species) 1
  1.2 Critical Habitat 3
  1.3 Consultation to Date 3
  1.4 Summary of Proposed Action 7
    1.4.1 Action Agency 7
    1.4.2 Applicant, Contacts, and Authorized Agent 7
    1.4.3 Authority 8
    1.4.4 Purpose of Action 8

2.0 EXISTING CONDITIONS 8
  2.1 Action Area Location and Site Description 8
  2.2 Plant Communities 9
  2.3 Surveys for Federal Listed Species and Habitat 9
  2.4 Hydrography 9
  2.5 Current Operations 9

3.0 DESCRIPTION OF THE ACTION TO BE CONSIDERED 10
  3.1 Description of General Activities 10
  3.2 Delineation of Action Area 10
  3.3 Specific Action Description 11
  3.4 Pile Driving Activities 13
  3.5 Avoidance and Minimization Measures 14

4.0 STATUS OF THE SPECIES AND CRITICAL HABITAT IN THE AREA 15
  4.1 General Life History for Green Sturgeon 15
  4.2 General Life History for Chinook Salmon 17
  4.3 General Life History for Steelhead 18
  4.4 General Life History for Delta Smelt 19
  4.5 General Life History for Longfin Smelt 20
  4.6 General Life History for Lange’s Metalmark Butterfly 21

5.0 MANNER IN WHICH ACTION MAY AFFECT SPECIES AND CRITICAL HABITAT 23
  5.1 Analysis of Effects to Listed and Candidate Species 23
    5.1.1 Analysis of Direct Effects to Fish 23
    5.1.2 Analysis of Direct Effects to LMB 30
    5.1.3 Analysis of Indirect Effects to Fish 32
    5.1.4 Analysis of Indirect Effects to LMB 32
    5.1.5 Analysis of Interrelated and Interdependent Effects to Fish 32
    5.1.6 Analysis of Interrelated and Interdependent Effects to LMB 33
    5.1.7 Analysis of Cumulative Effects to Fish 33
    5.1.8 Analysis of Cumulative Effects to LMB 33
  5.2 Analysis of Effects to Critical Habitat 34
    5.2.1 Analysis of Direct Effects 34
    5.2.2 Analysis of Indirect Effects 35
    5.2.3 Analysis of Interrelated and Interdependent Effects 35
    5.2.4 Analysis of Cumulative Effects 35

6.0 DETERMINATION OF EFFECT 35

7.0 REFERENCES 37

LIST OF TABLES

Table 1. Federal listed and candidate species, and critical habitat considered in this document. 2
Table 2. Aquatic Action Area Details 11
Table 3. Summary of Pile Driving Activity.*...13
Table 4. Fish Impact Criteria...24
Table 5. Modeled Extent of Sound Pressure Levels from Impact Driving of One Pile...............25
Table 6. Cumulative SEL levels at 10 meters and Distances to the 187 dB and 183 dB Cumulative SEL Criterion for Pile Driving. 26
Table 7. Permanent Impacts to Shallow Water Habitat 34

LIST OF APPENDICES

Appendix A - Table of Federally-Listed Species for the Area
Appendix B - Project Figures
Figure 1 Project Area Location
Figure 2 Project Overview
Figure 3 California Natural Diversity Database Results
Figure 4 Hydroacoustic Action Area
Figure 5 Wharf Replacement Details
Appendix C – Unattenuated Aquatic Action Area
Appendix D – Hydroacoustic Assessment
Appendix E – Sediment Toxicity Results
Appendix F – Essential Fish Habitat

LIST OF ACCRONYMS AND ABBRIEVATIONS

ACOE	US Army Corps of Engineers
Applicant	Georgia-Pacific Gypsum LLC
CDFW	California Department of Fish and Wildlife
CLSC	California State Lands Commission
dB	decibel
DPS	Distinct Population Segment
ESA	Endangered Species Act
ESU	Evolutionary Distinct Unit
Ft	feet or foot
GP	Georgia-Pacific
LMB	Lange's metalmark butterfly
MHHW	mean higher high water
µP	micro Pascal
m	meters
MOTEMS	Marine Oil Terminal Engineering and Maintenance Standards
NLAA	Not Likely to Adversely Affect
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Association
RMS	root mean square
RWQCB	Regional Water Quality Control Board
SEL	sound exposure level
Wharf	Georgia-Pacific Antioch Wharf
USFWS	US Fish and Wildlife Service

DEFINITION OF TERMS SPECIFIC TO PROPOSED PROJECT

Action - Required activities undertaken for mooring and berthing replacement and wharf repair, including avoidance and minimization proposed for unavoidable impacts.

Action Area - The regions where the Action will take place and additional areas that may be affected by the Action. The Action Area includes the Georgia-Pacific Antioch Wharf and adjacent staging, access, and work areas. The Action Area also includes areas outside the Project Area (see Section 3.0) to demonstrate potential acoustic effects of the Action.

Project Area – The areas where wharf replacement and improvements will take place. The Project Area includes the existing Georgia-Pacific Antioch Wharf structure and breasting dolphins to be demolished or removed, and the replacement wharf walkway structures, mooring dolphins, and breasting dolphins, along with adjacent staging, access, and work areas.

1.0 INTRODUCTION

The purpose of this Biological Assessment is to describe the proposed construction activities associated with required upgrades at the Georgia-Pacific Antioch Wharf (Action) located in Antioch, Contra Costa County, California (Wharf, Figure 1) in sufficient detail to determine to what extent the proposed Action may affect any of the threatened, endangered, or candidate species listed in Appendix A that are likely to be present in the Action Area, and any designated or proposed critical habitat in the Action Area. This Biological Assessment was originally submitted to U.S. Army Corps of Engineers (ACOE) on January 16, 2015, **was revised May 6, 2015 to address additional species concerns for U.S. Fish and Wildlife Service (USFWS), and has since been revised a third time as required by ACOE.**

On behalf of the Applicant, Georgia-Pacific Gypsum LLC (GP or Applicant), WRA, Inc. (WRA) submits this Biological Assessment to the Sacramento Corps Regulatory Division to accompany the Request for a Minor Impact Letter of Permission Permit for the Antioch Wharf Breasting Dolphins Replacement Project (Project) Reference # SPK-2011-00039. Project activities entail repair of an existing wharf to meet state engineering requirements of the California State Lands Commission (CSLC) Marine Facilities Division and to continue to safely accommodate larger vessels under current shipping contracts (see Figure 2). Based upon the analysis included herein, avoidance and minimization measures are recommended to avoid and limit take or other impacts to the listed species and critical habitat that may be affected by the proposed Action. Of the many species with potential to occur in the general region, only six aquatic species have the potential to occur in the Action Area: Delta smelt (*Hypomesus transpacificus*; Federally Threatened), Central Valley steelhead (*Oncorhynchus mykiss*; Federally Threatened), Southern Distinct Population Segment of green sturgeon (*Acipenser medirostris*; Federally Threatened), Central Valley spring-run Chinook salmon (*O. tshawytscha*; Federally Threatened), Sacramento River winter-run Chinook salmon (*O. tshawytscha*; Federally Endangered), and longfin smelt (*Spirinchus thaleichthys*; Federal Candidate). In addition to the six aquatic species, one terrestrial species, Lange's metalmark butterfly (LMB; *Apodemia mormo langei*) occurs within the Action Area. The Action Area also includes critical habitat for green sturgeon, Central Valley steelhead, and Delta smelt. This Biological Assessment is prepared in accordance with legal requirements set forth under Section 7 of the Endangered Species Act (ESA) (16 U.S.C. 1536 (c)).

1.1 Federally Listed Species Considered (Including Candidate Species)

Species considered in this document are listed in Table 1. Due to the lack of suitable habitat within the Project Area, it was determined that the proposed Action would have no effect on Callippe silverspot butterfly, Conservancy fairy shrimp, longhorn fairy shrimp, vernal pool fairy shrimp, valley elderberry longhorn beetle, vernal pool tadpole shrimp, tidewater goby, California tiger salamander, California red-legged frog, Alameda whipsnake, giant garter snake, Western snowy plover, California clapper rail, California least tern, salt marsh harvest mouse, San Joaquin kit fox, large-flowered fiddleneck, pallid manzanita, Contra Costa wallflower, Santa Cruz tarplant, Contra Costa goldfields or Antioch Dunes evening primrose. These species are not considered in this analysis because the Action is taking place in a freshwater to brackish deepwater subtidal area in the San Joaquin River where no vegetation is present. Furthermore, adjacent vegetated habitats are not documented to support these species.

Table 1. Federal listed and candidate species, and critical habitat considered in this document.

Common name (Scientific name) Federal Status	Effect Determination
Lange's Metalmark Butterfly (*Apodemia mormo langei*) E	**May Affect But Not Likely to Adversely Affect**
Conservancy Fairy Shrimp (*Branchinecta conservation*) E	No Effect
Longhorn Fairy Shrimp (*Branchinecta longiantenna*) E	No Effect
Vernal Pool Fairy Shrimp (*Branchinecta lynchi*) T	No Effect
Valley Elderberry Beetle (*Desmocerus californicus dimorphus*) T	No Effect
Vernal Pool Tadpole Shrimp (*Lepidurus packardi*) E	No Effect
Callippe Silverspot Butterfly (*Speyeria callippe callippe*) E	No Effect
Bay Checkerspot Butterfly (*Euphydryas editha bayensis*) T	No Effect
Green Sturgeon (*Acipenser medirostis*) T	**Likely to Adversely Affect**
Tidewater Goby (*Eucyclogobius newberryi*) E	No Effect
Delta Smelt (*Hypomesus transpacificus*) T	**Likely to Adversely Affect**
Central California Coast Coho Salmon (*Oncorhynchus kisutch*) E	No Effect
Central California Coastal Steelhead (*Oncorhynchus mykiss*) T	No Effect
California Central Valley Steelhead (*Oncorhynchus mykiss*) T	**Likely to Adversely Affect**
Northern California Steelhead (*Oncorhynchus mykiss*) T	No Effect
Central Valley Spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) E	**Likely to Adversely Affect**
Winter-run Chinook Salmon, Sacramento River (*Oncorhynchus tshawytscha*) E	**Likely to Adversely Affect**
Longfin Smelt (*Spirinchus thaleichthys*) FC	**Likely to Adversely Affect**
California Tiger Salamander (*Ambystoma californiense*) T	No Effect
California Red-legged Frog (*Rana aurora draytonii*) T	No Effect
Alameda Whipsnake (*Masticophis lateralis euryxanthus*) T	No Effect
Giant Garter Snake (*Thamnophis gigas*) T	No Effect
Western Snowy Plover (*Charadrius alexandrinus nivosus*) T	No Effect
California Clapper Rail (*Rallus longirostris obsoletus*) E	No Effect
California Least Tern (*Sternula antillarum (=Sterna, =albifrons) browni*) E	No Effect
Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*) E	No Effect
San Joaquin Kit Fox (*Vulpes macrotis mutica*) E	No Effect
Large-flowered fiddleneck (*Amsinckia grandiflora*) E	No Effect
Pallid manzanita (*Arctostaphylos pallida*) T	No Effect
Soft bird's-beak (*Cordylanthus mollis* ssp. *mollis*) E	No Effect
Contra Costa wallflower (*Erysimum capitatum* ssp. *angustatum*) E	No Effect
Santa Cruz tarplant (*Holocarpha macradenia*) T	No Effect
Contra Costa goldfields (*Lasthenia conjugens*) E	No Effect
Antioch dunes evening primrose (*Oenothera deltoides* ssp. *howellii*) E	No Effect
Critical Habitat and Essential Fish Habitat	**Effect Determination**
Green Sturgeon	**Not Likely to Destroy or Adversely Modify**
Central California Coast Steelhead	No Effect
Central Valley Steelhead	**Not Likely to Destroy or Adversely Modify**
Winter-run Chinook Salmon	No Effect
Spring-run Chinook Salmon	No Effect
Delta Smelt	**Not Likely to Destroy or Adversely Modify**

The analysis included herein concludes that the Action may adversely affect green sturgeon, Delta smelt, Central Valley steelhead, spring-run Chinook salmon, winter-run Chinook salmon

(Sacramento River) and longfin smelt. **For Lange's metalmark butterfly, the analysis concludes that the Action may affect, but is not likely to adversely affect the species.** For designated critical habitat of green sturgeon, Central Valley steelhead, and Delta smelt, the Action is not likely to destroy or adversely modify the habitat. The avoidance and minimization measures proposed by the Applicant, along with the beneficial aspects of the Action, will offset effects of the Action and avoid unnecessary take of these species.

1.2 Critical Habitat

Critical habitat is a term defined and used by the Endangered Species Act (ESA) as a specific geographic area that contains features essential for the conservation of a threatened or endangered species and that may require special management and protection. The ESA requires federal agencies to consult with the USFWS and National Marine Fisheries Service (NMFS) to conserve listed species on their lands and to ensure that any activities or projects they fund, authorize, or carry out will not jeopardize the survival of a threatened or endangered species.

Critical habitat is currently designated for green sturgeon, Delta smelt and Central Valley steelhead within the Project Area (Figure 3).

1.3 Consultation to Date

- In 2007, the CSLC Marine Facilities Division notified GP that a condition survey and berthing analysis of the existing wharf was required. In response, a preliminary survey of the terminal and analysis of the existing structures was completed and conceptual design plans were developed to replace the berthing system at the Antioch terminal. A new lease was signed between GP and CSLC in November of 2011. Per the lease, the proposed draft plans for the wharf rehabilitation were submitted on November 21, 2012. In a notice dated February 5, 2013 the CSLC notified GP of their acceptance of the proposed Rehabilitation Plan. Since that time, a feasibility study and preliminary design has been completed. GP will now request regulatory agency authorization, including a Letter of Permission from the Sacramento District ACOE, to structurally upgrade the mooring and berthing system at the existing wharf to meet engineering requirements of the CSLC and to accommodate larger vessels calling at the wharf under current shipping contracts.

- October 23, 2014 a site visit to the Project Area was conducted with Ramon Aberasturi and Mike Finan, ACOE, Bruce Oppenheim, NMFS, and Armin Halston, USFWS. **The Action was discussed, and species and critical habitat that could be affected were discussed. This included fish species and critical habitat, but Lange's metalmark butterfly was not identified as a potential concern by ACOE or USFWS at that time.**

Between January 9 and June 12, 2015, more than 65 email and phone call correspondences occurred between ACOE and WRA. The following section provides a summary of correspondence during that period.

- January 16, 2015 an electronic version of the Biological Assessment was submitted to Ramon Aberasturi, ACOE, with hard copies submitted to ACOE on January 19, 2015.

- January 28, 2015, ACOE requested information on acreage of specific areas within the aquatic Action Area. Requested information was sent to ACOE on January 28, 2015.

- February 4, 2015, ACOE requested additional figures and areas for the aquatic Action Area without pile driving sound attenuation. Requested information was sent to ACOE on February 9, 2015.

- February 9, 2015, ACOE requested information on terrestrial acoustic sound at the closest housing and to what degree the Action may affect those locations. Requested information was sent to ACOE on February 10, 2015.

- March 23, 2015, ACOE requested information on terrestrial acoustic effects of the Action on Lange's metalmark butterfly and requested WRA create a terrestrial Action Area. Lange's metalmark butterfly previously was identified as unlikely to occur or be affected by the Action. On March 25, 2015, the Authorized Agent requested a call with USFWS and ACOE to identify how acoustic effects should be analyzed for the species. March 31, 2015, ACOE informed the Authorized Agent USFWS had not responded and provided some preliminary information on the Lange's metalmark butterfly, anthropogenic sound effects on invertebrates, and a potential minimization measure.

- April 22, 2015, ACOE reported to WRA that USFWS provided ACOE with preliminary information on minimization measures but did not have information on potential sound effects to Lange's metalmark butterfly.

- April 23, 2015, the Authorized Agent provided supplemental information addressing potential effects of the Action on Lange's metalmark butterfly and minimization measures to ACOE. This information was determined to be insufficient by ACOE, and additional potential Action effects on the species non-adult life stage, the catch and release propagation program, and additional minimization measures were requested.

- April 29, 2015, the Authorized Agent provided additional supplemental information addressing potential Action effects to Lange's metalmark butterfly life stages and the use of sound attenuation for terrestrial acoustic noise. ACOE informed the Authorized Agent that USFWS requested a federal agency meeting to discuss the Action and the direct, indirect and cumulative effects to the species and the ongoing catch and release program. ACOE also requested additional information regarding the clarity of the project description with regards to an increase in larger vessel traffic at the dock and the resulting potential for cumulative effects on Lange's metalmark butterfly from future larger vessel traffic.

- **May 1, 2015, ACOE requested additional information on ship traffic at wharf, and on May 5, 2015 requested information if dredging would occur. Information on ship traffic added to the Biological Assessment and no dredging by GP was planned for the Project.**

- **May 6, 2015, the revised Biological Assessment was sent to ACOE to incorporate all of the supplemental information requested and submitted to the ACOE between January 16, 2015 and May 5, 2015, as summarized above.**

- **May 7, 2015, ACOE corresponded that the location and work window for the proposed Action were incorrectly identified based on the 2007 NMFS NLAA. WRA informed ACOE that the Project was not looking for coverage under the 2007 NLAA and once again requested that formal consultation be initiated.**

- **May 15, 2015, ACOE corresponded that formal consultation with USFWS and NMFS had not been initiated, and that the Biological Assessment still remained incomplete. No information was provided on why the Biological Assessment was considered incomplete, but ACOE was still concerned with potential Project effects to Lange's metalmark butterfly.**

- **May 18, 2015, ACOE corresponded that additional information was required for the Biological Assessment by USFWS. May 20, 2015, ACOE provided written comments from USFWS for what additional information to the Biological Assessment was required. ACOE informed WRA that it had forwarded on the Biological Assessment to NMFS for a "quick review". The full email of USFWS correspondence provided by ACOE is provided here:**

> ***"The Service has completed a brief review of the May 2015 Revised Biological Assessment, which you emailed me on May 7, 2015.***
>
> ***As for the proposed project description, it should include more detail concerning pile removal (e.g., what happens if they break and will water jetting be used). The proposed project description should also include a description of how ships utilize the dock, since the purpose of the subject proposed project is to safely accommodate the larger vessels currently accessing the wharf compared to past smaller vessels which the wharf was originally designed.***
>
> ***CNNDB Occurrences, Figure 3, should be revised to included Lange's metalmark butterfly***
>
> ***As for the effects to delta smelt, the BA does a good job of analyzing effects of increased hydroacoustics. The paragraph on turbidity needs to be further developed to include the expected raise and range of increased turbidity (NTUs), and duration of that raise above baseline. The paragraph also states that toxicity levels are not of concern, please provide the benchmark levels that were used and were they for humans or fish? The BA should also include an analysis of indirect effects (which can happen later in time) from gypsum offloading on the Lange's metalmark butterfly.***
>
> ***Due to the Service current priorities (drought and BDCP) and beside[s] a potential meeting with refuge staff, this is limit of technical assistance I can provide the subject proposed project until initiation of consultation.*"**

- **May 22, 2015, ACOE corresponded with concerns of ambient sound levels, that the tabletop levee identified in the Biological Assessment was part of the ADNWR preserve, and that additional discussion on sound propagation was required.**

ACOE also requested that the Action avoid the estimated 7-week flight period for Lange's metalmark butterfly. ACOE and the GP Project team then had a conference call to discuss what information was required to finalize the Biological Assessment. ACOE corresponded following the call that the FWS federal agency meeting has scheduled for May 28, 2015 and brought up additional acoustic concerns to Lange's metalmark butterfly.

- **May 27, 2015, for the ACOE and USFWS agency meeting, WRA provided a short Project summary and proposed minimization measures, responses to the USFWS Project description questions (received May 20, 2015), and outlined a list of questions for USFWS to help finalize the Biological Assessment.**

- **May 29, 2015, ACOE provided notes and a summary of the federal agency meeting with USFWS. ACOE requested additional information be provided for non-industrial human presence at ADNWR and that the Project completely avoid the Lange's metalmark butterfly flight season. ACOE corresponded that the Delta smelt section of the Biological assessment should be bolstered, and that there was not enough information available to support a mitigated decision for Lange's metalmark butterfly.**

- **June 2, 2015, ACOE and the GP Project team conducted a conference call to request to have WRA directly talk with USFWS to clarify what additional information and measures were requested from USFWS to complete the Biological Assessment. ACOE correspondence following the call included USFWS Lange's metal mark butterfly survey reports for 2013 and 2014, and requested additional revisions to the Biological Assessment to include buckwheat locations and information on human presence in ADNWR.**

- **June 4, 2015, WRA corresponded with ACOE outlining the list of revisions identified during the conference call that were required to finalize the Biological Assessment. ACOE responded with additional requested revisions to the Biological Assessment regarding human presence in ADNWR, the year work will be completed, additional documents from USFWS on recent beneficial sand placement at ADNWR, and a USFWS threats assessment document for Lange's metalmark butterfly (this was cited in the revised Biological Assessment previously and provided by ACOE May 6, 2015). ACOE also corresponded that NMFS had reviewed the Biological Assessment and did not have any changes or additions. ACOE informed WRA that formal consultation with both USFWS and NMFS would be required and that it was anticipated to take the full 135 day comment period, from the point formal consultation was initiated**

- **June 9, 2015, ACOE corresponded with concern over additional potential cumulative effects to Lange's metalmark butterfly, and details of volunteer events at ADNWR.**

- **June 12, 2015, ACOE corresponded with a description of information required to complete the Biological Assessment, which included the USFWS email language provided on May 20, 2015. Additional information requested included providing "relevant LMB [Lange's metalmark butterfly] maps and reports" provided by ACOE June 2-4, 2015, to revise the Project schedule, and that "pile driving activity**

may adversely affect the human environment". ACOE also identified that "the Project may adversely affect LMB larvae during pile driving". Additional correspondence from ACOE on June 12, 2015, identifies that the Biological Assessment does not adequately describe documented Lange's metalmark butterfly presence, and it "appears there may be potential for minor variations in air pressure (sound) to affect LMB larvae". ACOE identified there may be "cumulative effects to LMB larvae due to existing gypsum dust of the buckwheat leaf and anticipated minor variations in air pressure (sound) due to the proposed project". ACOE provided additional correspondence on outstanding issues with the Letter of Permission application.

The third revision to the Biological Assessment includes responses for additional requested information from USFWS and ACOE as described above following the submittal of the May 6, 2015 revised Biological Assessment to ACOE.

1.4 Summary of Proposed Action

The proposed Action consists of structural upgrades at the Wharf, including adding, replacing, and removing pilings and decking in order to comply with state engineering requirements of the CSLC and to safely continue accommodating larger vessels currently under shipping contracts. Potential impacts to federal listed species occurring during construction will be minimized by Action design and implementation.

1.4.1 Action Agency

The Action Agency for the proposed Action is the U.S. Army Corps of Engineers.

1.4.2 Applicant, Contacts, and Authorized Agent

The Georgia-Pacific Gypsum LLC is the Applicant and will be responsible for minimization and avoidance measures related to the Antioch Wharf Rehabilitation project. The address and telephone number is:

Georgia-Pacific Gypsum LLC
801 Minaker Drive
Antioch, CA 94956
Contact: Fred Curcio, Antioch Plant Manager
(925) 732-4526

This biological assessment was prepared by WRA, Inc. and serves as the Authorized Agent. Contact information for the Authorized Agent is:

WRA, Inc.
2169-G East Francisco Blvd.
San Rafael, California 94901
Contact: Daniel Chase
(415) 454-8868

Additional information provided for the preparation of this document includes the hydroacoustic assessment prepared by Illingworth & Rodkin, Inc., and engineering design by the Ben C. Gerwick, Inc.. The addresses and telephone numbers are:

Illingworth & Rodkin, Inc.
423 4th Street, Suite S3W
Marysville, California 95901
Contact: Keith Pommerenck
(707) 794-0400

Ben C. Gerwick, Inc. | COWI.
1300 Clay Street, 7th Floor
Oakland, California 94612
Contact: Jack Gerwick
(510) 267-7172

1.4.3 Authority

GP is undertaking the proposed Action as a requirement of CSLC.

1.4.4 Purpose of Action

The intent of the Action is to structurally upgrade the mooring and berthing system at the existing Wharf to meet current standards as required by the CSLC. A condition survey and berthing analysis of the Wharf determined that structural repairs are required to safely continue accommodating larger vessels and was a condition of the renewed lease with CSLC. The structural upgrades are seismically designed in accordance with Chapter 16 of the 2013 California Building Code as well as Chapter 31F of the 2013 California Building Code, in the CLSC Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS).

The above description of the purpose of the Action corrects a clerical error noted in Box 19. Project Purpose, in the Eng Form 4343 signed July 14, 2014, that misidentifies a component of the Project is to “accommodate larger vessels that *will* deliver gypsum to the plant under current shipping contracts”. The use of larger vessels is in place of previously smaller sized vessels and that no increase in the number of vessels, or gypsum volume will occur. Additional information on current operations with regards to larger vessel traffic is provided in Section 2.5.

2.0 EXISTING CONDITIONS

2.1 Action Area Location and Site Description

The Action Area is located in Antioch in northern Contra Costa County, California, just west of Highway 160 and north of Highway 4, on the shore of the San Joaquin River and about two miles west (down river) from the Antioch Bridge (Figure 1). The Project Area is currently a timber wharf that services a gypsum plant for Georgia-Pacific Gypsum LLC (Figure 2). The timber wharf is used for berthing of ships and offloading of gypsum.

2.2 Plant Communities

The Project Area is located in open water and does not contain plant communities. Based on the results of a subsurface exploration performed by Treadwell and Rollo, the site is underlain by river deposits to the maximum depth explored (elevation minus 134 ft Mean Lower Low Water). The river deposits generally consist of stiff to hard clays with varying amounts of sand and medium dense to very dense sand with varying amounts of silt and clay. The top layer sediment consists of stiff to very stiff clay and sandy clay. No rooted submerged aquatic vegetation is present within the Project Area.

The shoreline bordering the southern portion of the Project Area is a steep river bank armored with loose rock and is mostly unvegetated. Small areas of marsh vegetation occur along the waters edge, with more developed vegetation occurring west of the Project Area. Plant species detected along the shoreline include giant reed (*Arundo donax*), bulrush (*Bolboschoenus* spp.), soft rush (*Juncus effuses*), large leather-root (*Hoita macrostachya*), Himalayan blackberry (*Rubus armeniacus*), Hottentot fig (*Carpobrotus edulis*), and arroyo willow (*Salix lasiolepis*). Additionally, a few scattered coast live oak (*Quercus agrifolia*) and Oregon ash (*Fraxinus latifolia*) are found along the upper river bank. South of the Project Area, and extending from the top of the river bank, the upland area is largely ruderal and devoid of vegetation (WBC 2014).

2.3 Surveys for Federal Listed Species and Habitat

WRA searched the California Department of Fish and Wildlife (CDFW) Natural Diversity Database (CNDDB; CDFW 2014) for documented occurrences of federal listed species near the Project Area. Results are presented in Figure 3.

2.4 Hydrography

The bathymetry in the Project Area tapers dramatically from the shoreline to the San Joaquin River navigation area. Water depth at the wharf is approximately 10.7 m (35 ft) Mean Higher High Water (MHHW) (WBC 2014). Current speed based on NOAA's 2014 tidal predictions for the general Project Area are a maximum ebb current of approximately 1.2 knots, and a maximum flow current of 0.7 knots (BCG 2014).

2.5 Current Operations

The Wharf currently serves as a receiving terminal for ocean going vessels offloading gypsum to the Georgia-Pacific plant. **Ships utilizing the dock to offload gypsum first approach the berth under the command of a San Francisco Bar Pilot. Once the ship has berthed, mooring lines are connected to mooring points to secure the vessel. Next, the ship's offloading conveyor is positioned over the wharf hopper. The gypsum is then offloaded and transported to the plant dome storage. Once the gypsum offloading is completed, the mooring lines are released and the vessel departs the berth.**

Specific vessel size used for gypsum delivery is determined by the contracted ocean shipping line. This has resulted in the vessel size currently calling upon the Wharf to vary, as Georgia-Pacific has no control over what vessel is used to deliver the gypsum shipments. For several years, the trend in vessels arriving at the Wharf has been an increase in vessel size, as shipping line companies deliver shipments to more than one location on each trip. Previously, Georgia-Pacific occasionally received a 804 ft vessel, which is the largest size vessel to call at the Wharf past or present, but typically received vessels closer to 600 ft. The smaller 600 ft vessels have been retired and are now replaced with 750 ft vessels. So, instead of an occasional 804 ft vessel and typical 600 ft vessels, the Wharf will now see an occasionally 804 ft vessel and typical 750 ft vessels.

Despite this increase in vessel size, existing channel depth restrictions near the Wharf limits the draft on vessels, as the larger vessels offload cargo at other terminals prior to approaching the Wharf. The amount of gypsum the Georgia-Pacific plant receives will not increase with the Action, as the volume of gypsum that can be stored at the Georgia-Pacific plant is limited by the size of the storage dome. The vessel size, draft, and the amount of traffic that will utilize the Wharf will remain the same as current operations following the completion of the Project. There is no planned dredging for the Wharf, and there is no known dredging anticipated for the federally maintained navigation channel. The Action will result in no change in current terminal capacity or service.

3.0 DESCRIPTION OF THE ACTION TO BE CONSIDERED

3.1 Description of General Activities

General activities involve structural upgrades of the mooring and berthing system that are required to assure structural integrity and seismic stability consistent with MOTEMS requirements and to continue accommodating existing larger vessels currently calling on the Wharf.

3.2 Delineation of Action Area

The Action Area is defined in 50 CFR § 402.02 as, "all areas to be affected directly or indirectly by the Federal Action and not merely the immediate area involved in the action." The delineation of the Action Area accounts for effects associated with ground disturbance, changes to surface water and ground water quantity and quality, air quality effects, lighting effects, and noise disturbance.

For the six aquatic species, managed by NMFS and USFWS, the Action Area includes the location of the proposed mooring and berthing replacement and wharf repair and approximately 1,970 meters[1] radius around the work area (Figure 4). It is anticipated that West Island would act as a barrier to underwater sound generated as a result of the Project, and would therefore prevent the southeast portion of Sherman Island from being affected. Table 2 provides the area for the aquatic Action Area, and more specific areas of Action activity within the aquatic

---

[1] The NOAA Fisheries spreadsheet introduces the concept of "effective quiet." This concept assumes that energy from pile strikes that is less than 150 dB-SEL does not accumulate to cause injury. For any given condition, at some distance, sound attenuates to the level of effective quiet (i.e., 150 dB-SEL). The distance to a 150 dB-SEL for the largest pile being driven with the use of sound attenuation devices was assessed in Illingworth & Rodkin, Inc. (2014) *Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project Underwater Noise Assessment*. This distance is considered the full extent for potential impact of the proposed project.

environment. Additional information on unattenuated, or worst case scenario, hydroacoustic Action Areas are presented in Appendix C.

Table 2. Aquatic Action Area Details

Area	Acreage	Square Feet	Radius (meters)*	Description
Action Area	776.82	33,838,223	1,970	The anticipated maximum distance for 150 dB using attenuation; discussed in greater detail and shown on Fig 4 of the Biological Assessment (BA).
Acoustic Impact Area	49.07	2,137,672	275	The anticipated maximum distance for cumulative SEL of 183 dB using attenuation; discussed in greater detail and shown on Fig 4 of BA.
10m Buffer From Pile Driving Locations	1.18	51,448	10	The anticipated maximum distance for 206 dB using attenuation; 10m buffer applied around each pile driving location.
Above water work - demolition	7.91	344,560	60	Maximum area anticipated for wharf demolition and barge/tug support work area.
Above water work – new construction	6.73	293,302	60	Maximum area anticipated for new construction and barge/tug support work area.

*= Parts of a buffer that extends onto the shore (i.e. out of the channel) was not included in the area calculation as the impact to federal species is aquatic based

For the one terrestrial species managed by USFWS, an additional terrestrial Action Area is provided that includes the wharf repair area and an acoustic radius modeled from sound levels anticipated from impact hammer driving traveling 548 m (1,800 ft) before ambient levels would be reached[2]. This distance was used to identify a terrestrial acoustic Action Area, which encompasses 318 acres over water and land (Appendix B, Supplemental Figure 1). When in a direct line of sight to the pile, sound within the terrestrial Action Area is anticipated to be above ambient conditions during impact hammer driving.

3.3 Specific Action Description

The structural upgrade of the Wharf will involve replacing five of the existing timber breasting and mooring dolphins by constructing new breasting dolphins and mooring dolphins to meet the state engineering requirements of the CSLC Marine Facilities Division, and to continue safely accommodating larger vessels that are delivering gypsum to the plant under current shipping contracts. There will be no expansion of the existing wharf offloading or storage capacity.

[2] Draft Antioch Wharf Initial Study. 2014. Noise

Project activities will include both in-water work (pile removal and pile driving) and over-water work (wharf demolition, new dolphin and walkway construction, and timber repairs), and is described in more detail below.

The wharf upgrade plan entails demolition of five (5) of the existing timber breasting and mooring dolphins (containing a total of 150 14-inch diameter creosote treated timber piles) and replacement by construction of four (4) new breasting dolphins, each with a cone fender system, and three (3) new mooring dolphins, with connecting walkways (Figure 2 and Figure 5). The new dolphins will be hollow core steel monopiles: breasting dolphins at 72-inch diameter with tip elevations of about minus 97 ft (installed about 65 ft below the mudline); mooring dolphins at 42-inch to 48-inch diameter with tip elevations of about minus 56 to minus 61 ft (installed at about 51 to 56 ft below the mudline); and walkway support piles at 24-inch to 30-inch diameter with tip elevations about minus 43 to minus 67 ft (installed about 38 to 48 ft below the mudline). Removal of existing creosote treated timber piles will occur with a clamshell buck or a chain. **If a pile breaks above the mudline, the remaining piece will be reconnected to and removed, likely using a clamshell bucket's jaws to grab the pile. The remaining portion of the pile will then be removed to below the mudline. No water jetting is proposed for use during pile removal.**

Construction will be entirely supported from barges moored in the water. Construction activities and materials will be staged from barges anchored close to the specific work. Two general types of barges will be used during construction – material barges and derrick barges. Material barges typically have a flat deck for optimal loading of materials. These barges will store construction materials such as timber, steel piles, precast concrete, fenders, and handrail and will be secured to the derrick barges. Derrick barges are equipped with revolving cranes built into the barge that will be used for pile driving and removal, and are connected to mooring anchors and spuds used to secure the floating equipment into place during construction. Barges will be positioned around the wharf by tugboats.

All demolition and construction activities are anticipated to occur between August 1 and **November** 30, 2015. During this period, an estimated 24 days of in-water construction is planned. **Within the work window, impact pile driving for the Project will only occur between October 1 and November 30, 2015.** The Action will involve a one-time short duration construction event, and no ongoing project related activity is anticipated.

The original solid deck walkways of the Wharf will be replaced with new light permitting walkway decks constructed of grip strut type planking (expanded metal grating). The total shadowed area has been reduced by 157 square ft by narrowing the walkways. The reduced shadow walkway area extends an estimated 830 square ft over river water at about 9 ft depth or less (< 0.02 acre) and extends an estimated total of 1475 square ft over river water at about 20 ft depth or less (~ 0.03 acre).

Sea-level rise was assessed for the functional lifetime of the rehabilitated Wharf, and this aspect was included in the Project design basis (BCG 2014). The Project engineer's design estimate for the mean sea-level change is based on the "State of California sea level rise interim guidance document" (2010), developed by the Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team, with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust. While the design life of the Wharf is 25 years, the service life is assumed to extend till 2070, about 55 years from construction. During this period, sea-level rise of approximately 2.0 ft is assumed. Modeling the projected sea-level rise, the estimated 25 year significant wave of 2.5 ft for this location, and MHHW; there would still be about 4.0 ft of clearance between the water and the deck. The fenders have been located at an elevation that is compatible with current as well as future water levels. Additionally, all of the steel components in or near the splash zone are specified to have coatings or galvanizing to protect them from corrosion.

During a routine above-water inspection to verify geometry for design, damage to an existing timber pile and approximately 12 existing timber stringers was noted. To mitigate the damage to the timber pile, GP plans to install a fiberglass sleeve around the damaged pile and fill the annulus with cementitious grout. The addition of new stringers adjacent to the damaged stringers is also planned so that the new stringers can transfer the load to the cap beams below. Repairs to the structure will happen concurrently with the construction of the replacement portions of the wharf.

3.4 Pile Driving Activities

The contractor and Applicant's engineer anticipate using vibratory and impact hammers to drive the piles. It is estimated that each pile will require approximately 15 minutes of vibratory driving and 100 to 700 blows with an impact hammer to drive the piles to their final elevation (Illingworth & Rodkin 2014). It is anticipated that an APE 400 vibratory hammer and a Delmag D160 diesel impact hammer would be required to drive the 42-inch, 48-inch, and the 72-inch piles; while the 24-inch and the 30-inch walkway piles will be installed using an ICE 44 vibratory hammer and a Delmag D62 diesel impact hammer (Illingworth & Rodkin 2014).

For the vibratory hammer, each pile is estimated to be driven 30 ft in approximately 15 minutes. Impact hammer driving would then be used until the pile reaches its required depth, and is anticipated to result in 20 blows per foot. The project is anticipated to install one (1) pile per day for the 72-inch piles and up to two (2) piles per day for all other piles. An estimated 24 days of in-water construction is planned. **All pile driving activities are anticipated to occur between October 1 and November 30, 2015.** A description of the type of pile to be driven and their location is provided in Table 3 and Figure 5.

Table 3. Summary of Pile Driving Activity.*

Location Name		Total Pile Quantity	Diameter (inches)	Pile Embedment Depth (feet)	Estimated Number of Pile Strikes
Breasting Dolphin Piles	BD1, BD2, BD3, BD4	4	72	65	700
Mooring Piles	MD1, MD2	2	42	51	420
	MD3	1	48	56	520
Walkway Piles	WB1	1	24	38	160
	WB2, WB6	2	24	48	360
	WB3, WB4, WB5	3	30	35	100

* Table modified from Illingworth & Rodkin 2014

3.5 Avoidance and Minimization Measures

The applicant proposes a number of avoidance and minimization measures to reduce the potential for take of listed fish species. Prior to construction, a construction employee education program will be conducted to discuss potential listed species on the site. At minimum, the program will consist of a brief presentation by persons knowledgeable in listed species biology and legislative protection to those personnel performing in-water work within the Action Area. Contractors, their employees, and agency personnel will undergo sensitive species training prior to involvement with construction activities in the Project Area. The program will include the following:

- A description of the species and their habitat needs,
- Reports of occurrences in the Project Area,
- An explanation of the status of each listed species and their protection under the ESA, and
- A list of measures being taken to reduce potential effects to the species during construction and implementation.

Fact sheets conveying this information will be prepared for distribution to the above-mentioned people and anyone else involved with in-water work activities in the Project Area. Records of sensitive species training will be retained by the approved biologist.

For all work being performed:

1) Standard construction best management practices (BMPs) will be implemented during demolition and construction. BMPs used on site will include:
   a) A Spill Prevention and Control Plan will be developed and will contain measures to prevent and control potential spills of hazardous materials associated with mechanical equipment (oil, gas, hydraulics, etc.), as well as measures to minimize contact with the stream bed, such as work pads. The Plan and materials necessary to implement it will be accessible on site;

   b) A debris containment boom will be installed around the work area. Any debris discharged into water will be recovered immediately.

Methods proposed for use during above-water construction for the avoidance and minimization of potential hydroacoustic effects to Lange's metalmark butterfly include:

1) Impact pile driving will not occur from August 1 through September 29 to correspond with the adult flight season and survey period.

Methods proposed for use during in-water construction for the avoidance and minimization of potential hydroacoustic effects to fish include:

2) All in-water work shall be performed within the environmental work window for the San Francisco Bay Delta between August 1 and November 30.

3) A vibratory hammer will be used to start the installation of each pile, and will continue as long as geotechnical conditions permit. Vibratory hammer use will be conducted without sound attenuation minimization measures.

4) Underwater sound monitoring shall be performed during pile driving activities. Accumulated sound exposure levels (SEL) shall adhere to the incidental take SEL limits permitted by NMFS and USFWS. All incidents of exceedance of the SEL standard shall be reported to the permitting agency within 24 hours. Underwater sound reduction measures will include one or more of the following:
    a) use of a bubble curtain surrounding piles during pile driving operations;
    b) use of an impact hammer cushion block;
    c) use of impact hammers only during daylight hours;
    d) gradually increasing energy and frequency of impacts to permit wildlife to vacate the surrounding area; and
    e) installation of pipe caisson with a vibratory hammer to isolate piles from the water column.

5) A qualified biologist will monitor pile driving activity. Any injury or mortality of listed fish, along with the SEL, will be reported to the permitting agency within 24 hours.

6) All water quality protection requirements identified in the 401 certification for the Project will be followed.

4.0 STATUS OF THE SPECIES AND CRITICAL HABITAT IN THE AREA

The life history information presented below is largely taken from the *Supplemental Biological Opinion for the Completion of Pile Driving and Other Remaining Activities* (NMFS, Southwest Region, August 21, 2009) and further informed by the Services Reinitiation of Formal Endangered Species Consultation and Amendment to the Biological Opinion (File # 1-1-96-F-40) for the New Benicia Martinez Bridge Project (January 9, 2001), the 2008 Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project and State Water Project, and the 2001 NMFS Biological Opinion for the San Francisco-Oakland Bay Bridge East Span Seismic Project.

4.1 General Life History for Green Sturgeon

The Southern Distinct Population Segment (DPS) of green sturgeon was listed as threatened by the NMFS on April 7, 2006 (71 FR 17757). Critical habitat for the species was designated on October 9, 2009 (74 FR 52300). A 5-year status review of green sturgeon was completed on October 24, 2012; that review affirmed the need to retain green sturgeon as a threatened species.

Like all sturgeon, North American Green sturgeon are anadromous, long-lived, and a slow growing species (Adams et al. 2002). Along the Pacific Coast, North American Green sturgeon have been documented offshore from Ensenada, Mexico to the Bering Sea, Alaska and found in freshwater rivers from the Sacramento River to British Columbia (Moyle 2002). Two DPS of green sturgeon have been identified along the western coast of North America, and are known to occur in near shore marine waters, and are commonly observed in coastal bays, estuaries, and coastal marine waters from southern California to Alaska (Lindley el al. 2008). Of the two DPS, only the southern DPS is listed as a threatened species under the ESA. The southern DPS is designated as populations originating from coastal watersheds south of the Eel River (California) where the only known spawning population is in the Sacramento River (50 CFR part 226).

The life cycle of southern DPS green sturgeon can be broken into four distinct phases based on developmental stage and habitat use: (1) larvae and post-larvae less than 10 months of age; (2) juveniles less than or equal to three or four years of age; (3) coastal migrant females between three or four and thirteen, and males between three or four and nine years of age; and (4) adult females greater than or equal to thirteen years of age and males greater than or equal to nine years of age (Nakamoto et al. 1995).

Confirmed spawning populations of North American green sturgeon currently are found in only three river systems, the Sacramento and Klamath Rivers in California, and the Rogue River in southern Oregon (Erickson el al. 2002, Farr and Kern, 2005). During the late summer and early fall, sub-adults and non-spawning adult Green sturgeon frequently can be found aggregating in estuaries along the Pacific coast (Emmett el al. 1991). Relatively large concentrations occur in the Columbia River estuary, Willapa Bay and Grays Harbor, with smaller aggregations in San Francisco Estuary (Emmett et al. 1991, Moyle et al. 1992).

Green sturgeon may migrate long distances upstream to reach spawning habitat. Southern DPS green sturgeon adults typically begin their upstream spawning migrations into the San Francisco Bay by late February to early March, reach Knights Landing by April, and spawn between March and July (Heublein 2006). Peak spawning is believed to occur between mid-April to mid-June and thought to occur in deep, fast water (> 3 m), of large rivers (Emmett et al. 1991, Adams et al. 2002). Recent data regarding adult southern DPS green sturgeon has been collected from monitors located from the Golden Gate Bridge to the upper Sacramento River. Some fish that entered the estuary continued to the Sacramento River to spawn. Spawning has been documented on the mainstem over 240 miles upstream, both upstream and downstream of the Red Bluff Diversion Dam (Brown, 2007). Based on the distribution of sturgeon eggs, larvae, and juveniles in the Sacramento River, CDFG (2002) indicated that southern DPS green sturgeon spawn in late spring and early summer above Hamilton City possibly to Keswick Dam.

Adults captured in the Sacramento-San Joaquin Delta are known to feed on invertebrates such as shrimp, mollusks, amphipods, and additionally upon small fish (Adams el al. 2002). Juvenile green sturgeon in the San Francisco Estuary have been shown to feed on opossum shrimp (*Neomysis mercedie*) and amphipods (*Corophium spp*.) (Moyle 2002). Juvenile distribution and habitat use is still largely unknown, and juveniles are presumed present year round in all parts of the San Francisco Bay Estuary (Israel and Klimley 2008).

The waters adjacent to the Project Area provide a migratory corridor, and possibly rearing habitat for this species. Spawning habitat is not supported in the area; however, the species may still occur seasonally. Additionally, the Project Area contains critical habitat for this species.

4.2 General Life History for Chinook Salmon

There are two Evolutionarily Significant Units (ESU) of Chinook salmon designated for protection under the ESA. The Sacramento River winter-run Chinook salmon was reclassified from threatened to endangered by NMFS on January 4, 1994 (59 FR 440) and was reaffirmed as endangered on June 28, 2005 (70 FR 37160). Critical habitat for the species was originally designated on June 16, 1993 (58 FR 33212). The Central Valley spring-run Chinook salmon was listed as threatened by NMFS on September 16, 1999 (64 FR 50394) and was reaffirmed on June 28, 2005 (70 FR 37160). Critical habitat for spring-run Chinook salmon was designated on September 2, 2005 (70 FR 52488).

Chinook salmon runs are designated on the basis of adult migration timing; however, distinct runs also differ in the degree of maturation at the time of river entry, thermal regime and flow characteristics of their spawning site, and actual time of spawning (Myers et al. 1998). Both winter-run and spring-run Chinook salmon tend to enter freshwater as immature fish, migrate far upriver, and delay spawning for weeks or months. For comparison, fall-run Chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of rivers, and spawn within a few days or weeks of freshwater entry (Healey 1991). Adult Sacramento River winter-run Chinook salmon enter San Francisco Bay from November through June (Hallock and Fisher 1985), and delay spawning until spring or early summer. Adult Central Valley spring-run Chinook salmon enter the Sacramento Delta beginning in January and enter natal streams from March to July (Myers et al. 1998). Central Valley spring-run Chinook salmon adults enter freshwater in the spring, hold over summer, and spawn in the fall. Central Valley spring-run Chinook salmon juveniles typically spend a year or more in freshwater before migrating toward the ocean. Adequate in-stream flows and cool water temperatures are more critical for the survival of Central Valley spring-run Chinook salmon due to over-summering by adults and/or juveniles.

Sacramento River winter-run Chinook salmon spawn primarily from mid-April to mid-August, peaking in May and June, in the Sacramento River reach between Keswick Dam and the Red Bluff Diversion Dam. Central Valley spring-run Chinook salmon typically spawn between September and October depending on water temperatures. Chinook salmon generally spawn in gravel beds that are located at the tails of holding pools (USFWS 1995). Eggs are deposited within the gravel where incubation, hatching, and subsequent emergence take place. The length of time required for eggs to develop and hatch is dependent on water temperature, and quite variable. Sacramento River winter-run Chinook salmon fry (newly emerged juveniles) begin to emerge from the gravel in late June to early July and continue through October (Fisher 1994). Central Valley spring-run Chinook salmon fry emerge from November to March and spend about 3 to 15 months in freshwater prior to migrating towards the ocean (Keljson et al. 1981). Post-emergent fry seek out shallow, near shore areas with slow current and good cover, and begin feeding on small terrestrial and aquatic insects and crustaceans.

In the Sacramento River and other tributaries, juveniles often migrate downstream from December through March (Moyle 2002). Fry may spend time rearing within riverine and/or estuarine habitats including natal tributaries, the Sacramento River, non-natal tributaries to the Sacramento River, and the Delta. Within estuarine habitat, juvenile Chinook salmon movements are generally dictated by tidal cycles, following the rising tide into shallow water habitats from the deeper main channels, and returning to the main channels when the tide recedes (Levy and Northcote 1982; Levings 1982; Healey 1991). Juvenile Chinook salmon forage in shallow areas with protective cover, such as intertidal and subtidal mudflats, marshes, channels and sloughs (McDonald 1960, Dunford 1975).

As juvenile Chinook salmon increase in length, they tend to school in the surface waters of the main and secondary channels and sloughs, following the tides into shallow water habitats to feed (Allen and Hassler 1986). Keljson et al. (1981) reported that juvenile Chinook salmon demonstrated a diel migration pattern, orienting themselves to near shore cover and structure during the day, but moving into more open, offshore waters at night. The fish also distributed themselves vertically in relation to ambient light. During the night, juveniles were distributed randomly in the water column, but would school up during the day into the upper three meters of the water column. Juvenile Sacramento River winter-run Chinook salmon migrate to the sea after only rearing in freshwater for four to seven months, and occur in the delta from October through early May (CDFG 1998). Most Central Valley spring-run Chinook salmon smolts are present in the delta from mid-March through mid-May depending on flow conditions (CDFG 2000).

The waters adjacent to the Project Area provide a migratory corridor and juvenile rearing and foraging habitat for spring-run Chinook salmon, and potential rearing habitat for winter-run Chinook salmon. Spawning habitat is not supported in the area; however, each species may still occur seasonally. The Project Area does not contain critical habitat for either ESU of this species.

4.3 General Life History for Steelhead

The Central Valley Distinct Population Segment (DPS) of steelhead was originally designated as threatened by NMFS on March 19, 1998 (63 FR 13347) and was reaffirmed on January 5, 2006 (71 FR 834). Critical habitat for the species was designated on September 2, 2005 (70 FR 52488).

Steelhead are an anadromous form of *Oncorhynchus mykiss*, spending some time in both freshwater and saltwater. The older juvenile and adult life stages occur in the ocean, until the adults ascend freshwater streams to spawn. Unlike Pacific salmon, steelhead are iteroparous, or capable of spawning more than once before death (Busby et al. 1996). Eggs (laid in gravel nests called redds), alevins (gravel dwelling hatchlings), fry (juveniles newly emerged from stream gravels), and young juveniles, remain in freshwater until they become large enough to migrate to the ocean to finish rearing and maturing to adults. General reviews for steelhead in California document much variation in life history (Barnhart 1986, Busby et al. 1996, McEwan 2001). Although variation occurs, steelhead usually live in freshwater for two years, then spend one or two years in the ocean before returning to their natal stream to spawn.

Steelhead from the tributaries of San Francisco Bay, typically migrate to freshwater between November and April, peaking in January and February. They migrate to the ocean as juveniles from March through June, with peak migration occurring in April and May (Fukushima and Lesh 1998). Steelhead fry generally rear in edgewater habitats and move gradually into pools and riffles as they grow larger. Cover is an important habitat component for juvenile steelhead, both as a velocity refuge and as a means of avoiding predation (Shirvell 1990, Meehan and Bjorn 1991). Steelhead, however, tend to use riffles and other habitats not strongly associated with cover during summer rearing more than other salmonids. Young steelhead feed on a wide variety of aquatic and terrestrial insects, and emerging fry are sometimes preyed upon by older juveniles. Rearing steelhead juveniles prefer water temperatures of 7.2-14.4 degrees Celsius

(C) and have an upper lethal limit of 23.9 C (Barnhart 1986, Moyle 2002). They can survive in water up to 27 C with saturated dissolved oxygen conditions and a plentiful food supply. Fluctuating diurnal water temperatures also aid in survivability of salmonids (Busby et al. 1996).

Juvenile steelhead emigrate episodically from natal streams during fall, winter, and spring high flows. Emigrating Central Valley steelhead use the lower reaches of the Sacramento-San Joaquin Rivers and the Delta for rearing and as a migration corridor to the ocean. Barnhart (1986) reported that steelhead smolts in California range in size from 140 to 210 millimeter (mm) fork length. Juvenile steelhead in the Sacramento River Basin migrate downstream during most months of the year, but the peak period of emigration occurs in the spring, with a much smaller peak in the fall.

The waters adjacent to the Project Area provide a migratory corridor and juvenile rearing and foraging habitat for this species. Spawning habitat is not supported in the area; however, the species may still occur seasonally. Additionally, the Project Area contains critical habitat for this species.

4.4 General Life History for Delta Smelt

The USFWS proposed to list the Delta smelt as threatened with proposed critical habitat on October 3, 1991 (56 FR 50075). The USFWS listed the Delta smelt as threatened on March 5, 1993 (58 FR 12854), and designated critical habitat for this species on December 19, 1994 (59 FR 65256). The Delta smelt was one of eight fish species addressed in the Recovery Plan for the Sacramento–San Joaquin Delta Native Fishes (USFWS 1995). A 5-year status review of the Delta smelt was completed on March 31, 2004; that review affirmed the need to retain the Delta smelt as a threatened species.

The Delta smelt is a member of the Osmeridae family (northern smelts) (Moyle 2002) and is one of six species currently recognized in the Hypomesus genus (Bennett 2005). The Delta smelt is endemic to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta) in California, and is restricted to the area from San Pablo Bay upstream through the Delta in Contra Costa, Sacramento, San Joaquin, Solano, and Yolo counties (Moyle 2002). Their range extends from San Pablo Bay upstream to Verona on the Sacramento River and Mossdale on the San Joaquin River. The Delta smelt was formerly considered to be one of the most common pelagic fish in the upper Sacramento- San Joaquin Estuary. While aspects of this species life history are known, certain key components of wild fish, such as spawning habitat requirements and locations are less well known and often inferred by laboratory observations, trawl and sample catch locations of spent females and young larvae, and comparisons with similar species (USFWS 2008).

Delta smelt are euryhaline species that generally occur in water with less than 10-12 parts per thousand (ppt) salinity, although they have been collected in San Pablo Bay at 18.5 ppt and in the Carquinez Strait at 13.8 ppt. Collection activities tend to indicate that Delta smelt can spawn in temperatures ranging from 7 to 22 degrees Celsius. Delta smelt tend to be concentrated near the zone where out flowing fresh water and incoming salt water mix (mixing zone). The species inhabit open surface waters of the Delta and Suisun Bay. Delta smelt are found at all life stages in greatest abundance in the top 2 meters of the water column and usually not in close association with the shoreline (USFWS 2004). Delta smelt usually aggregate but do not appear to be a strongly schooling species. Genetic analyses have confirmed that *H. transpacificus* presently exists as a single intermixing population (Trenham et al. 1998).

Spawning occurs in shallow water habitats in the Delta. Adult smelt migrate upstream from brackish water habitat associated with the mixing zone before spawning to disperse into river channels and tidally influenced backwater sloughs. The spawning season varies from year to year, between late winter (December) to early summer (July). Laboratory observations have indicated that Delta smelt are broadcast spawners with sinking (demersal) eggs with adhesive properties. It is postulated that the eggs sink and attach to substrates like tules, tree roots and other submerged vegetation in shallow waters (USFWS 2004). Newly hatched and juvenile Delta smelt forage in shallow waters until they reach 16 to 18 mm in length. Once they develop a swim bladder, they rise up higher into the water column and are washed downstream into the mixing zone. By August juvenile smelt are typically 40-50 mm (USFWS 2004).

Delta smelt feed on planktonic copepods, small crustaceans, amphipods, and to a lesser extent insect larvae. They are fed upon by subadult striped bass (*Morone saxatilis*) and have been found in the stomach contents of black crappie (*Pomoxis nigromaculatus*) and white catfish (*Ameiurus catus*) (USFWS 2004).

This species is known to occur in the waters adjacent to the Project Area; however, shallow water spawning habitat does not occur in or adjacent to the Project Area. The Project Area provides habitat for adult and juvenile Delta smelt. Additionally, the Project Area contains critical habitat for this species.

4.5 General Life History for Longfin Smelt

On August 8, 2007 the USFWS was petitioned to add the longfin smelt to the list of Threatened and Endangered Species. During the most recent review by the USFWS it was determined that the San Francisco Bay-Delta DPS of longfin smelt warranted protection under the Endangered Species Act. However, the USFWS has not yet listed the species, and it remains a candidate species at the federal level (USFWS 2013a).

The longfin smelt is an anadromous fish found in California's bay, estuary, and nearshore coastal environments. The range of longfin smelt extends along the Pacific coast of North America from the Sacramento-San Joaquin estuary in California, north to the Gulf of Alaska. Outside of California the species primarily exists in scattered and isolated bays or estuaries (Moyle 2002). The San Francisco Estuary supports the southern-most longfin smelt population, and the largest population in California (Moyle 2002). Longfin smelt are known to inhabit the entire San Francisco Estuary, including portions of the Napa River, Suisun and Napa marshes, and the Sacramento-San Joaquin Delta (CDFW 2009).

This species is a member of the Osmeridae family (Moyle 2002). Most notably, they are distinguished from other smelts by the large pectoral fins for which they are named. Lifespan of the species is generally two years, but three-years-old smelt have been observed (CDFW 2009). Longfin smelt reach 6-7 cm SL in the first 9-10 months of life. Growth is minimal during their first winter, but the growth rate increases again in their second summer and fall when they reach 9-11 cm SL. The largest members of the species are female fish that may reach up to 15 cm in their third year (Calfish 2014).

The species can tolerate salinities ranging from freshwater to nearly pure seawater. Most longfin smelt occupy the middle or bottom of a water column and tend to favor temperatures in the range of 16-18°C and salinities ranging from 15-30 ppt (Calfish 2014). While longfin smelt encounter a wide variety of water temperatures, and salinities during their life cycle, they are rarely found in water temperatures greater than 22°C (CDFW 2009). Their spatial distribution within a bay or estuary is seasonally variable based on these temperature and salinity tolerances. Longfin smelt can also make daily migrations; remaining deep during the day and rising to the surface at night. Avoiding surface waters during the day helps them avoid predation from birds, marine mammals, and other fish (Calfish 2014). Generally speaking longfin smelt are found closer to the ocean during summer and move into streams during winter months for spawning (Baxter 1999).

Spawning occurs between February and April when fish move into freshwater streams and rivers (Calfish 2014). Spawning areas are generally gravel or sandy substrate where rocks and aquatic plants are present. Spawning occurs at night, and after fertilization, the eggs adhere to plants and gravel in the area. Eggs typically hatch at around 40 days. Winter and spring outflows transport recently hatched larvae downstream to Suisun Bay, San Pablo Bay, and San Francisco (Baxter 1999).

As juveniles longfin smelt feed on copepods and cladocerans. With subsequent growth their diet expands to include mysids and amphipods (CDFW 2009). Longfin smelt are an important prey species and are fed upon by many species of predatory fish. However, striped bass (*Morone saxatilis*) are a dominant predator of longfin smelt in the San Francisco Bay area (CDFW 2009). The other primary threats to the San Francisco Bay population are due mainly to the effects of water diversions from the Delta (Moyle 2002).

This species is known to occur in the waters adjacent to the Project Area; however, shallow water spawning habitat does not occur in or adjacent to the Project Area. The Project Area provides habitat for juvenile rearing and adult migration. Critical habitat for this species has not been designated.

4.6 General Life History for Lange’s Metalmark Butterfly

The USFWS listed Lange’s metalmark butterfly (LMB) as endangered on June 1, 1976 (41 FR 22041 22044). Critical habitat for the species was proposed February 8, 1977 (42 FR 7972 7976); however was never formally designated. LMB is one of three species addressed in the Revised Recovery Plan for Three Endangered Species Endemic to Antioch Dunes, California (USFWS 1984). A 5-year status review of LMB was completed on July 10, 2008; that review affirmed the need to retain the LMB as an endangered species.

LMB is endemic to California, persisting in the wild only in the 67-acre Antioch Dunes National Wildlife Refuge (ADNWR), **and on sand dune habitat immediately adjacent to the ADNWR**. LMB inhabits stabilized dunes and the species’ life cycle is closely tied to its larval food plant, naked stemmed buckwheat (*Erigonum nudum auriculatum*). **As communicated by ACOE, the USFWS presumes presence of LMB where naked stemmed buckwheat occurs (correspondence with ACOE May 29, 2015 and June 12, 2015). This area includes ADNWR and areas immediately to the west (PG&E parcel) and east of the Sardis Unit, as shown in the mapped density of buckwheat in Supplemental Figure 2 (Appendix B). Based on the USFWS 2006 buckwheat density figure, naked stemmed buckwheat occurs in small low density patches in the eastern part of the Georgia-Pacific property. Georgia-Pacific however does not have any knowledge of the locations where the naked-stemmed buckwheat occurs on their property, and no members of the genus *Erigonum* where observed during a 2014 survey of habitat adjacent to the Project Area (WBC 2014). The area USFWS mapped with buckwheat is outside of the Project Area (Figure 2).**

Adults begin to emerge in early August and the mating flight season can last until mid to late September, a period of approximately seven weeks (USFWS 1984, Johnson et al. 2007). Peak flight season usually occurs in the last week of August and first week of September (Johnson et al. 2007). Butterflies of both sexes live for approximately one week, and feed on the nectar of the buckwheat as well as on butterweed (*Senecio flaccidus var. douglasii*), San Joaquin snakeweed (*Gutierrezia californica*), and silver lupine (*Lupinus albifrons*). **Most male LMB are believed to travel only a short distance, less than 90 feet, and female LMB are believed to travel up to 1,200 feet in search nectar plants and buckwheat (correspondence from ACOE on May 29, 2015 and June 2, 2015).** During the flight season, eggs are laid on buckwheat stems. The eggs remain dormant until the rainy season and then the hatched larvae feed on new buckwheat growth during winter and spring. The caterpillars pupate in mid-summer at the base of the buckwheat.

Threats to this species include habitat loss and modification, invasive exotic vegetation, industrial development, wildfires, and herbicides. Historic sand mining initially fragmented and destroyed much of the natural dune habitat in the region. Wildfire, construction, and agricultural activities also contributed to additional habitat loss. Currently, invasive plant species have stabilized the dune structure, inhibiting the growth of the buckwheat, which needs open sand to become established. **Fixation of nitrogen emissions in dune habitats also encourages the growth of invasive plants, which exclude the buckwheat, which has been identified as a threat by USFWS from the nearby Oakley Generating Station (USFWS 2010).** Herbicides used to remove invasive plants from the dunes may affect LMB pupation or have effects on food plant quality. **USFWS has identified gypsum dust as a possible low level threat to LMB eggs, larvae, and host plants;** however, there is no evidence**, let alone available data, nor research** to support dust adversely affecting LMB or their host plant (USFWS 2008, Richmond et al. 2015). A ranking of 17 threats, in order of decreasing importance, identified invasive grasses and forbs and demographic stochasticity as the greatest threats to LMB and gypsum (dust) and butterfly diseases as the least important threats (Richmond et al. 2015). **The complete threat list to LMB, ranked by USFWS and reported in Richmond et al. (2015) in importance from the greatest threat to the least threat, is:**

1) **Invasive grasses and forbs;**
2) **Demographic stochasticity;**
3) **Altered substrate (i.e. reduced open sand areas);**
4) **Nitrogen deposition;**
5) **Wildfire;**
6) **Climate change;**
7) **Altered disturbance regime;**
8) **Loss of nectar plants;**
9) **Increased woody vegetation;**
10) **Vector control;**
11) **Dispersal limitation;**
12) **Development;**
13) **Floristic diversity;**
14) **Host plant disease;**
15) **Predation/parasites;**
16) **Gypsum; and**
17) **Butterfly disease.**

Recovery of the LMB has been aided through a catch and release propagation program which began in August 2007. This collaborative program serves as an insurance against extinction, and includes the USFWS and the LMB working group. The program involves seasonal collection of adult LMB and the rearing and release of larvae back to ADNWR occur annually, along with the propagation of LMB's host plant, the naked-stemmed buckwheat. During the peak flight season in late August or early September, typically five adult females or 10% of the peak flight number are collected (Johnson et al. 2011). The collected adults are moved to Moorpark College propagation lab, where eggs are deposited on naked stemmed buckwheat. Larvae generally hatch out in February, and are reared till their release back to ADNWR, which typically occurs in late June (USFWS 2012a).

In addition to the catch and release propagation program, USFWS leads annual LMB surveys in ADNWR that began in 1986. Surveys consist of ADNWR refuge staff, interns, and volunteers and typically include five to 15 people (USFWS 2015). The survey period starts the first week of August and continues until a zero count is reached. In 2013, survey work continued until September 26th and the peak number of LMB observed was 28 individuals and a total count of 78 LMB was reported (USFWS 2014). For 2014, survey work continued until September 18th and the peak number of LMB observed was 44 individuals and a total count of 139 LMB was reported (USFWS 2015).

The aquatic based Project Area does not contain suitable habitat for LMB. **UFWS has mapped naked stemmed buckwheat within the eastern portion of the Georgia-Pacific property, and assumes presence of LMB where naked stemmed buckwheat occurs; however, this area is outside of the aquatic based Project Area.** The Project Area parcel does fall between the ADNWR; and is approximately 300 m (984 ft) from the eastern boundary of the Stamm Unit (western portion of refuge) and approximately 125 m (410 ft) from the western boundary of the Sardis Unit (eastern portion of the refuge). **Therefore, LMB does not occur within the Project Area, but does occur within the terrestrial Action Area.**

5.0 MANNER IN WHICH ACTION MAY AFFECT SPECIES AND CRITICAL HABITAT

The proposed Action is likely to adversely affect listed species that may be within the Action Area. The proposed Action is not likely to destroy or adversely modify critical habitat within the Action Area.

5.1 Analysis of Effects to Listed and Candidate Species

The following section provides an analysis of potential effects from the proposed Action on listed and candidate species.

5.1.1 Analysis of Direct Effects to Fish

Direct effects are those effects caused directly by the proposed Action that occur on-site within the Project Area and during Action implementation, i.e., ground disturbance within the Action Area.

Potential effects from in-water work to fish species from pile driving activities as well as the Action Area buffer was assessed in the Illingworth & Rodkin, Inc. (2014) *Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project Underwater Noise Assessment*, included in

Appendix D. Pile driving produces underwater noise, which manifests as pressure waves in the aquatic environment. In order to evaluate the potential effect to fishes exposed to elevated levels of underwater sound produced during pile driving, Illingworth & Rodkin assessed the anticipated sound levels calculated from results of measurements from similar projects, along with the threshold established by the Federal Highway Administration (FHWA), California Department of Transportation (Caltrans) and NMFS.

The assessment estimates the levels of underwater sound (peak and root mean square [RMS] pressure, as well as accumulated Sound Exposure Level [SEL]) received by fishes that are exposed to elevated levels of underwater sound produced during pile driving. Distance from each pile that the sound attenuates to threshold levels was determined, and the sound impact was used to compute effects to fish species that are presumed stationary. Sound levels for both attenuated and unattenuated (i.e. no means of reducing underwater sound levels) were provided in the assessment and are addressed below, along with specific distances within which specific thresholds are exceeded. Based on past projects it is estimated that sound levels can be reduced up to 10 dB using a properly deployed attenuation device (Illingworth & Rodkin 2014). Effects are addressed as a condition where fish are assumed to be stationary relative to the pile driving.

In general, species of herring, croakers, and shad are hearing specialists while most other fish are hearing generalists (ICF Jones and Stokes, and Illingworth and Rodkin, Inc., 2009). Sound specialists are likely to be affected by sound to a greater degree than sound generalists, and smaller fish are generally more susceptible to injury from sound than larger fish (ICF Jones and Stokes, and Illingworth and Rodkin, Inc. 2009). As such, the effects that are presented in this section are presumably higher than those that will actually occur during Action activities because:

a) impact calculations were determined using small fish and stationary fish in order to calculate a maximum potential impact area;
b) several of the listed fish species that may occur adjacent to the Action Area use the waters predominantly as a migratory corridor or seasonally for rearing habitat and not spawning, i.e. not stationary; and
c) the currents and river flow adjacent to the Action Area are a detriment to stationary fish activity.

The criteria used for the onset of physical injury and adverse behavioral effects are listed in the table below. The onset of physical injury uses dual criteria - peak pressure and SEL. The onset of physical injury is expected if either of these criteria are exceeded. The criterion for accumulated SEL is based upon the mass of the fishes under consideration. Because Delta smelt and longfin smelt are known to occur within the Action Area, the more conservative 183 dB SEL criterion, which applies when fish smaller than 2 grams are present, may be required

Table 4. Fish Impact Criteria

Effect	Metric	Fish mass	Threshold
Onset of physical injury	Peak pressure	N/A	206 dB (re: 1 μPa)
	Accumulated Sound Exposure Level (SEL)	≥ 2 g	187 dB (re: 1μPa^2•sec)
		< 2 g	183 dB (re: 1μPa^2•sec)
Adverse behavioral effects	Root Mean Square Pressure (RMS)	N/A	150 dB (re: 1 μPa)

The peak sound pressure level, average RMS sound pressure level, and SELs anticipated for impact hammer driving during the Action were predicted using near source levels for impact pile driving and NMFS practical loss sound propagation assumption. NMFS recommends using the Practical Spreading Loss model (TL = 15*log(R1/R0)), unless data are available to support a different model. The extent of sound levels anticipated for the Action are provided in Table 5.

Table 5. Modeled Extent of Sound Pressure Levels from Impact Driving of One Pile[3].

Modeling Scenario	Distance to Marine Mammal Acoustic Criteria in Meters			Distance to Fish Acoustic Criteria in Meters			Distance to Behavioral Zone
	RMS (dB re: 1uPa)			Peak (dB re: 1uPa)	Cumulative SEL[4] (dB re:1uPa-sec2)		RMS (db re:1uPa)
	Level B Harassment	Level A Injury					
	160	180	190	206	187	183	150
72-inch Piles (Pile ID: BD 1-4) Estimated 700 Pile Strikes per Pile							
Modeled Unattenuated	1,970[5]	130	35	30	620[5]	1,065[5]	7,630[5]
Assuming a 10 dB Reduction with Attenuation	510	35	<10	<10	160	275	1,970[5]
48-inch Pile (Pile ID: MD 3) Estimated 520 Pile Strikes							
Modeled Unattenuated	765[5]	50	15	15	155	265	2,955[5]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	40	70	765[5]
42-inch Piles (Pile ID: MD 1&2) Estimated 420 Pile Strikes per Pile							
Modeled Unattenuated	765[5]	50	15	15	135	235	2,955[5]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	35	60	765[5]
30-inch Piles (Pile ID: WB 3-5) Estimated 100 Pile Strikes per Pile							
Modeled Unattenuated	580	40	<10	15	40	70	2,255[5]
Assuming a 10 dB Reduction with Attenuation	150	<10	<10	<10	10	20	580
24-inch Piles (Pile ID: WB 2&6) Estimated 360 Pile Strikes per Pile							
Modeled Unattenuated	510	35	<10	<10	95	160	1,970[5]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	25	40	510

[3] Table from Illingworth & Rodkin 2014

[4] Base on the driving of one pile. SEL criteria apply to impact pile driving events that occur during one day. See Table 5 for predicted accumulated SEL for various daily pile driving scenarios.

[5] Distance to underwater noise thresholds is constrained by river topography

Modeling Scenario	Distance to Marine Mammal Acoustic Criteria in Meters			Distance to Fish Acoustic Criteria in Meters			Distance to Behavioral Zone
	RMS (dB re: 1uPa)			Peak (dB re: 1uPa)	Cumulative SEL[4] (dB re:1uPa-sec2)		RMS (db re:1uPa)
	Level B Harassment	Level A Injury					
	160	180	190	206	187	183	150
24-inch Pile (Pile ID: WB 1) Estimated 160 Pile Strikes							
Modeled Unattenuated	510	35	<10	<10	60	100	1,970[5]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	15	25	510

Accumulated SEL levels associated with impact pile driving from the Action will vary daily and will depend on amount of pile driving. The estimated accumulated SEL levels at 10 meters distance from the pile being driven and the distance to the accumulated 187 dB and 183 dB SEL level with and without an attenuation system are provided in Table 6.

Table 6. Cumulative SEL levels at 10 meters and Distances to the 187 dB and 183 dB Cumulative SEL Criterion for Pile Driving[6].

Modeling Scenario	Total Strikes	Attenuation	Cumulative SEL (dB) at 10 Meters	Distance to 187 dB Cumulative SEL (Meters)	Distance to 183 dB Cumulative SEL (Meters)
One 72-inch pile	700	Unattenuated	217	620[5]	1065[5]
		Attenuated	207	160	275
MD1 (42-inch) & WB1 (24-inch)	580	Unattenuated	207	145	245
		Attenuated	197	40	65
MD2 (42-inch) & WB2 (24-inch)	780	Unattenuated	208	170	290
		Attenuated	198	45	75
BD1 (72-inch) & WB3 (30-inch)	800	Unattenuated	217	585	1005[5]
		Attenuated	207	150	260
WB4 (30-inch) & WB5 (30-inch)	200	Unattenuated	200	60	100
		Attenuated	190	15	25
WB6 (24-inch) & MD3 (48-inch)	880	Unattenuated	209	180	315
		Attenuated	198	50	80

[6] Table from Illingworth & Rodkin 2014

Modeling Scenario	Total Strikes	Attenuation	Cumulative SEL (dB) at	Distance to 187 dB Cumulative	Distance to 183 dB
WB5 (30-inch) & WB6 (24-inch)	460	Unattenuated	204	95	165
		Attenuated	194	25	40

Certain construction elements of the Action could create sound waves that affect fish and marine mammals. It is possible that pile installation could create sound pressure levels in excess of the 180-decibel referenced to one micropascal threshold established by the NMFS. Sound pressure levels become harmful to aquatic wildlife above this threshold. Pile driving that results in sound pressure waves outside the Project Area that exceed the 206-decibel referenced to one micropascal and accumulated sound exposure level (for multiple strikes) of 183 decibels referenced to one micropascal square-second threshold could injure nearby sensitive fish species.

The SEL values for smaller fish were used in order to determine a maximum impact area. The implementation of sound attenuation measures, which include a bubble curtain and an impact hammer cushion block, will reduce the maximum distance the 183 dB threshold would extend for the largest piles being driven from 1,065 meters down to 275 meters. The 275 meter range represents an Acoustic Impact Area (Figure 5) and any fish within that area would be subject to direct effects, or cumulative SEL impacts, of between 183 and 187 dB. The distance where adverse behavioral effects may occur would also be diminished through the use of sound attenuation devices. As identified in Table 5, attenuation will reduce the maximum distance the 150 dB threshold would extend for the largest piles being driven from 7,630 meters down to 1,970 meters. The 1,970 meter range represents the full extent of the Action Area, as fish outside of this range are not anticipated to be effected by the Action.

In addition to the sound attention usage, a soft start will be used at the start of each day pile driving occurs or following a break of one hour or longer in pile driving. The soft start involves the gradual increase of energy and frequency of impacts to permit wildlife to vacate the surrounding area. Because special status fish within the Action Area will be mobile juveniles or adults (as opposed to eggs or larvae which tend to be subject to drift and are not freely mobile), they will have the opportunity to vacate the Acoustic Impact Area before peak sound levels occur.

Utilizing the outlined avoidance and minimization levels is anticipated to reduce sound levels during impact pile driving to levels at or below the 206 dB peak criteria. The cumulative SEL however is still anticipated to exceed the 183 and 187 dB criteria. To reduce the effect of any potential exceedance the cumulative SEL will have, work will be restricted to an environmental work window of August 1 to November 30. The work window is informed by NMFS, USFWS, and CDFW recommendations for avoidance of potential impacts to fish species in this region of the San Francisco Bay Delta. In-water work conducted within the work window will minimize the possibility that work activities may affect fish species as listed fish species are less likely to utilize the Action Area for rearing or migration during this period, and are less likely to occur in a more sensitive life stage (i.e. egg or larvae). Additionally, hydroacoustic and biological monitoring will be conducted during pile driving activity to identify any exceedance in threshold levels and associated observable biological effects to listed fish.

Based on the hydroacoustic assessment, and the minimization measures, temporary direct effects to listed fish are estimated from the **maximum** hydroacoustic impact (using highest sound pressure levels) as follows:

- any fish in the Acoustic Impact Area of 275 meters will be subject to direct effects, or cumulative SEL impacts, of between 183 and 187 dB.
- Fish within ten meters of pile driving may be exposed to peak sound levels of 206 dB.
- Fish within 1,970 meters would be exposed to RMS sound levels of 150 dB.

These direct effects from pile driving activity are anticipated to be temporary, and no ongoing or permanent adverse effects of the Action are anticipated.

Additional in-water work for the removal of existing piles, along with the deployment of spuds from the derrick barge, may contribute to increased water turbidity and mobilization of substrate. Elevated turbidity can impair gill function, reduce oxygen availability in the water column, decrease physiological capabilities, and increase stress in fish (Heath 1995). The increase in turbidity is anticipated to be localized and dissipate quickly due to tidal currents and river flow conditions. Project activities that may result in temporary increases in turbidity are likely to occur with other forms of disturbance or sound generation, such as the movement of tugs and cranes. These disturbances are likely to cause fish to move away from the areas where increases in turbidity would occur, prior to directly being exposed to the turbidity. **While turbidity can impact sensitive life stages of fish, elevated turbidity alone does not represent a uniform impact to protected fish species, as Delta smelt distribution has been correlated with turbidity which can help increase foraging efficiency and decrease predation threat (IEP 2015). Within the Delta, turbidity is generally between 20-40 nephelometric turbidity units (NTUs), and can increase to 250-500 NTUs during higher river flows (CDWR 2013). The actual distance suspended sediment caused by the Project would move is dependent upon multiple factors (i.e. tide, river flow, wind condition, etc.) and turbidity from pile removal and vibratory driving is anticipated to be confined within 45.7 m (150 ft) of the pile and would likely dissipate within five minutes (USFWS 2013). For much more sediment intensive activities, like clamshell dredging, turbidity generally extends a maximum of 304 m (1,000 ft) at the surface and 457 m (1,500 ft) near the substrate when using ineffective equipment (LTMS 2009). Any area of potential turbidity increase is well within the 1,970 m Action Area, and is anticipated to occur within less than 20% of the area identified with the 275 m Acoustic Impact Area (Figure 4).** Turbidity may result in habitat, such as the shallow water habitat between the wharf and the shoreline, being temporarily unsuitable for fish. By restricting in-water work to the work window will reduce the potential for sensitive life stages of listed fish to occur and be affected by Project generated turbidity. **Additionally, all water quality protection requirements identified by the Regional Water Quality Control Board (RWQCB) in the 401 certification for the Project will be followed.**

The suspension of sediment can also result in the release of contaminants into the water column, which can result in immediate or long term impacts for fish (LTMS 2009). In 2009 a vibracore sample analysis of sediment contamination in the vicinity of the GP wharf was investigated. **Benchmarks used as reference values for the test, as identified in the table**

in Appendix E, included San Francisco Bay Ambient Levels, Montezuma Wetlands Project (MWP) Sediment Acceptance Criteria[7], CalEPA California Human Health Screening Levels (CHSSLs), U.S. EPA Preliminary Remediation Goals (PRGs), and San Francisco Bay RWQCB Environmental Screening Levels (ESLs)[8]. The MWP and ESLs test for environmental thresholds while CHSSLs, PRGs, and ESLs test for human thresholds. Results of the sediment testing (Appendix E) determined there were no constituents of concern above benchmark levels for toxicity (Weston 2010). Therefore, any mobilized sediment or increased turbidity caused by the Action are likely to only result in temporary affects to listed fish, and no ongoing or permanent adverse effects of the Action are anticipated.

There will be no vessel delivery of gypsum shipments during construction of the replacement Wharf, and therefore there will be no direct effect from noise, draft, or fugitive dust of gypsum shipment vessel traffic to listed fish.

Above-water work for the demolition and construction of the replacement portion of the Wharf will involve welding, drilling, and associated construction related activity, and is expected to contribute minimally to hydroaccoustic direct effects. The sound produced by this activity is likely to be deadened as the sources will be out of the water, and is typical not a high pressure sound wave such as those produced by an impact hammer. To minimize potential adverse effects from demolition and construction, worker environmental training and BMPs including a debris containment boom and spill prevention kits will be used. Above-water work will be temporary, and is not anticipated to result in any adverse effects to listed fish.

5.1.2 Analysis of Direct Effects to LMB

Direct effects are those effects caused directly by the proposed Action that occur on-site within the Project Area and during Action implementation, i.e., ground disturbance within the Action Area.

Relatively little is currently known about acoustic impacts to terrestrial invertebrates (U.S. Department of Transportation 2004; Morley et al. 2014). Generally speaking, many

---

[7] MWP: Criteria used by San Francisco RWQCB staff to determine if dredged material is suitable for reuse in beneficial environments, such as wetlands. Since 1992, testing of dredged materials for proposed beneficial reuse projects has followed recommendations in Regional Board Resolution No. 92-145, Sediment Screening Criteria and Testing Requirements for Wetland Creation and Upland Beneficial Reuse (SFBRWQCB, 1992). The recommended screening criteria in Resolution 92-145 were based on 1992 estimates of ambient chemical concentrations in sediments and soils, and on NOAA effects-based sediment concentrations of chemical constituents of concern.

[8] ESLs: Under most circumstances, the presence of a chemical in soil, soil gas, or groundwater at concentrations below the corresponding ESL can be assumed to not pose a significant threat to human health, water resources, or the environment. ESLs address a greater range of media and endpoints than do other commonly-used screening levels, and reflect the broader scope of environmental concerns outlined in the San Francisco Bay (Region 2) Water Quality Control Plan (Basin Plan). Environmental concerns related to soil quality include direct exposure, leaching to groundwater, terrestrial receptors, and ceiling levels. Environmental concerns related to groundwater include drinking water, vapor intrusion, aquatic receptors, and ceiling levels.

invertebrates, including butterflies, are able to hear and communicate at frequencies below 10kHz and are able to hear within the main frequency spectrum of most anthropogenic noise and are thus likely to be impacted by it (Morley et al. 2014). Some research has been conducted regarding road noise on invertebrates. Grasshoppers and cicadias alter courtship frequencies and sound levels in response to noisy roads (Lampe et al. 2012; Shieh et al. 2012). According to the U.S. Department of Transportation, a few studies have indicated that several species are sensitive especially to low frequency vibration. Honeybees will stop moving for up to twenty minutes for sounds between 300 and 1 kHz at intensities between 107-120 dB (Frings and Little 1957). Frings and Frings (1959) reported that flies of the order *Diptera* showed a startle response at 80-800 Hz (at 80 dB) and at 120-250 Hz (from 3-18 dB above ambient levels). Most research is focused on how noise affects behavioral adaptions, and there is almost nothing in regard to how noise affects physiology such as development, neurobiology, genetics, or individual fitness (Morley et al. 2014).

For the Project, the main point of acoustic concern is due to impact pile driving. Conventional pile drivers are typically diesel powered; the impact of the hammer dropping onto the pile is the dominant noise component. Noise levels are difficult to measure or standardize, because they are affected by pile type and length, but peak levels in air tend to be about 100 dBA at 50 feet (USEPA 1971). In addition to the loudness of a noise produced, the noise impact severity of a particular source is also dependent on the temporal pattern of its emission. Pile driving would be required to install 13 piles for the replacement wharf, at an average of only 1-2 piles driven per day. As part of the project, pile driving will be conducted with both a vibratory hammer and a diesel impact hammer. It is estimated that each pile will require approximately 15 minutes of vibratory driving and 100 to 700 blows with an impact hammer to drive the piles to final tip elevation. Since noise levels from impact-hammer pile drivers are always higher than those from vibratory-hammer pile drivers, which are anticipated to be at or below ambient noise conditions, the Project construction noise impact discussion below considers only impact-hammer pile driver potential effects.

For the Project, the longest size pile that will be driven are the 72-inch piles at about 102 feet in length each. The mudline where the piles will be set is approximately -30 feet Mean Lower Low Water. Once the piles are upright, they will initially be driven with a vibratory hammer, which is anticipated to drive the pile 30 feet. An impact hammer will then be used to drive the remaining 37 feet of pile to design tip elevation. That will place the point of impact for the impact hammer, and point of sound production, approximately 42 feet above the water line. As the pile is driven, the point of impact will decrease in elevation above the water line until the final design elevation is met. During this process piles will become obscured from the Antioch Dunes National Wildlife Refuge once they fall below the existing height of riparian trees and vegetation lining the shoreline. Once the line-of-site with the noise point source is broken, a sound reduction of 5 – 20 dBA (NoiseNet 2008) can be anticipated. The other sized pile are not as long as the 72-inch pile, and are anticipated to have less than 40 feet of pile above the water line that will be driven with an impact hammer, and would fall below the riparian vegetation line sooner.

In acoustics, because of the inverse-square law, the sound pressure of a spherical wavefront radiating from a point source decreases by 50% as the distance from the source is doubled (GSU 2015). This means that for every doubling of distance from the source, noise levels decrease by 6 dBA. The inverse-square law results in a rapid loss of sound intensity as the distance from the point source increases, as the energy twice as far from the source point is spread over four times the area. Therefore, if an unattenuated peak sound level is assumed at 100 dBA at 50 feet (point source measurement), then the noise levels at a distance of 100 feet would be 6 dBA less than those at the point source (Caltrans 2013). As sound moves farther from the point source, unattenuated noise levels would be approximately 82 dBA at 400 feet and 76 dBA at 900 feet. Pre-project (background) ambient noise measurements taken within the Project site vicinity survey found daytime instantaneous noise levels there ranged from 50 dBA to 82 dBA[2]. **Because sound levels from impact hammer driving are anticipated to be above ambient conditions, the Project incorporates minimization measures to prevent any potential acoustic disturbance to LMB.**

The Project will avoid impact pile driving during the LMB adult flight season, which ranges from August 1st to September 29th (Johnson et al. 2007, USFWS 2014, USFWS 2015). There are no thresholds or standards identified for acoustic impacts to LMB, and acoustic impacts are not identified as a threat to the species. There is no available science on what effect, if any, above ambient acoustic levels would have on the species life history or physiology. **Despite this absence of data, the Project will avoid impact hammer driving during this period to prevent any potential adverse acoustic effects from the Project to adult breeding, feeding, or sheltering.**

The proposed period when impact pile driving would occur for the Project is October 1st through November 30th. During this period, the only LMB life stage anticipated to occur within or adjacent to ADNWR would be eggs, which remain dormant until the rainy season (USFWS 2014). The adult flight season would be over, and larvae generally hatch out in February and the larvae reared in the captive breeding program are not released back to ADNWR until around late June (USFWS 2012a). Potential Project acoustic levels are not anticipated to affect eggs, as any wind and associated movement of the buckwheat would be much greater than the any potential minor vibrations in air pressure from sound resulting from impact hammer driving. Furthermore, any eggs present would be scattered around the host plants and would therefore receive additional acoustic sheltering from the physical structure of the plants. **Thus, the project is not anticipated to directly affect eggs or larvae.**

The Project has incorporated measures to protect LMB from potential acoustic effects of impact hammer driving. The Project will not result in the direct loss or modification of habitat for LMB, as all work occurs outside of LMB habitat.

There will be no vessel delivery of gypsum shipments during the replacement of the Wharf, and therefore there will be no direct effect to noise, draft, or fugitive dust of gypsum shipment vessel traffic to LMB.

The Project will not result in the direct loss or modification of habitat for LMB. Based on the minimization measures incorporated into the Project, adult LMB behavior during collection will not be affected, and the Project will have no effect on the timing, work, or access of staff conducting the collection. Furthermore, propagation and rearing occurs away from ADNWR, and release occurs in June, which is outside of the Project window, and will therefore not be affected. Based on the absence of habitat in the Project Area, there will be no direct effects on naked-stemmed buckwheat, LMB's host plant. The Project is not likely to adversely affect LMB, and will therefore have no effect on the catch and release propagation program.

5.1.3 Analysis of Indirect Effects to Fish

Indirect effects are those caused by or those that will result from the proposed Action later in time and outside the Project Area, but are still reasonably certain to occur. The Project will not result in a change in current terminal capacity or service as a result of the Action. Additional effects analysis of the vessels and gypsum shipment is provided as an interrelated effect. No indirect effects of the Action are anticipated for listed fish species.

5.1.4 Analysis of Indirect Effects to LMB

Indirect effects are those caused by or those that will result from the proposed Action later in time and outside the Project Area, but are still reasonably certain to occur. The Project will not result in a change in current terminal capacity or service as a result of the Action. **While potentially considered an indirect effect,** additional effects analysis of the vessels and gypsum shipment is provided as an interrelated effect. No indirect effects of the Action are anticipated for LMB.

5.1.5 Analysis of Interrelated and Interdependent Effects to Fish

Interrelated actions are those actions that are part of the primary action and dependent upon that primary action for their justification.

The Project will not result in a change in current terminal capacity or service as a result of the Action. There will be no change in the number of vessels or the number of or volume of gypsum shipments, and no change in Georgia-Pacific plant operation as a result of the Action (see Section 2.5). The increase in larger vessel traffic is limited to the size of the vessels that will arrive at the dock, not the number of vessels or volume of material being moved and thus will not result in any increase in fugitive dust, or other visual or underwater sound effects to fish. Additionally, the volume of gypsum shipments arriving at the Wharf will not change, and because the channel limits the draft for vessels, no increase in vessel draft is anticipated to occur as a result of the Action. There is also no planned dredging for the Wharf. Therefore, vessel traffic in the Project Area and downstream is expected to be unchanged as a result of the Action. While vessel traffic may also be considered an indirect or interdependent effect, it is considered as an interrelated effect with this analysis. Interrelated effects will not adversely affect listed fish species as a result of the Action.

Interdependent actions are those actions that have no independent utility apart from the primary action. Construction, maintenance, and use of a road required to access a site is an example of an interdependent effect. Increased boat traffic around the **Wharf** will result as part of the Action during construction. Work boats and material barges will be used to perform the Action. Effects from the use of work boats and material barges will last for the duration of the Action. Acoustic effects from the use of work boats and material barges are anticipated to be minimal, and are adequately captured in the Action Area as depicted. No interdependent effects are expected as a result of the Action because all construction and activities are considered under the primary Action.

5.1.6 Analysis of Interrelated and Interdependent Effects to LMB

Interrelated actions are those actions that are part of the primary action and dependent upon that primary action for their justification. The Project will not result in a change in current terminal capacity or service as a result of the Action. There will be no change in number of vessels or the number of or volume of gypsum shipments, and no change in Georgia-Pacific plant operation as a result of the Action (see Section 2.5). The increase in larger vessel traffic is limited to the size of the vessels that will arrive at the dock, not the number of vessels or volume of material being moved and thus will not result in any increase in fugitive dust, or noise effects to LMB**. There is no anticipated increase in fugitive dust anticipated during gypsum offloading. While the potential for increased gypsum delivery exists with larger vessels, the amount of gypsum the Georgia-Pacific plant can store, and would be offloaded at the Wharf, is limited by the size of the dome storage. There is no proposal at this time to change the dome storage capacity. A change in dome storage or creation of additional dome storage space would be permitted under a separate action. While gypsum dust has been identified as a potential threat to LMB eggs, larvae, and host plants, there is no evidence or research to support gypsum dust adversely affecting LMB or their host plant (USFWS 2008, Richmond et al. 2015). In addition to potential gypsum dust sources,** vessel traffic may also be considered an indirect or interdependent effect, it is considered as an interrelated effect with this analysis. Interrelated effects will not adversely affect LMB as a result of the Action.

Interdependent actions are those actions that have no independent utility apart from the primary action. Construction, maintenance, and use of a road required to access a site is an example of an interdependent effect. No interdependent effects are expected as a result of the Action because all construction and activities are considered under the primary Action.

5.1.7 Analysis of Cumulative Effects to Fish

Cumulative effects are those effects of future state or private activities, not involving federal activities, that are reasonably certain to occur within the action area of the federal action subject to consultation {50 CFR §402.02}. Future dredging or new dock projects would be considered cumulative effects. Furthermore, because no increase in the number of vessels visiting the dock is proposed, no cumulative effect from increased vessel traffic is anticipated. There are no currently proposed non-federal actions in the Action Area; therefore, no cumulative effects are anticipated to occur.

5.1.8 Analysis of Cumulative Effects to LMB

Cumulative effects are those effects of future state or private activities, not involving federal activities, that are reasonably certain to occur within the action area of the federal action subject to consultation {50 CFR §402.02}. **Nitrogen emission deposition from the nearby Oakley Generating has been identified as a threat by USFWS, and resulted in captive rearing of LMB and cultivation of their host and nectar plants for mitigation (USFWS 2010). Nitrogen fixation in the dunes, along with the captive rearing program and annual species surveys conducted by USFWS at ADNWR are cumulative impacts. Additionally in 2010, a safe harbor agreement between PG&E and the USFWS was completed for the area immediately west of the Sardis Unit which allowed continued service access for**

PG&E along the parcel[9]. Beneficial placement dredge sediment at ADNWR by the Port of Stockton was also authorized by USFWS in 2013[10]. While considered a benefit for the habitat, this activity is still considered a cumulative impact. Any increase in the frequency of trains or similar ambient noise level increases could **also** be considered a cumulative effect. **No additional proposed non-federal actions in the Action Area are known at this time.**

5.2 Analysis of Effects to Critical Habitat

The following section provides an analysis of potential effects from the proposed Action on critical habitat.

5.2.1 Analysis of Direct Effects

Direct effects are those effects caused directly by the proposed Action that occur on-site within the Project Area and during Action implementation, i.e., ground disturbance within the Action Area. The proposed Action will affect critical habitat for green sturgeon, Central Valley steelhead, and Delta smelt.

The proposed Action will require the removal of existing creosote treated pilings and the placement of steel monopoles. The new steel monopoles will result in a permanent impact of 34.63 square feet (0.0008 acres) to shallow water habitat (Table 7). This impact will not result in the loss or reduction in Primary Constituent Elements of critical habitat for green sturgeon, Central Valley steelhead, or Delta smelt; and will not result in impact to spawning habitat for these species.

Table 7. Permanent Impacts to Shallow Water Habitat

Pile Location	Square Feet	Acres
Mooring Dolphin 1	9.62	0.00022
Mooring Dolphin 2	9.62	0.00022
Mooring Dolphin 3	12.26	0.00029
Walkway Monopile (1x)	3.13	0.00007
Net Permanent Impact	**34.63**	**0.00080**

The Project will result in the removal of 150 14-inch diameter creosote treated timber piles and approximately 20 cubic yards less fill than the existing Wharf. Removal of the timber piles will benefit critical habitat for listed fish as removing these piles will reduce the amount of creosote potentially leaching into San Joaquin River and the downstream San Francisco Bay-Delta waters (Werme et al 2010). Additionally, the replacement Wharf will result in 157 square feet

---

9 **ACOE communication dated May 29, 2015.**

10 **USFWS Reference Number 08ESMF00-2013-I-0500 dated July 3, 2013 and USFWS letter of concurrence dated July 10, 2013.**

less over-water shadowing, and the new walkway will be made from a light transmitting material. Because of the reduction in fill, shading, and the removal of creosote treated piles, the Action will have a beneficial effect for critical habitat within the Action Area.

5.2.2 Analysis of Indirect Effects

Indirect effects are those caused by or those that will result from the proposed Action later in time and outside the Project Area, but are still reasonably certain to occur. The impact of sea-level rise over the functional lifespan of the Wharf has been evaluated with the Project design, and is not anticipated to affect the Wharf. Additionally, steel components within the splash zone of the Wharf will have coatings or galvanization to protect them from corrosion. Indirect effects will not adversely affect critical habitat as a result of the Action.

5.2.3 Analysis of Interrelated and Interdependent Effects

Interrelated actions are those actions that are part of the primary action and dependent upon that primary action for their justification. No other interrelated effects are expected as a result of the Action.

Interdependent actions are those actions that have no independent utility apart from the primary action. No interdependent effects are known for the Action Area.

5.2.4 Analysis of Cumulative Effects

Cumulative effects are those effects of future state or private activities, not involving federal activities, that are reasonably certain to occur within the action area of the federal action subject to consultation {50 CFR §402.02}. There are no currently proposed non-federal actions in the Action Area; therefore, no cumulative effects are anticipated to occur.

6.0 DETERMINATION OF EFFECT

The cumulative SEL arising from the construction aspects of the Action is anticipated to exceed the 183 and 187 dB criteria and as such could result in harm to fish species within the Project Area. Through careful analysis of the biological resources within the Project Area, the Applicant has developed avoidance and minimization measures for the Action that minimize impacts to federally-listed fish species within the Action Area. **These species include: Central Valley steelhead, Winter and Spring-run Chinook salmon, green sturgeon, delta smelt and longfin smelt.** Numerous protection measures have been incorporated into the proposed Project design. Thus, while the proposed Action may affect and is likely to adversely affect listed fish species in the Action Area, the implementation of the proposed measures described above will greatly minimize the potential impacts, including the potential for take occurring.

The Applicant has incorporated measure to protect LMB in the ADNWR from the Action. The Project will not result in the direct loss or modification of habitat for LMB, as all work occurs outside of LMB habitat. **Targeted protection measures, including restricted pile driving during the adult flight season have been incorporated into the proposed Project design to prevent potential effects to adult LMB.** There will be no effect of the Project on the captive breeding program because adults will not be affected during collection, rearing occurs away from ADNWR, and release occurs outside of the Project window. In addition, while an increase in the size of vessel has already occurred, there will be no increase in the number of vessels or in the volume of materials being off-loaded at the dock, which will ensure no indirect or cumulative effects occur as the result of increased fugitive dust or noise from vessel traffic. **Adverse effects to adult LMB will be avoided by restricting impact hammer driving during the flight season, and will occur outside of the period larvae are present. The only life stage of LMB anticipated to occur within the Action Area during impact pile driving are eggs, which are not anticipated to be affected by sound or minor air pressure changes caused by sound (compared to natural wind conditions). Based on the avoidance measures provided in the Biological Assessment, the Project may affect, but is not likely to adversely affect LMB.**

The Project will result in the removal of creosote treated piles and a reduction in both fill and shading within the Project Area. The Action will result in improved aquatic habitat conditions within the Project Area. Furthermore, the Action is not likely to destroy or adversely modify critical habitat in the Action Area.

Due to several factors including a lack of suitable habitat within the Action Area, it was determined that the proposed project would not affect Callippe silverspot butterfly, Bay checkerspot butterfly, Conservancy fairy shrimp, longhorn fairy shrimp, vernal pool fairy shrimp, valley elderberry longhorn beetle, vernal pool tadpole shrimp, tidewater goby, coho salmon, California tiger salamander, California red-legged frog, Alameda whipsnake, giant garter snake, Western snowy plover, California clapper rail, California least tern, San Joaquin kit fox, large-flowered fiddleneck, pallid manzanita, Contra Costa wallflower, Santa Cruz tarplant, Contra Costa goldfields or Antioch dunes evening primrose.

7.0 REFERENCES

Adams, P.B., C.B. Grimes, S.T. Lindley, and M.L. Moser. 2002. Status review for North American green sturgeon, *Acipenser medirostris*. NOAA, National Marine Fisheries Service. Southwest Fisheries Science Center, Santa Cruz, CA 50 pp.

Allen, M.A., and T.J. Hassler. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishers and Invertebrates (Pacific Southwest), Chinook salmon. U.S. Fish and Wildlife Service, BiotogiClll Report 82 (11.49).

Barnhart, R.A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (pacific Southwest), steelhead. United States Fish and Wildlife Service Biological Report 82 (11.60).

Baxter, R. D. 1999. Osmeridae. Pages 179-216 in J. Orsi, editor. Report on the 1980-1995 fish, shrimp and crab sampling in the San Francisco Estuary. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 63.

Ben C. Gerwick, Inc. (BCG). 2014. Breasting Dolphin Replacement Project Basis of Design. Oakland, California.

Bennett, W.A. 2005. Critical assessment of the Delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science [Internet] 3(2) http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1

Black, S. H., and D. M. Vaughan. 2005. Species Profile: *Apodemia mormo langei*. In Shepherd, M. D., D. M. Vaughan, and S. H. Black (Eds). Red List of Pollinator Insects of North America. CD-ROM Version 1 (May 2005). Portland, OR: The Xerces Society for Invertebrate Conservation.

Brown, K. 2007. Evidence of spawning by green sturgeon, *Acipenser medirostris*, in the upper Sacramento River, California. Environmental Biology of Fishes 79:297-303.

Busby, PJ., T.C. Wainwright, GJ. Bryant, LJ. Lierheimer, R.S. Waples, F.W. Waknitz, and I,V. Lagomarsino. 1996. Status Review ofWest Coast Steelhead from Washington, Idaho, Oregon, and California. National Marine Fisheries Service, August 1996. NOAA Technical Memorandum, National Marine Fisheries Service-NWFSC-27.

Calfish. 2014. California Fish Species: Longfin Smelt *Spirinchus thaleichthys*. http://calfish.ucdavis.edu/species/?ds=241&uid=48. Accessed: December 15, 2014.

California Department of Fish and Game (CDFG). 1998. Areport to the Fish and Game Commission: A status review of the spring-run Chinook (*Oncorhynchus tshawytscha*) in the Sacramento River drainage. Candidate Species Status Report 98-01. June 1998.

CDFG. 2000. Spring-run Chinook salmon annual report. Prepared for the California Fish and Game Commission. Habitat Conservation Division, Native Anadromous Fish and Watershed Branch. Sacramento, 19 pages.

CDFG. 2002. California Department of Fish and Game comments to NMFS regarding green sturgeon listing.

CDFW. 2009. A status review of the longfin smelt (*Spirinchus thaleichthys*) in California. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=10263. Accessed: December 18, 2015.

California Department of Transportation (Caltrans). 2013. Transportation and Construction Vibration Guidance Manual. September Available: http://www.dot.ca.gov/hq/env/noise/pub/TCVGM_Sep13_FINAL.pdf.

California Department of Water Resources (CDWR). 2013. Appendix 5H – Aquatic Construction and Maintenance Effects. Bay Delta Conservation Plan. Public Draft. November. Sacramento, CA. Prepared by ICF International (ICF 00343.12). Sacramento, CA.

Chambers, J. 1956. Fish passage development and evaluation program. Progress Report No.5. U.S. Army Corps of Engineers, North Pacific Division, Portland, OR.

Dunford, W.E. 1975. Space and food utilization by salmonids in marsh habitats in the Fraser River Estuary. M.S. Thesis. University of British Colombia, Vancouver, B.C., 81 pp.

Emmett, R.L., S.A. Hinton, S.L. Stone, and M.E. Moncao. 1991. Distribution and abundance of fishes and invertebrates in West Coast estuaries, Volume ll: Species life history summaries. ELMR Report NO.8. NOAAlNOS Strategic Environmental Assessments Division, Rockville, MD. 329pp.

Endangered and Threatened Wildlife and Plants: Final Rulemaking To Designate Critical Habitat for the Threatened Southern Distinct Population Segment of North American Green sturgeon; Final Rule. *Federal Register* 74 (9 October 2009) 52300-52302. Print.

Erickson, D.L., J.A. North, J.E. Hightower, J. Weber, and L.Lauck. 2002. Movement and habitat use of green sturgeon Acipenser medirostris in the Rogue River, Oregon, USA. Journal of Applied Icthyology 18:565~569.

Farr, R.A., and J.C. Kern. 2005. Green sturgeon population characteristics in Oregon. Final progress report. Sport Fish Restoration Project F-178-R, Oregon Department of Fish and Wildlife, Portland, Oregon. 73 pp.

Fisher, F.W. 1994. Past and Present Status of Central Valley Chinook salmon. Conservation Biology 8(3):870-873.

Frings, H. and F. Little. 1957. Reactions of honey bees in the hive to simple sounds. Science 125:122.

Frings, H. and M. Frings. 1959. Reactions of swarms of Pentaneura aspera (Diptera: tendipedidae) to sound. Annals of the Entomological Society of America 52:728-733.

Fukushima L., and E.W. Lesh. 1998. Adult and juvenile anadromous salmonid migration timing in California streams. California Department of Fish and Game 84(3): 133-145.

Georgia State University (GSU). 2015. Inverse Square Law, Sound. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/acoustic/invsqs.html. Accessed: April 14, 2015

Hallock, R.J. and F.W. Fisher. 1985. Status of Winter-run Chinook salmon, Oncorhynchus tshawytscha, in the Sacramento River. Anadromous Fisheries Branch, California Department of Fish and Game. January 25, 1985.

Healey, M.C. 1991. The life history of Chinook salmon (Oncorhynchus tshawytscha). Pages 311393 In: C. Groot and L. Margolis (eds.), Life history of Pacific salmon. University of British Columbia Press, Vancouver, British Columbia.

Heath, A.G. 1995. Water pollution and fish physiology. Second Edition. CRC Press Inc. Boca Raton, Florida.

Heublin, J.C. 2006. Migration of Green sturgeon (Acipenser mediroSlris) in the Sacramento River. Masters Thesis. San Francisco State University. 63 pp.

ICF Jones and Stokes, and Illingworth and Rodkin, Inc. 2009. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish.

Illingworth & Rodkin, Inc. 2014. Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project Underwater Noise Assessment. Marysville, California.

Interagency Ecological Program (IEP). 2015. An updated conceptual model of Delta smelt biology: our evolving understanding of an estuarine fish. Technical Report 90.

Israel, J.A., and A.P. Klimley. 2008. Life History Conceptual Model for North American green Sturgeon (Acipenser medirostris). University of California, Davis.

Johnson, J.J., T. Longcore, A. Clause, G. Pratt, J. Dunn, and K. Osborne. 2007. Propogation handbook for Lange's metalmark butterfly *Apodemia mormo langei*. First edition. Moorpark College. Moorpark, CA.

Johnson, J.J., J. Jones, M. Bauder, M. Wagner, D. Flannery, D. Werner, et al. 2011. Captive rearing of Lange's metalmark butterfly, 2010-2011. The urban Wildlands Group. Los Angeles, CA.

Keljson, M.A., P.F. Raquel, and F.W. Fisher. 1981. Life history of fall-run juvenile Chinook salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin Estuary. In R.D. Cross and D.L. Williams (editors), Proceedings of the National Symposium on Freshwater Inflow to Estuaries, pages 88-108. U.S. Fish and Wildlife Service, FWSIOBS-81-04.

Lampe U., Schmoll T, Franzke A, Reinhold K. 2012. Staying tuned: grasshoppers from noisy roadside habitats produce courtship signals with elevated frequency components. Funct. Ecol. 26, 1348–1354

Levings, C.D. 1982. Short term use of low-tide refugia in a sand flat by juvenile chinook, (Oncorhynchus Ishawylscha), Fraser River estuary. Canadian Technical Reports ofFisheries and Aquatic Sciences, Number 1111. 7 pages.

Levy, D.A., and T.G. Northcote. 1982. Juvenile salmon residency in II marsh area of the Fraser River estuary. Canadian Journal of Fisheries and Aquatic Sciences 39:270-276.

Lindley, S.T., M.L. Moser, D.L. Erickson, M. Belchik, D.W. Welch, E. Rechisky, J.T. Kelly, J.C. Hublein, and A.P. Klimley. 2008. Marine migration of North American green sturgeon.

Long Term Management Strategy (LTMS). 2009. Programmatic Essential Fish Habitat (EFH) Assessment for the Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region. San Francisco, California.

McEwan, D. 2001. Central Valley steelhead. Pages 1-44 in R.L. Brown, editor. Contributions to the Biology of Central Valley Salmonids. Volume 1. California Department of Fish and Game Bulletin 179.

Meehan, W.R., and T.C. Bjorn. 1991. Salmonid distribution and life histories. Pages 47- 82 in Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. W.R. Meehan, editor. American Fisheries Society Special Publication 19. American Fisheries Society. Bethesda, Maryland.

Morley EL, Jones G, Radford AN. 2014. The importance of invertebrates when considering the impacts of anthropogenic noise. Proc. R. Soc. B 281: 20132683. Available online at < http://dx.doi.org/10.1098/rspb.2013.2683>. Accessed 24 March 2015.

Moyle P.B., P.I. Foley, and R.M. Yoshiyama. 1992. Status of green sturgeon, Acipenser medirostris, in California. Final Report submitted to the National Marine Fisheries Service, University of California, Davis, 11 pp.

Moyle, P.B. 2002. Inland fishes of California, 2nd edition. University of California Press, Berkeley and Los Angeles, CA. 502 pp.

Myers, J.M, R.G. Kope, G.J. Bryant, D. Tee1, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. U.S. Dept. OfCommer., NOAA Tech. Memo. NMFS-NWFSC-35. 443 pages.

Nakamoto, R.I., T.T. Kisanuki, and G. H. Gold5mith.1995. Age growth ofK.lamath River green sturgeon (Acipenser medirostris). U.S. Fish and Wildlife Service Project 93-FP-13, Yreka, CA, 20 pp.

National Marine Fisheries Service (NMFS). 2000. Biological Opinion Benicia-Martinez Bridge Construction. SWR-00-SA-0222:MCV. Dated: November 20, 2000.

NMFS. 2001. *Biological Opinion San Francisco-Oakland Bay Bridge East Span Seismic Safety Project*. NMFS File No. 151422SWR99SR190. Dated: October 30, 2001.

NMFS. 2009. *Supplemental Biological Opinion for the Completion of Pile Driving and Other Remaining Activities*. San Francisco-Oakland Bay Bridge. NMFS File No. 151422SWR99SR190. Dated: August 21, 2009.

NoiseNet. 2008. Calculating levels. Available: http://www.noisenet.org/noise_terms_calcs.htm. Accessed: April 14, 2015.

Richmond, O.M.W., Kelly, D. and Longcore, T. 2015. Lange's Metalmark Butterfly Threat Assessment and Ranking of Potential Management Alternatives: Final Report. U.S. Fish and Wildlife Service, Pacific Southwest Region. National Wildlife Refuge System Inventory and Monitoring Initiative. Sacramento, CA, USA.

Shieh B-S, Liang S-H, Chen C-C, Loa H-H, Liao C-Y. 2012 Acoustic adaptations to anthropogenic noise in the cicada Cryptotympana takasagona Kato (Hemiptera: Cicadidae). Acta Ethol. 15, 33 – 38. (doi:10.1007/s10211-011-0105-x)

Shirvell, e.s. 1990. Role of instrearn rootwads as juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (O. mykiss) cover habitat under varying stream flows. Canadian Journal of Fisheries and Aquatic Sciences 47:852-860.

Stark, J.D., X.D. Chen, and C.S. Johnson, 2012. Effects of herbicides on Behr's metalmark butterfly, a surrogate species for the endangered butterfly, Lange's metalmark. Environmental Pollution. 164:24-27. May 2012.

Trenham, P.C., H.B. Shaffer and P.B. Moyle. 1998. Biochemical identification and assessment of population subdivision in morphometrically similar native and invading smelt species (Hypomesus) in the Sacramento-San Joaquin Estuary, California. T. Am. Fish. Soc. 127: 417-424

U.S. Department of Transportation, 2004. Synthesis of Noise Effects on Wildlife Populations. Federal Highway Administration. September 2004. Available online at http://www.fhwa.dot.gov/environment/noise/noise_effect_on_wildlife/effects/effects.pdf. Accessed 24 March 2015.

United States Environmental Protection Agency (USEPA), 1971. Noise from Construction Equipment and Operations, Building Equipment and Home Appliances, PB 206717.

USFWS, 1984. Recovery Plan (ESA): Revised recovery plan for three endangered species endemic to Antioch Dunes, California. Available online at http://ecos.fws.gov/docs/recovery_plan/Antioch%20Dunes%20Species%20(1).pdf. Accessed 24 March 2015.

USFWS. 1995. Sacramento-San Joaquin Delta Native Fishes Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

USFWS. 2001. Reinitiation of Formal Endangered Species Consultation and Amendment to the Biological Opinion (File # 1-1-96-F-40) for the New Benicia-Martinez Bridge Project. USFWS File No. 1-1-01-F-28. Dated: January 9, 2001.

USFWS. 2004. Formal Programmatic Consultation on the Issuance of Section 10 and 404 Permits for Projects with Relatively Small Effects on the Delta smelt (Hypomesus transpacificus) and its critical habitat within the jurisdiction of the Sacramento Field Office of the U.S. fish and Wildlife Service, California. December.

USFWS. 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operation of the Central Valley Project and State Water Project. BO: 81420-2008-F-1481-5. Sacramento, California.

USFWS. 2010. Proposed Oakley Generation Station Project and its potential effects to the Endangered Lange's Metalmark Butterfly, Endangered Contra Costa Wallflower, Endangered Antioch Dunes Evening Primrose, and Designated Critical Habitat for the Two Listed Plants. USFWS File No. 81420-2009-TA-1107. Dated October 13, 2010.

USFWS. 2012a. Habitat restoration for three endangered species at the Antioch Dunes National Wildlife Refuge and captive propagation of the endangered Lange's metalmark butterfly. Central Valley Project Improvement Act habitat restoration program FY 2009 to 2010 Final Report – R09PG20050. Petaluma, CA.

USFWS. 2012b. Antioch Dunes National Wildlife Refuge. Available: http://www.fws.gov/refuge/Antioch_Dunes/about.html. Accessed: April 13, 2015.

USFWS. 2013a. Endangered and Threatened Wildlife and Plants; 12-month Finding on a Petition to List the San Francisco Bay-Delta Population of the Longfin Smelt as Endangered or Threatened. Docket No. FWS-R8-ES-2008-0045. Bay Delta Fish & Wildlife Office. Website: http://www.fws.gov/sfbaydelta/species/longfin_smelt.cfm

USFWS. 2013b. Formal Endangered Species Act Consultation on the Mukilteo Multimodal Project Snohomish County, Washington. Biological Opinion 01EWFW00-2013-F-0360. Lacey, Washington.

USFWS. 2014. 2013 Lange's metalmark butterfly surveys. San Francisco Bay National Wildlife Refuge Complex, Fremont, California.

USFWS. 2015. 2014 Lange's metalmark butterfly surveys. San Francisco Bay National Wildlife Refuge Complex, Fremont, California.

Werme, C., J. Hunt, E. Beller, K. Cayce, M. Klatt, A. Melwani, E. Polson, and R. Grossinger. (2010). Removal of Creosote-Treated Pilings and Structures from San Francisco Bay. Prepared for California State Coastal Conservancy. Contribution No. 605. San Francisco Estuary Institute, Oakland, California.

Weston 2010. Results of Chemical and Physical Testing of Sediments from the Georgia-Pacific Gypsum Processing Plant Dock. Weston Solutions, Inc. Oakland, CA. February 2010.

Wild Equity Institute, Communities for a Better Environment, and Sierra Club California, 2011. Potential Effects of Oakley Generating Station on Endangered Species. Available online at http://www.energy.ca.gov/sitingcases/oakley/documents/others/2011-05-17_Potential_Effects_of_Oakley_Generating_Station_on_Endangered_Species_TN-60702.pdf. Accessed 24 March 2015.

Wood Biological Consulting, Inc. (WBC). 2014. Biological Resource Assessment for the Antioch Wharf Rehabilitation Project City of Antioch Contra Costa County, California. Walnut Creek, California. Prepared: November 12, 2014.

This page intentionally left blank.

APPENDIX A - Table of Federally-Listed Species for the Area

This page intentionally left blank.

SPECIES	STATUS*	HABITAT	POTENTIAL FOR OCCURRENCE
Mammals			
salt-marsh harvest mouse *Reithrodontomys raviventris*	FE	Primary habitat in pickleweed-dominated saline emergent marshes of San Francisco Bay. Do not burrow, build loosely organized nests. Require adjacent upland areas for escape from high tides.	**Unlikely.** The Project Area and adjacent areas do not contain salt marsh habitats to support this species. The nearest documented occurrence of this species is 2.5 miles west of the Project Area.
San Joaquin kit fox *Vulpes macrotis mutica*	FE	Found in annual grasslands or grassy open stages with scattered shrubby vegetation. Need loose-textured sandy soils for burrowing and suitable prey base.	**Not Present.** The Project Area does not contain open grassland habitats necessary for this species. All documented occurrences of this species within 5 miles of the Project Area were located due south in the Antioch hills. These hills are separated from the Project Area by extensive development, precluding this species' presence nearby.
Birds			
California brown pelican *Pelecanus occidentalis californicus*	FD	Winter/non-breeding visitor to estuarine and coastal marine waters. Nests in colonies on offshore islands, from the Channel Islands southward, that are free of mammalian predators and human disturbance. Individuals use breakwaters, jetties, sand bars, etc. for loafing and roosting.	**Unlikely.** This species does not nest in northern California. However, it may occasionally forage within the Project Area or use the pier for loafing.
California clapper rail *Rallus longirostris obsoletus*	FE	Found in tidal salt marshes of the San Francisco Bay. Require mudlfats for foraging and dense vegetation on higher ground for nesting.	**Not Present.** Tidal salt marsh habitat is not present within the Project Area or adjacent Areas. The Project Area is located outside the known range of this species. The nearest documented occurrence of this species is over 11 miles west of the Project Area (CDFW 2014).

SPECIES	STATUS*	HABITAT	POTENTIAL FOR OCCURRENCE
western snowy plover *Charadrius alexandrinus nivosus*	FT	Found on sandy beaches, salt pond levees, and shores of large alkali lakes. Need sandy gravelly or friable soils for nesting.	**Unlikely.** Typical breeding and foraging habitat are not present in the Project Area or adjacent areas, and there are no documented occurrences of this species nearby (CDFW 2014).
California least tern *Sterna antillarum browni*	FE	Breeding colonies in San Francisco Bay found in abandoned salt ponds and along estuarine shores. Nests on barren to sparsely vegetated site near water.	**Unlikely.** Typical sparsely-vegetated breeding habitat is not present in the Project Area. This species may occasionally forage within the waters of the Project Area, but is unlikely to breed there. The nearest documented breeding occurrence for this species is over 7 miles west of the Project Area in Pittsburg (CDFW 2014)
Reptiles and Amphibians			
Alameda whipsnake *Masticophis lateralis euryxanthus*	FT	Prefers a chaparral habitat with rock outcroppings and small mammal burrows for basking and refuge. Can occur in adjacent communities, including grassland and oak savanna. Found in the east bay hills.	**Not Present.** Suitable chaparral habitat is not present in or near to the Project Area. Extensive development separates the Project Area from any suitable habitat for this species to the south in the Antioch hills.
California tiger salamander *Ambystoma californiense*	FT	Inhabits annual grass habitat and mammal burrows. Seasonal ponds and vernal pools crucial to breeding.	**Not Present.** Suitable aquatic and upland habitat is not present in the Project Area. The nearest documented occurrence of this species is 1.1 miles south of the Project Area (CDFW 2014). This occurrence is from 1983 and since then the area has been subject to extensive development and no wetland features with potential for breeding remain in the area. The species is considered extirpated from the area.

SPECIES	STATUS*	HABITAT	POTENTIAL FOR OCCURRENCE
California red-legged frog *Rana aurora draytonii*	FT	Associated with quiet perennial to intermittent ponds, stream pools, and wetlands. Prefers shorelines with extensive vegetation. Documented to disperse through upland habitats after rains.	**Not Present.** Suitable aquatic and upland habitat is not present in the Project Area. The nearest documented occurrence of this species is over 3.5 miles south of the Project Area, and is separated from the Project Area by extensive development (CDFW 2014).
giant garter snake *Thamnophis gigas*	FT	Inhabits agricultural wetlands and other waterways such as irrigation and drainage canals, sloughs, ponds, small lakes, low gradient streams, and adjacent uplands in the Central Valley. Habitat requirements consist of (1) adequate water from early-spring through mid-fall, (2) emergent, herbaceous wetland vegetation for escape cover and foraging habitat, 3) grassy banks and openings in waterside vegetation for basking, and (4) higher elevation uplands for cover and refuge from flood waters during the snake's dormant season in the winter.	**Unlikely.** This species has been documented 2.2 miles northeast of the Project Area across the San Joaquin River (CDFW 2014). The Project Area is along a deep (35 feet) portion of the San Joaquin River, and does not contain canals, sloughs, ponds or associated aquatic features used by the species. The closest occurrence of the species is within Sherman Island, which contains higher quality habitat that is much different than the industrial and urban development surrounded Project Area. Additionally the steep banks of the Project Area are armored with loose rock that is mostly unvegetated, further reducing the suitability of the Project Area for the species.
Fishes			
green sturgeon *Acipenser medirostris*	FT	Spawn in the Sacramento River and the Klamath River. Spawn in deep pools or "holes" in large, turbulent, freshwater river mainstems. Adults live in oceanic waters, bays, and estuaries when not spawning. Species is known to forage in estuaries and bays.	**Present.** This species is known to occur in the waters adjacent to the Project Area, and the Project Area is located within designated critical habitat for this species.

SPECIES	STATUS*	HABITAT	POTENTIAL FOR OCCURRENCE
coho salmon- central California coast ESU *Oncorhynchus kisutch*	FE, NMFS	Federal listing includes populations between Punta Gorda and San Lorenzo River. State listing includes populations south of San Francisco Bay only. Occurs inland and in coastal marine waters. Requires beds of loose, silt-free, coarse gravel for spawning. Also needs cover, cool water and sufficient dissolved oxygen.	**Not Present.** This species is considered extirpated from San Francisco Bay and San Joaquin River basin.
steelhead - central CA coast DPS *Oncorhynchus mykiss irideus*	FT, NMFS	Federal listing includes all runs from the Russian River south to Soquel Creek, inclusive. Includes the San Francisco and San Pablo Bay basins but excludes the Sacramento-San Joaquin River basins. Adults migrate upstream to spawn in cool, clear, well-oxygenated streams. Juveniles remain in fresh water for one or more years before migrating downstream to the ocean.	**Unlikely.** While this species is known to occur in the San Francisco Bay, the Project Area is located in the San-Joaquin River basin, outside of this ESU's range. Any steelhead found within the Project Area would be designated as Central Valley DPS fish.
steelhead - Central Valley DPS *Oncorhynchus mykiss irideus*	FT, NMFS	The Central Valley ESU includes all naturally-spawned populations (and their progeny) in the Sacramento and San Joaquin Rivers and their tributaries, excluding San Francisco and San Pablo bays and their tributaries.	**Present.** This species is known to occur in the waters adjacent to the Project Area, and the Project Area is located within designated critical habitat for this species.
Chinook Salmon - California coastal ESU *Oncorhynchus tshawytscha*	FT, NMFS	California Coastal Chinook Salmon ESU includes all naturally spawned populations of Chinook salmon from rivers and streams south of the Klamath River (exclusive) to the Russian River (inclusive). Adult numbers depend on pool depth and volume, amount of cover, and proximity to gravel. Water temps >27 degrees C lethal to adults.	**Not Present.** Project Area is outside of the known range for this species.

Chinook salmon - Central Valley spring-run ESU *Oncorhynchus tshawytscha*	FT, NMFS	Occurs in the Feather River and the Sacramento River and its tributaries, including Butte, Mill, Deer, Antelope and Beegum Creeks. Adults enter the Sacramento River from late March through September. Adults migrate upstream to spawn in cool, clear, well-oxygenated streams from mid-August through early October. Juveniles migrate soon after emergence as young-of-the-year, or remain in freshwater and migrate as yearlings.	**Present.** This species is known to occur in the waters adjacent to the Project Area, and the Project Area is located within designated critical habitat for this species.
Chinook salmon – Sacramento winter-run ESU *Oncorhynchus tshawytscha*	FE, NMFS	Prior to the construction of Shasta Dam, likely spawned in the headwaters of the Sacramento in streams fed mainly by the flow of constant-temperature springs. Currently spawn in the mainstem of the Sacramento from Redding downstream to Tehama. Adults migrate upstream to spawn in cool, clear, well-oxygenated streams.	**Present.** This species is known to occur in the waters adjacent to the Project Area.
Delta smelt *Hypomesus transpacificus*	FT	Lives in the Sacramento-San Joaquin estuary in areas where salt and freshwater systems meet. Occurs seasonally in Suisun Bay, Carquinez Strait and San Pablo Bay. Seldom found at salinities > 10 ppt; most often at salinities < 2 ppt.	**Present.** This species is known to occur in the waters adjacent to the Project Area, and has been documented within 5 miles of the Project Area (CDFW 2014).
longfin smelt Spirinchus thaleichthys	FC	Euryhaline, nektonic and anadromous. Found in open waters of estuaries, mostly in middle or bottom of water column. Prefer salinities of 15 to 30 ppt, but can be found in completely freshwater to almost pure seawater.	**Present.** This species is known to occur in the waters adjacent to the Project Area, and has been documented within 5 miles of the Project Area (CDFW 2014).
tidewater goby *Eucyclogobius newberryi*	FE	Found in the brackish waters of coastal lagoons, marshes, creeks, and estuaries. Unique among fishes of the Pacific coast, gobies are restricted to waters of low salinity in coastal wetlands. They feed along the bottom, preferring clean, shallow, slow-moving waters	**Not Present.** This species is not known to occur near the Project Area, and is considered extirpated from San Francisco Bay.

Invertebrates			
vernal pool fairy shrimp *Branchinecta lynchi*	FT	Inhabit small, clear-water sandstone-depression pools, grassy swales, slumps, or basalt-flow depression pools.	**Not Present.** No seasonal wetland habitat containing suitable hydrological conditions is located within the Project Area.
vernal pool tadpole shrimp *Lepidurus packardi*	FE	Pools commonly found in grass-bottomed swales of unplowed grasslands. Some pools are mud-bottomed and highly turbid.	**Not Present.** No vernal pool habitat containing suitable hydrological conditions is located in the Project Area.
conservancy fairy shrimp *Branchinecta conservatio*	FE	Inhabit rather large, cool-water vernal pools with moderately turbid water that generally last until June. Requires an average of 7 weeks of inundation to mature.	**Not Present.** No seasonal wetland habitat containing suitable hydrological conditions is located within the Project Area.
Lange's metalmark butterfly *Apodemia mormo langei*	FE	All the life stages of Lange's metalmark butterflies are found close to the larval food plant, buckwheat (*Eriogonum nudum* ssp. *auriculatum*). Adults may also use butterweed *and* snakeweed for nectar, as well as lupine for mating. Historically restricted to sand dunes along the southern bank of the Sacramento-San Joaquin River and currently found only at Antioch Sand Dunes in Contra Costa County.	**Present.** This species is known within the Antioch Dunes National Wildlife Refuge, within 0.25 miles from the pier. However, this species is unlikely to occur within the Project Area. The 2014 biological resource assessment pertaining to this project (Wood Biological Consulting 2014) found no host plants on the site; **however, USFWS has mapped the host plant present (Appendix B – Supplemental Figure 2).** Discussion of potential Project related acoustic effects and minimization measures are provided in the body of the Biological Assessment.
Plants			
large-flowered fiddleneck *Amsinckia grandiflora*	FE	Cismontane woodland, valley and foothill grassland. 275-305 m.	**Not Present.** No suitable habitat. The Project Area is in and adjacent to open water habitat. The Project Area does not contain cismontane woodland or valley and foothill grassland. In addition, the Project Area is below the elevation requirements of this species.

soft bird's beak *Cordylanthus mollis ssp. mollis*	FE	Coastal salt marshes. 0-3 m.	**Not Present**. Salt marsh habitat for this species is not present within or adjacent to the Project Area.
Contra Costa goldfields *Lasthenia conjugens*	FE	Cismontane woodland, playas (alkaline), valley and foothill grassland, vernal pools / mesic. 0-470 m.	**Not Present**. No suitable habitat for this species exists within the Project Area. The Project Area is in and adjacent to open water habitat. The Project Area does not contain cismontane woodland, alkaline playas, valley and foothill grassland, or vernal pools necessary for this species.
Contra Costa wallflower *Erysimum capitatum ssp. angustatum*	FE	Inland Dunes (known only from the Antioch Dunes in Contra Costa COunty). 3-20 m.	**Unlikely.** Marginally suitable dune habitat exists within the Project Area. A 2014 Biological Resource Assessment (Wood Biological Consulting 2014) did not document this species on the site and determined that a high level of surface disturbance likely precludes presence.
Antioch dunes evening primrose *Oenothera deltoides ssp. howellii*	FE	Endemic to California, and restricted to remnant river bluffs and inland dunes and found only in Contra Costa and Sacramento counties, from sea level to 30 m (0-100 ft).	**Unlikely.** Marginally suitable dune habitat exists within the Project Area. A 2014 Biological Resource Assessment (Wood Biological Consulting 2014) did not document this species on the site and determined that a high level of surface disturbance likely precludes presence.

APPENDIX B – Figures

This page intentionally left blank.

Figure 1. Project Location Map

Georgia-Pacific Antioch Wharf
Breasting Dolphins Replacement
Contra Costa County, California

WRA ENVIRONMENTAL CONSULTANTS

Map Date: December 2014
Map By: Chris Zumwalt
Base Source: ESRI World Topo

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 1 Location.mxd

ENVIRONMENTAL CONSULTANTS

Georgia-Pacific
Antioch Wharf
Breasting Dolphins
Replacement Project

Contra Costa County, CA

Figure 2

Wharf Project Area

Overview

Map Date: December 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/2/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 2 Overview 20150107.mxd

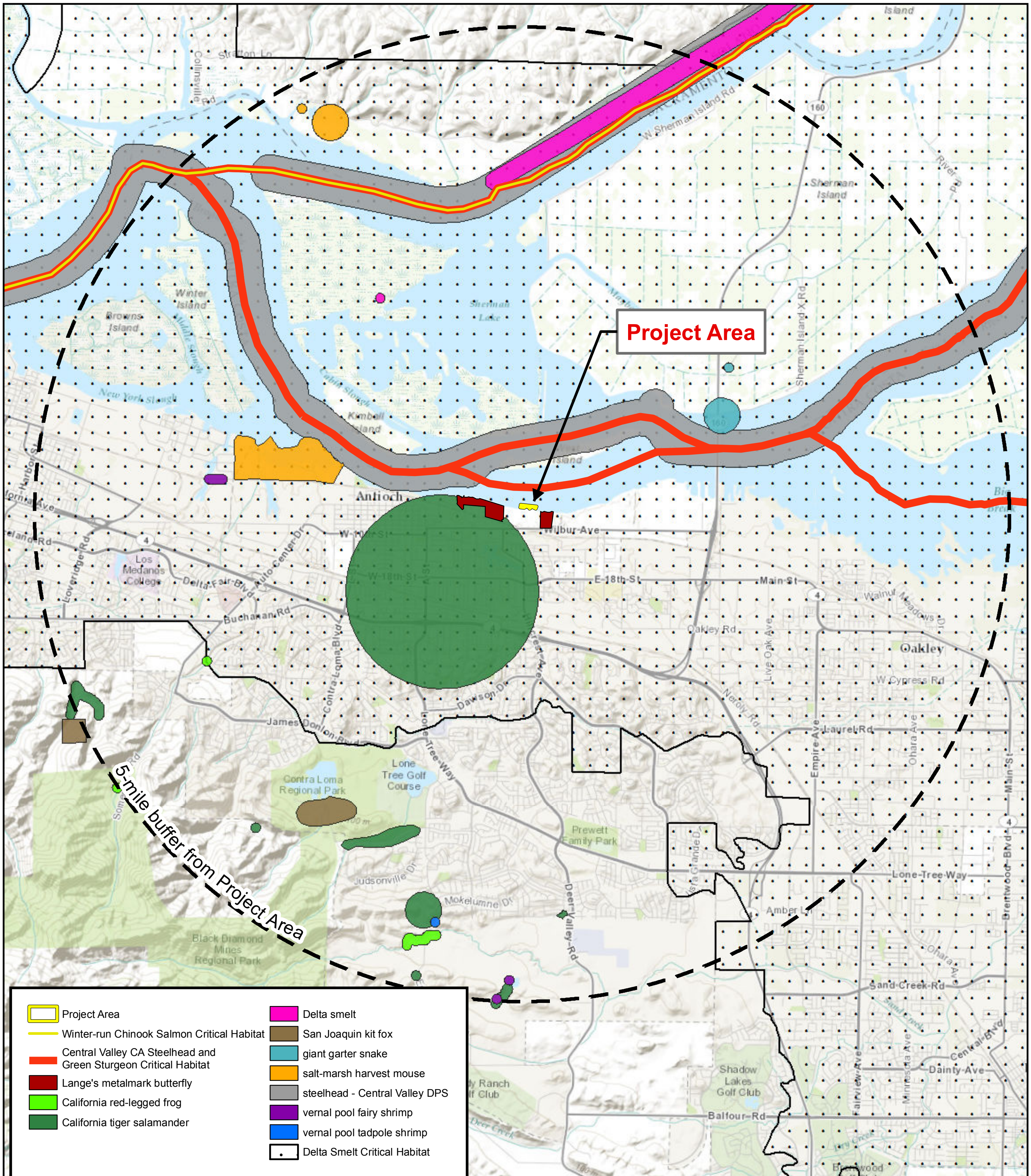


Figure 3. CNDDB Wildlife Occurrences and Critical Habitats

Georgia-Pacific Antioch Wharf Breasting Dolphins Replacement Project
Contra Costa County, CA

wra ENVIRONMENTAL CONSULTANTS

Date: December 2014
Map By: Chris Zumwalt
Base Source: USGS Topo

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 3 CNDDB .mxd

wra
ENVIRONMENTAL CONSULTANTS

Georgia-Pacific
Antioch Wharf
Breasting Dolphins
Replacement Project

Contra Costa County,
CA

Figure 4

Hydroacoustic

Action Area

N
W E
S

0 900 1,800 2,700
Feet

Map Date: December 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/02/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 5 Action Area.mxd

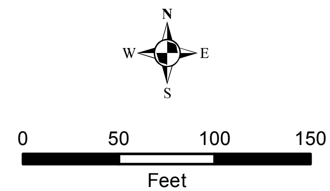
wra
ENVIRONMENTAL CONSULTANTS

Georgia-Pacific
Antioch Wharf
Breasting Dolphins
Replacement Project

Contra Costa County, CA

Figure 5

Wharf Project Area Details



Map Date: December 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/2/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 4 Wharf Details.mxd

Georgia-Pacific Antioch Wharf Breasting Dolphins Replacement Project

Contra Costa County, CA

Supplemental Figure 1. USFWS Acoustic Action Area

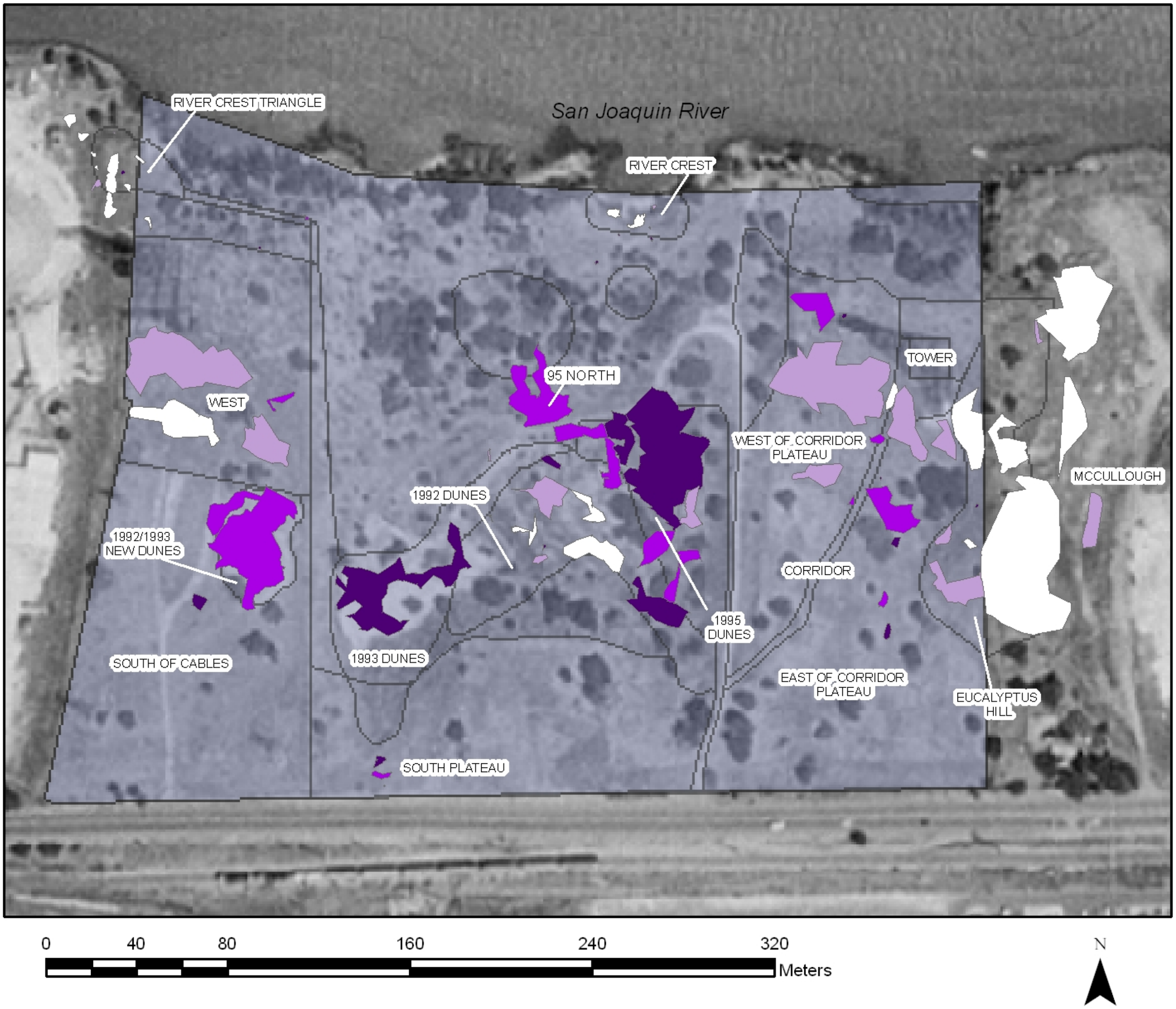
N
W E
S

0 500 1,000 1,500
Feet

Map Date: April 2015
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/02/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 3 Supplemental USFWS.mxd

Sardis Buckwheat Density 2005-2006



Supplemental Figure 2. Buckwheat Density in Sardis Unit

Buckwheat Percent Cover

- 1-24
- 25-49
- 50-74
- 75-100

U.S. Fish and Wildlife Service

Antioch Dunes National Wildlife Refuge

P.O. Box 524
Newark, CA 94560

510-521-9624
www.fws.gov/sfbayrefuges/

March, 2006

This page intentionally left blank.

APPENDIX C - Unattenuated Aquatic Action Area

This page intentionally left blank.

Supplemental Information 2:
SPK-2011 00039
Antioch Wharf Breasting Dolphin Replacement
February 9, 2015

The following figures and table are intended to supplement the Biological Assessment (WRA 2015) for the Georgia-Pacific Antioch Wharf Project. This information was requested by the US Army Corps of Engineers to assist with the consultation process with National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS).

NMFS Hydroacoustic Action Area

Supplemental Figure 1. NMFS Hydroacoustic Action Area. This figure depicts the anticipated distance the 150 dB threshold (Action Area) and the cumulative SEL of 187 dB threshold (Acoustic Impact Area) will extend from impact pile driving locations when sound attenuation methods are used. The 187 dB threshold is intended for fish >2 grams. The area (acres) each threshold is anticipated to extend is provided in the table below.

Supplemental Table 1. Area and radius for hydroacoustic effects identified in Supplemental Figure 1.

Area	Acreage	Square Feet	Radius (meters)*	Description
Action Area	776.82	33,838,223	1,970	The anticipated maximum distance for 150 dB using attenuation; discussed in greater detail and shown on Fig 4 of the Biological Assessment (BA).
Acoustic Impact Area	22.07	961,412	160	The anticipated maximum distance for cumulative SEL of 187 dB using attenuation; discussed in greater detail in the BA and shown on Supplemental Figure 1.
10m Buffer From Pile Driving Locations	1.18	51,448	10	The anticipated maximum distance for 206 dB using attenuation; 10m buffer applied around each pile driving location.

ENVIRONMENTAL CONSULTANTS

Georgia-Pacific
Antioch Wharf
Breasting Dolphins
Replacement Project

Contra Costa County, CA

Supplemental Figure 1.

NMFS Hydroacoustic Action Area

N
W E
S

0 300 600 900
Meters

Map Date: February 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/02/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 1 Supplemental.mxd

Hydroacoustic Impact Areas Without Sound Attenuation

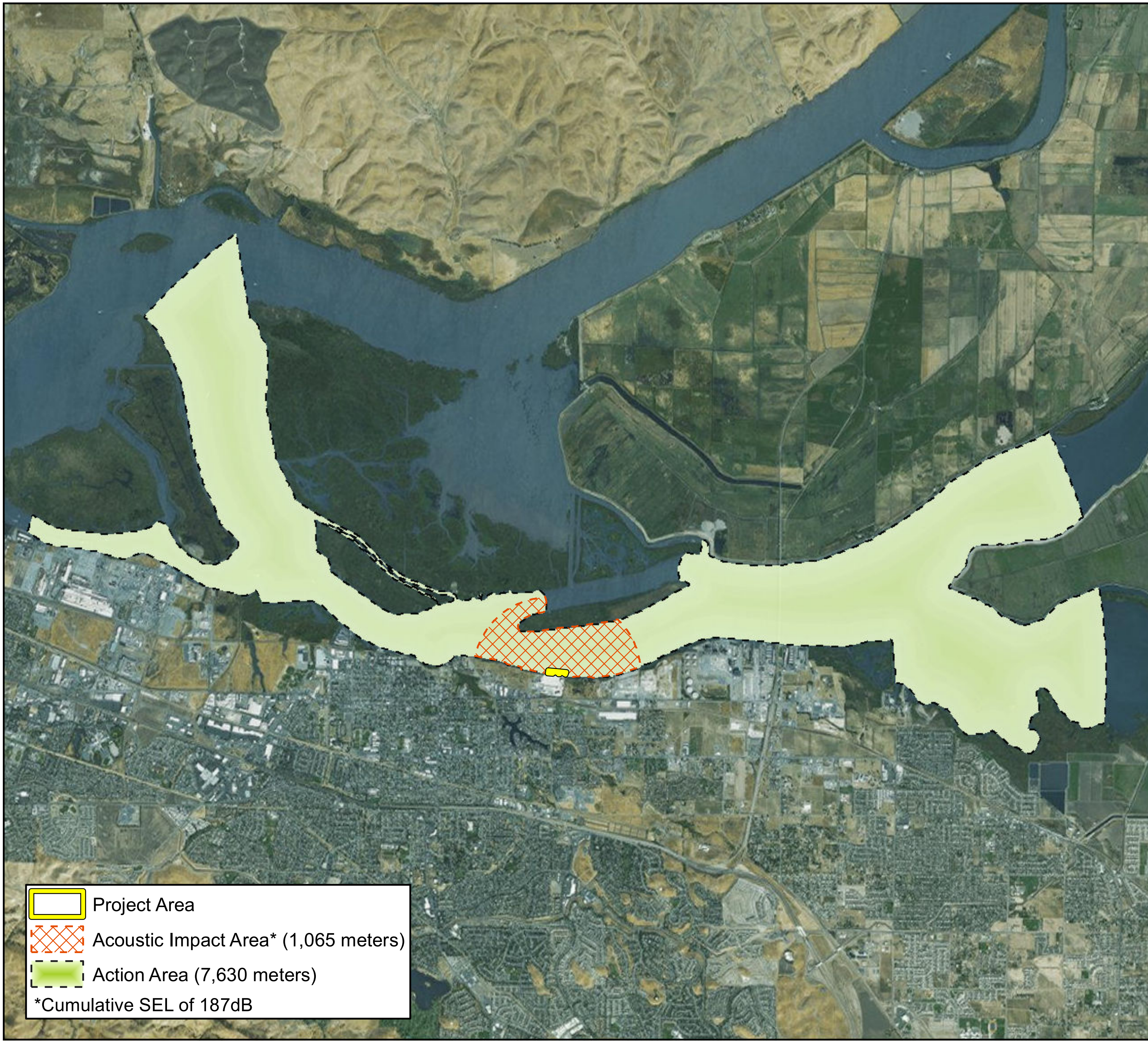
The following information is intended to provide the anticipated area for the hydroacoustic thresholds when no sound attenuation is used. Two figures are provided which illustrate the increased area impacted when pile driving is unattenuated. The project design incorporates multiple approaches to attenuate potentially harmful hydroacoustic levels and minimize the impact to listed fish. These measures are provided in detail in the BA.

NMFS Unattenuated Hydroacoustic Action Area

Supplemental Figure 2. NMFS Unattenuated Hydroacoustic Action Area. This figure depicts the anticipated distance the 150 dB threshold (Action Area) and the cumulative SEL of 187 dB threshold (Acoustic Impact Area) will extend from impact pile driving locations when no sound attenuation is used. The 187 db threshold is intended for fish >2 grams. The area (acres) each threshold is anticipated to extend is provided in the table below. As described in the BA, river bathymetry and island/terrestrial land masses are anticipated to distort and limit the extent of the Action Area.

Supplemental Table 2. Area and radius for unattenuated hydroacoustic effects identified in Supplemental Figure 2.

Area	Acreage	Square Feet	Radius (meters)*	Description
Action Area	5,6163.82	244,667,785	7,630	The anticipated maximum distance for 150 dB using attenuation; discussed in greater detail and shown on Fig 4 of the Biological Assessment (BA).
Acoustic Impact Area	184.67	8,044,131	620	The anticipated maximum distance for cumulative SEL of 187 dB using attenuation; discussed in greater detail in the BA and shown on Supplemental Figure 2.
30m Buffer From Pile Driving Locations	3.48	151,804	30	The anticipated maximum distance for 206 dB using attenuation; 30m buffer applied around each pile driving location.



ENVIRONMENTAL CONSULTANTS

Georgia-Pacific Antioch Wharf Breasting Dolphins Replacement Project

Contra Costa County, CA

Supplemental Figure 2.

NMFS Unattenuated Hydroacoustic Action Area

N
W E
S

0 900 1,800 2,700
Meters

Map Date: February 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/02/2010

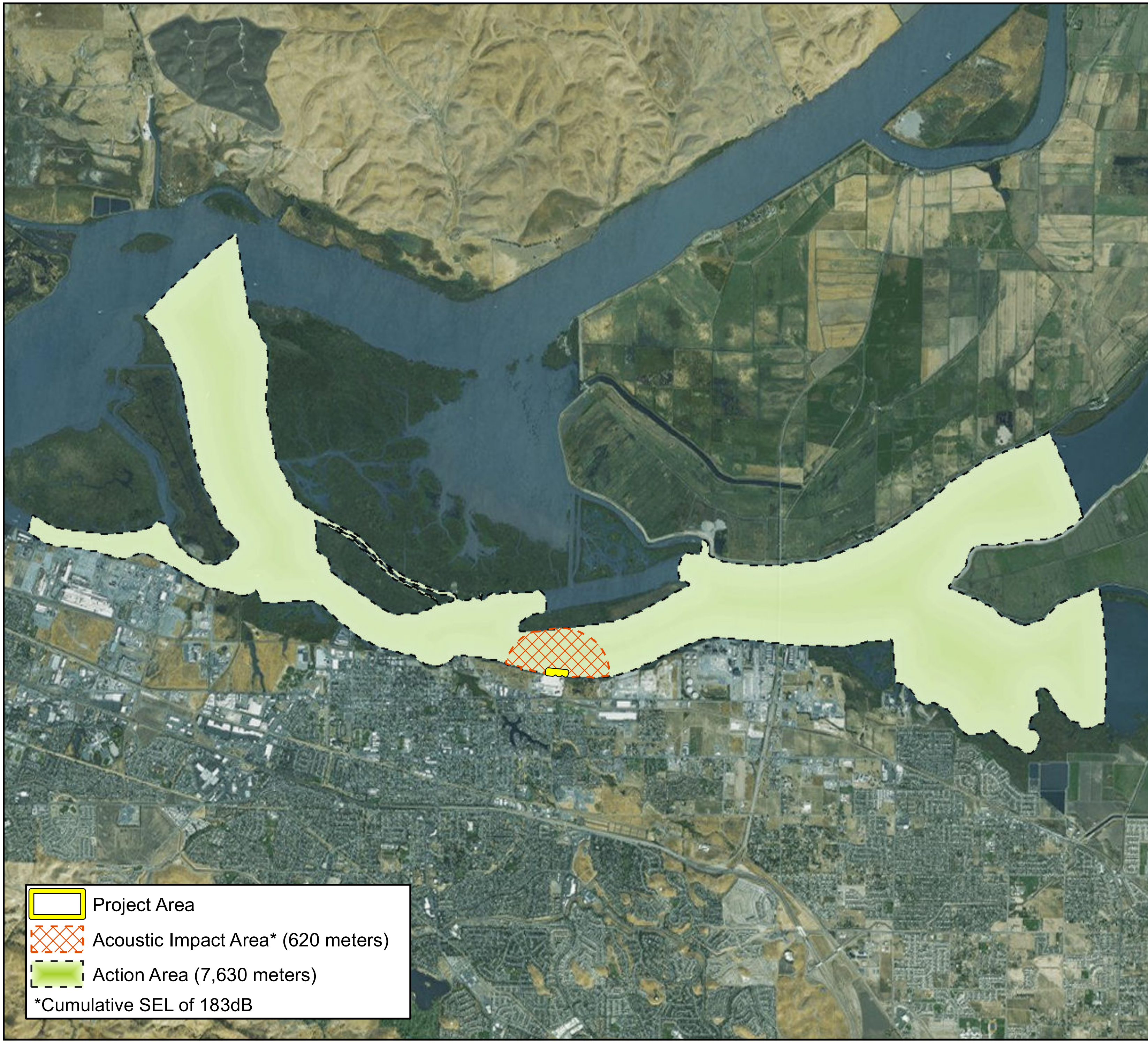
Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 2 Supplemental.mxd

USFWS Unattenuated Hydroacoustic Action Area

Supplemental Figure 3. USFWS Unattenuated Hydroacoustic Action Area. This figure depicts the anticipated distance the 150 dB threshold (Action Area) and the cumulative SEL of 183 dB threshold (Acoustic Impact Area) will extend from impact pile driving locations when no sound attenuation is used. The 183 dB threshold is intended for fish <2 grams. The area (acres) each threshold is anticipated to extend is provided in the table below. As described in the BA, river bathymetry and island/terrestrial land masses are anticipated to distort and limit the extent of the Action Area.

Supplemental Table 3. Area and radius for unattenuated hydroacoustic effects identified in Supplemental Figure 3.

Area	Acreage	Square Feet	Radius (meters)*	Description
Action Area	5,6163.82	244,667,785	7,630	The anticipated maximum distance for 150 dB using attenuation; discussed in greater detail and shown on Fig 4 of the Biological Assessment (BA).
Acoustic Impact Area	377.20	16,430,953	1,065	The anticipated maximum distance for cumulative SEL of 183 dB using attenuation; discussed in greater detail in the BA and shown on Supplemental Figure 3.
30m Buffer From Pile Driving Locations	3.48	151,804	30	The anticipated maximum distance for 206 dB using attenuation; 30m buffer applied around each pile driving location.



ENVIRONMENTAL CONSULTANTS

Georgia-Pacific Antioch Wharf Breasting Dolphins Replacement Project

Contra Costa County, CA

Supplemental Figure 3.

USFWS Unattenuated Hydroacoustic Action Area

Map Date: February 2014
Map By: Chris Zumwalt
Base Source: ESRI Streaming 11/02/2010

Path: L:\Acad 2000 Files\24000\24305\GIS\ArcMap\Fig 3 Supplemental.mxd

APPENDIX D – Hydroacoustic Assessment

Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project

UNDERWATER NOISE ASSESSMENT

Draft November 2014
Final January 2015

Prepared for:

Ben C. Gerwick, Inc
1300 Clay Street
Oakland, CA 94612

Prepared by:

ILLINGWORTH & RODKIN, INC.
Acoustics • Air Quality

423 4th Street, Suite S3W
Marysville, CA 95901

Project No: 14-191

TABLE OF CONTENTS

I. Introduction **1**

II. Underwater Sounds from Pile Driving **1**

Fundamentals of Underwater Noise 1

III. Underwater Sound Thresholds **4**

Fish 4

IV. Underwater Sound Generating Activities **6**

Project Related Noise Sources 6

Discussion of Underwater Sound Generation from Pile Driving 7

Prediction of Underwater Sound from Project Pile Driving 8

Impact Pile Driving 9

V. Conclusion **11**

List of Tables

Table 1 - Definitions of Underwater Acoustical Terms 3

Table 2 - Adopted Impact Pile Driving Acoustic Criteria for Fish 5

Table 3 - Piles Associated with New Terminal Construction Activities 7

Table 4 - Underwater Sound Levels at 10 Meters Based on Similar Projects 8

Table 5 - Modeled Extent of Sound Pressure Levels from Unattenuated and Attenuated Impact Driving of One Pile 10

Table 6 - Cumulative SEL levels at 10 meters and Distances to the 187 dB and 183 dB Cumulative SEL Criterion for Pile Driving 11

I. INTRODUCTION

Georgia–Pacific proposes to drive thirteen (13) piles in the San Joaquin River to replace a portion of their terminal in Antioch, CA. This report is an assessment of potential sound levels generated by planned pile driving activities for the Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project. The project proposes to install three (3) 24-inch steel pipe piles, three (3) 30-inch steel pipe piles, two (2) 42-inch steel pipe piles, one (1) 48-inch steel pipe pile, and four (4) 72-inch steel pipe piles as part of the new structure.

Pile driving will be conducted with both a vibratory hammer and a diesel impact hammer. It is estimated that each pile will require approximately 15 minutes of vibratory driving and 100 to 700 blows with an impact hammer to drive the piles to final tip elevation.

This report includes the prediction of underwater sound levels. Calculations are based on the results of measurements for similar projects. Predicted underwater sound levels are compared against interim thresholds that have been accepted by the Federal Highway Administration (FHWA), California Department of Transportation (Caltrans), and the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS). These thresholds are discussed in this report.

Pile driving will produce underwater noise in and around the project area. Most of the pile driving activities would be in water about 30 feet deep, and would be in the vicinity of the existing docks. It is difficult to predict underwater sound levels from pile driving activities without actual measurements of similar piles in the area. However, it is possible to estimate the sound level based on the results of measurements that have been previously performed for similar projects in different areas. In this analysis, available underwater sound data for projects involving the installation of similar types of piles were reviewed. The sound levels for proposed pile driving activities were estimated using these data combined with an understanding of how and where these activities would occur. These predictions are essentially a best estimate based on empirical data and engineering judgment, but by their very nature contain a degree of uncertainty. The duration of driving for each pile installation and number of piles strikes were also estimated as part of the noise prediction process, based on available data from similar projects and engineering estimates.

II. UNDERWATER SOUNDS FROM PILE DRIVING

Fundamentals of Underwater Noise

Sound is typically described by the pitch and loudness. Pitch is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Loudness is intensity of sound waves combined with the reception characteristics of the auditory system. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe sound. A decibel (dB) is a unit of measurement describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. For underwater sounds, a reference pressure of 1 micropascal (µPa) is commonly used to describe sounds in terms of decibels. Therefore, 0 dB on the decibel scale would be a measure of sound pressure of 1 µPa. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc.

When a pile driving hammer strikes a pile a pulse is created that propagates through the pile and radiates sound into the water, the ground substrate, and the air. Sound pressure pulse as a function of time is referred to as the waveform. In terms of acoustics, these sounds are described by the peak pressure, the root-mean-square pressure (RMS), and the sound exposure level (SEL). The peak pressure is the highest absolute value of the measured waveform, and can be a negative or positive pressure peak. For pile driving pulses, RMS level is determined by analyzing the waveform and computing the average of the squared pressures over the time that comprise that portion of the waveform containing the vast majority of the sound energy.[1] The pulse RMS has been approximated in the field for pile driving sounds by measuring the signal with a precision sound level meter set to the "impulse" RMS setting and is typically used to assess impacts to marine mammals. Another measure of the pressure waveform that can be used to describe the pulse is the sound energy itself. The total sound energy in the pulse is referred to in many ways, such as the "total energy flux".[2] The "total energy flux" is equivalent to the unweighted SEL for a plane wave propagating in a free field, a common unit of sound energy used in airborne acoustics to describe short-duration events referred to as dB re: 1µPa2-sec. Peak pressures and RMS sound pressure levels are expressed in dB re: 1µPa. The total sound energy in an impulse accumulates over the duration of that pulse. Figure 1 illustrates the descriptors used to describe the acoustical characteristics of an underwater pile driving pulse. Table 1 includes the definitions of terms commonly used to describe underwater sounds.

The variation of instantaneous pressure over the duration of a sound event is referred to as the waveform. Studying the waveforms can provide an indication of rise time; however, rise time differences are not clearly apparent for pile driving sounds due to the numerous rapid fluctuations that are characteristic to this type of impulse. A plot showing the accumulation of sound energy over the duration of the pulse (or at least the portion where much of the energy accumulates) illustrates the differences in source strength and rise time. An example of the characteristics of a typical pile driving pulse is shown in Figure 1.

[1] Richardson, Greene, Malone & Thomson, *Marine Mammals and Noise*, Academic Press, 1995 and Greene, personal communication.

[2] Finerran, et. al., *Temporary Shift in Masked Hearing Thresholds in Odontocetes after Exposure to Single Underwater Impulses from a Seismic Watergun*, Journal of the Acoustical Society of America, June 2002.

Table 1 - Definitions of Underwater Acoustical Terms

Term	Definition
Decibel, dB	A unit describing, the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air is 20 micropascals (µPa) and 1 µPa for underwater.
Equivalent Noise Level, L_{eq}	The average noise level during the measurement period.
L_{01}, L_{10}, L_{50}, L_{90}	The sound levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period.
Peak Sound Pressure, unweighted (dB)	Peak sound pressure level based on the largest absolute value of the instantaneous sound pressure. This pressure is expressed in this report as a decibel (referenced to a pressure of 1 µPa) but can also be expressed in units of pressure, such as µPa or PSI.
RMS Sound Pressure Level, (NMFS Criterion)	The average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy for one pile driving impulse.[3]
Sound Exposure Level (SEL), dB re: 1 μPa^2 sec	Proportionally equivalent to the time integral of the pressure squared and is described in this report in terms of dB re: 1 μPa^2 sec over the duration of the impulse. Similar to the unweighted Sound Exposure Level (SEL) standardized in airborne acoustics to study noise from single events.
Cumulative SEL	Measure of the total energy received through a pile-driving event (here defined as pile driving over one day
Waveforms, µPa over time	A graphical plot illustrating the time history of positive and negative sound pressure of individual pile strikes shown as a plot of µPa over time (i.e., seconds)
Frequency Spectra, dB over frequency range	A graphical plot illustrating the distribution of sound pressure vs. frequency for a waveform, dimension in RMS pressure and defined frequency bandwidth

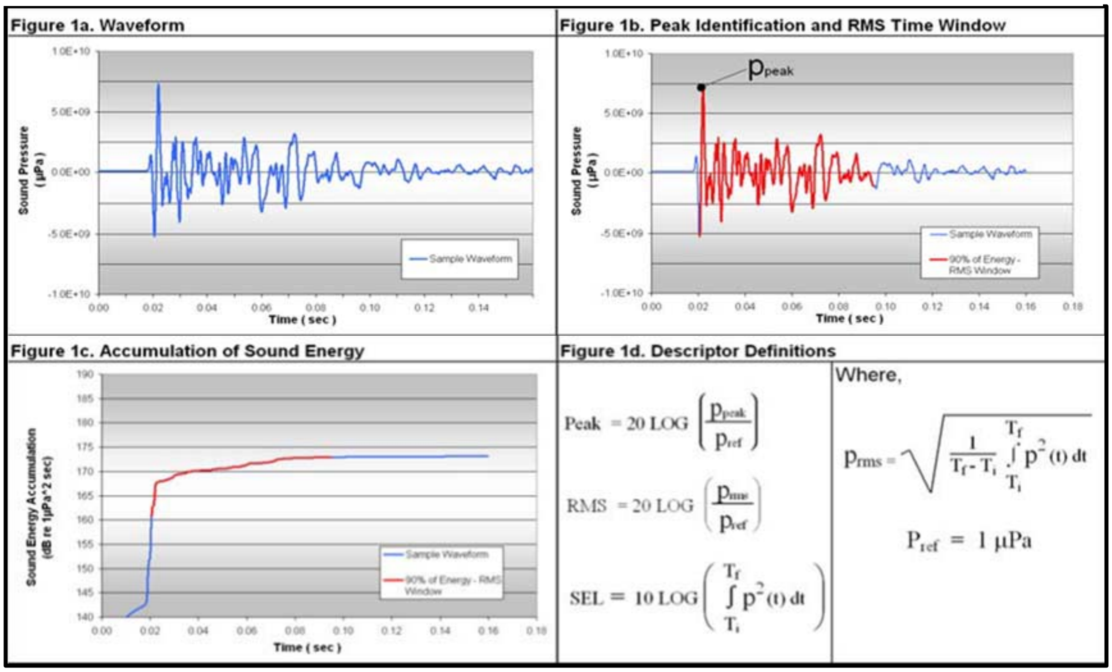
SEL is an acoustic metric that provides an indication of the amount of acoustical energy contained in a sound event. For pile driving, the typical event can be one pile driving pulse or many pulses such as pile driving for one pile or for one day of driving multiple piles. Typically, SEL is measured for a single strike and a cumulative condition. The cumulative SEL associated with the driving of a pile can be estimated using the single strike SEL value and the number of pile strikes through the following equation:

$$SEL_{CUMULATIVE} = SEL_{SINGLE\ STRIKE} + 10 \log (\#\ of\ pile\ strikes)$$

For example, if a single strike SEL for a pile is 165 dB and it takes 1,000 strikes to drive the pile, the cumulative SEL is 195 dBA (165 dB + 30 dB = 195 dB), where 10 * Log10(1000) = 30.

[3] The underwater sound measurement results obtained during the Pile Installation Demonstration Project indicated that most pile driving impulses occurred over a 50 to 100 millisecond (msec) period. Most of the energy was contained in the first 30 to 50 msec. Analysis of that underwater acoustic data for various pile strikes at various distances demonstrated that the acoustic signal measured using the standard “impulse exponential-time-weighting” (35-msec rise time) correlated to the RMS (impulse) level measured over the duration of the impulse.

Figure 1 - Characteristics of a Pile Driving Pulse



III. UNDERWATER SOUND THRESHOLDS

Underwater sound effects to fish and marine mammals are discussed below. In this report, peak pressures and RMS sound pressure levels are expressed in decibels re: 1 µPa. Sound exposure levels are expressed as dB re: 1µPa2-sec.

Fish

A Fisheries Hydroacoustic Workgroup (FHWG) that consisted of transportation officials, resources agencies, the marine construction industry (including Ports), and other experts was formed in 2003 to address the underwater sound issues associated with marine construction. The first order of business was to document all that was clearly known about the effects of sound on fish, which was reported in "The Effects of Sound on Fish."[4] This report recommended preliminary guidance to protect fish. A graph showing the relationship between the SEL from a single pile strike and injurious effects to fish based on size (i.e., mass) was presented. Fish with a mass of about 0.03 grams were expected to have no injury for a received SEL of a pile strike below 194 dB and suffer 50% mortality at about 197 dB. The report also described possible effects to the auditory system (i.e., auditory tissue damage and hearing loss), based on a received dose of sound. The recommendations were frequency dependent, based on the hearing thresholds of fish or most sensitive auditory bandwidths. For salmonids, hearing effects would be expected at or near the thresholds for injury based on the single strike SEL. A further investigation into the effects of pile

[4] Hastings, M and A. Popper. 2005. The Effects of Sound on Fish. Prepared for the California Department of Transportation. January 28 (revised August 23).

driving sounds on fish was also recommended.

Caltrans commissioned a subsequent report to provide additional explanation of, and a practical means to apply, injury criteria recommended in "The Effects of Sound on Fish." This report is entitled "Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper," (White Paper).[5] The White Paper recommended a dual criterion for evaluating the potential for injury to fish from pile driving operations. The dual approach considered that a single pile strike with high enough amplitude, as measured by zero to peak (either negative or positive pressure) could cause injury. A peak pressure threshold for a single strike was recommended at 208 dB. In 2007, Carlson et al provided an update to the White Paper in a memo titled "Update on Recommendation for Revised Interim Sound Exposure Criteria for Fish during Pile Driving Activities."[6] In this memo, they propose criteria for each of three different effects on fish: 1) hearing loss due to temporary threshold shift, 2) damage to auditory tissues, and 3) damage to non-auditory tissues. These criteria vary due to the mass of the fish and if the fish is a hearing specialist or hearing generalist. In preparing this update, Dr. Mardi Hastings summarized information from some current studies in a report titled "Calculation of SEL for Govoni et al. (2003, 2007) and Popper et al. (2007) Studies."

On June 12, 2008, NMFS; U.S. Fish and Wildlife Service (USFWS); California, Oregon, and Washington Departments of Transportation; California Department of Fish and Game; and the U.S. Federal Highway Administration generally agreed in principal to interim criteria to protect fish from pile driving activities, as shown in Table 2. Note that the peak pressure criterion of 206 dB was adopted (rather than 208 dB), as well as accumulated SEL criteria for fish smaller than 2 grams. NMFS interpretation of the interim criteria is described by Woodbury and Stadler (2009).[7]

Table 2 - Adopted Impact Pile Driving Acoustic Criteria for Fish

Interim Criteria for Injury	Agreement in Principle
Peak	206 dB for all sizes of fish
Cumulative SEL	187 dB for fish size of two grams or greater. 183 dB for fish size of less than two grams.
Behavior effects threshold for all sizes of fish is 150 dB RMS	

The primary difference between the adopted criteria and previous recommendations is that the single strike SEL was replaced with a cumulative SEL over a day of pile driving. NMFS does not consider sound that produces an SEL per strike of less than 150 dB to accumulate and cause injury.

5 Popper, A., Carlson, T., Hawkins, A., Southall, B. and Gentry, R. 2006. Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper. May 14.

6 Carlson, T, Hastings, M and Popper, A. 2007. Memo to Suzanne Theiss, California Department of Transportation, Subject: Update on Recommendations for Revised Interim Sound Exposure Criteria for Fish during Pile Driving Activities. December 21.

7 Stadler, J. and Woodbury, D. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Proceedings of inter-noise 2009, Ottawa, Canada. August 23-26.

The adopted criteria listed in Table 2 are for pulse-type sounds (e.g., pile driving) and does not address sound from vibratory driving of piles; there are no acoustic thresholds that apply to the lower amplitude noise produced by vibratory pile driving. In fact, the acoustic thresholds developed for fish only apply to impact pile driving.

The Bureau of Ocean Energy Management, (BOEM—formerly Minerals Management Service), Caltrans, and National Cooperation of Highway Research Programs (NCHRP 25–28)/Transportation Research Board (TRB) have funded studies to identify the onset of injury to fish from impact pile driving. One of the goals of these studies was to provide quantitative data to define the levels of impulsive sound that could result in the onset of barotrauma injury to fish.[8] Laboratory simulation of pulse-type pile driving sounds enabled careful study of the barotrauma effects to Chinook salmon. The neutrally buoyant juvenile fish were exposed to impulsive sounds and subsequently evaluated for barotrauma injuries. Significant barotrauma injuries were not observed in fish exposed to 960 pulses at 180 dB SEL per pulse or 1,920 pulses at 177 dB per pulse. In both exposures, the resulting accumulated SEL was 210 dB SEL. Results of these studies are under review. At this time, the criteria in Table 2 are used by NMFS to judge impacts to fish. Potential behavior impacts that might occur above 150 dB RMS are not used to restrict pile driving.

IV. UNDERWATER SOUND GENERATING ACTIVITIES

Project Related Noise Sources

The primary sound generating activities associated with this project would be vibratory driving followed by impact driving of the steel shell piles. Preliminary indications are that an APE 400 vibratory hammer and a Delmag D160 diesel impact hammer would be required to drive the 42-inch, 48-inch, and the 72-inch piles. The 24-inch and the 30-inch walkway piles will be installed using an ICE 44 vibratory hammer and a Delmag D62 diesel impact hammer. The driving periods are not likely to be continuous. The required pile embedment and estimated number of pile strikes per pile is shown in Table 3.

---

8 Halvorsen MB, Casper BM, Woodley CM, Carlson TJ, Popper AN (2012) Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds. PLoS ONE 7(6): e38968. oi:10.1371/journal.pone.0038968

Table 3 - Piles Associated with New Terminal Construction Activities

Location	Quantity	Diameter (inches)	Pile Embedment Depth (feet)	Estimated Number of Pile Strikes
Breasting Dolphin Piles	4	72	65	700
Mooring Piles	2	42	51	420
	1	48	56	520
Walkway Piles	1	24	38	160
	2	24	48	360
	3	30	35	100

For vibratory installation it is estimated that the piles will be driven 30 feet; which would take approximately 15 minutes for each pile. For impact pile driving, pile installation is estimated to require 20 blows per foot until the pile reaches its required depth. A full pile driving event was assumed to require 100 to 700 pile strikes. The project would install one (1) pile per day for the 72-inch piles and up to two (2) piles per day for all other piles. In terms of underwater sound effects on fish, the highest cumulative sound levels would occur under any scenario where a 72-inch pile is impact driven in one day.

Impact pile driving produces pulsed-type sounds, while vibratory driving will produce more continuous-type sounds. The distinction between these two general sound types is important because they have differing potential to cause physical effects, particularly with regard to hearing. Pulsed sounds, such as impact pile driving, explosions, or seismic air guns, are brief, distinct acoustic events that occur either as an isolated event (e.g., explosion) or repeated in some succession (e.g., impact pile driving). Pulsed sounds are all characterized by discrete acoustic events that include a relatively rapid rise in pressure from ambient conditions to a maximum pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures. Pulsed sounds are typically high amplitude events that have the potential to cause hearing injury. Continuous or non-pulsed sounds can be tonal or broadband. These sounds include vessels, aircraft, machinery operations such as vibratory pile driving or drilling, and active sonar systems. This project will have both pulsed and continuous type sounds from pile installation.

Discussion of Underwater Sound Generation from Pile Driving

A review of underwater sound measurements for similar projects was undertaken to estimate the near-source sound levels for vibratory and impact pile driving. Sounds from similar-sized steel shell piles have been measured in water for several projects. Measurements conducted for the Richmond Inner Harbor Project, Richmond San Rafael Bridge Seismic Retrofit, Trinidad Pier Replacement, Amorco Wharf Construction Project, the US Navy Test Pile Program and the US Navy Explosive Handling Wharf Project (EHW) are most representative due to the similar pile size and depth of water at the site. The projects included installation of 24-inch, 36-inch, 48-inch, and

72-inch diameter steel pipe piles. It is estimated that the noise levels for the 30-inch piles will be similar to the 36-inch piles and 42-inch piles will be the same as the 48-inch piles. Table 4 shows the acoustical measurements that were made during the installation of these piles.[9,10,11,12,13]

Table 4 - Underwater Sound Levels at 10 Meters Based on Similar Projects

Pile Driving Scenario	Peak Pressure (dB re:1µPa)	RMS Sound Pressure Level (dB re:1µPa)	SEL (dB re: 1µPa^{2}sec)	Data Source
24-in. Diameter Impact Pile Driving	205	189	178	Amorco Wharf Construction
30-in. Diameter Impact Pile Driving (similar to 36 in)	208	190	177	U.S. Navy Kitsap Bangor
42 & 48-in. Diameter Impact Pile Driving	209	192	180	U.S. Navy Kitsap Bangor
72-in. Diameter Impact Pile Driving	214	199	189	Richmond San Rafael Bridge

Prediction of Underwater Sound from Project Pile Driving

Estimated noise impacts are discussed specifically for each type of pile driving. The near source sound levels were used to predict underwater sound levels at various distances from the pile being driven. These levels represent unattenuated conditions (i.e., no air bubble curtain or other means of reducing underwater sound levels). Based on past projects it is estimated that sound levels can be reduced up to 10 dB using a properly deployed attenuation device.

Sound from pile installation (i.e., impact driving) would transmit or propagate from the construction area. Transmission loss (TL) is the decrease in acoustic pressure as the sound pressure wave propagates away from the source. TL parameters vary with frequency, temperature, sea conditions, current, source and receiver depth, water depth, water chemistry, and bottom composition and topography. NMFS has developed an underwater acoustic calculator that uses practical spreading to predict sound levels at various distances from the source. The formula for transmission loss is TL = X log10 (R/10), where X is the calculated drop off rate and R is the distance from the source assuming the near source levels are at 10 meters. This TL model, based on the default practical spreading loss assumption, was used to predict underwater sound levels generated by pile installation from this project. For this analysis a TL of 18 to 20 Log(R/10) (i.e.,

[9] Illingworth & Rodkin. 2012. Naval Base Kitsap at Bangor Test Pile Program: Acoustic Monitoring Report. Prepared by Illingworth & Rodkin, Inc. for U.S. Navy.

[10] Illingworth & Rodkin, Inc. 2013. Naval Base Kitsap at Bangor Trident Support Facilities Explosive Handling Wharf (EHW-2) Project - Acoustic Monitoring Report , BANGOR, WASHINGTON. 23 April 2013, Revised 15 May 2013. Prepared by Illingworth & Rodkin, Inc. for U.S. Navy. Available at http://www.nmfs.noaa.gov/pr/pdfs/permits/navy_kitsap_ehw2_acoustics2013.pdf, accessed October 15, 2014.

[11] Illingworth & Rodkin. 2009. Trinidad Pier Replacement. Prepared by Illingworth & Rodkin, Inc.

[12] Illingworth & Rodkin. 2003. Letter to Michael Cheney reporting results of underwater sound measurements. Prepared by Illingworth & Rodkin, Inc. for Castrol Oil.

[13] Illingworth & Rodkin. 2005. Letter to Sharon Lim (Tesoro) reporting results of underwater sound measurements. Prepared by Illingworth & Rodkin, Inc. for Tesoro.

18 dB loss per ten-fold increase in distance) was used for vibratory pile driving and a 17 Log TL(R/10) function was used for impact driving. These TL values were measured based on the drop off rate for EHW measurements in relatively deep water across the Hood Canal. This rate of transmission loss was much less than that measured by Blackwell in the Knik Arm of 22 to 29 dB per 10-fold increase in distance.[14] However, NMFS recommends a default practical spreading loss of 15 dB per ten-fold increase in distance when reliable data not available. Measurements conducted during pile driving for the project could further refine the rate of sound propagation or TL.

Impact Pile Driving

Peak sound pressure levels, average RMS sound pressure levels, and SELs from impact driving were predicted using the near source levels for impact pile driving and the practical loss sound propagation assumptions described above. Table 5 shows the extent of sound levels for the NMFS marine mammal and fish criteria.

Reducing sounds from impact pile driving using air bubble curtains is common. Caltrans reports a large range in sound reduction from almost no reduction to 30 dB as a result of use of these curtains. During the EHW project (i.e., the source of impact pile driving levels for this assessment) the reduction from an air bubble curtain was between 8 and 14 dB. Therefore, this assessment assumes that underwater sounds could be reduced at least 10 dB with the use of a properly designed and deployed air bubble curtain attenuation system.

Accumulated SEL levels associated with impact pile driving will vary daily, depending on the amount of pile driving. Table 6 shows the estimated accumulated SEL levels at 10 meters and the estimated distances to the accumulated 187 dB and 183 dB SEL level with and without an attenuation system. Reduction in the SEL level requires a properly designed and deployed air bubble curtain system.

[14] Blackwell, S.B., 2005. Underwater Sound Measurements of Pile-Driving Sounds during the Port MacKenzie Dock Modifications, 13-16 August 2004. Greeneridge Sciences Report 328-1.March 2005.

Table 5 - Modeled Extent of Sound Pressure Levels from Unattenuated and Attenuated Impact Driving of One Pile

Modeling Scenario	Distance to Marine Mammal Acoustic Criteria in Meters			Distance to Fish Acoustic Criteria in Meters			Distance to Behavioral Zone
	RMS (dB re: 1uPa)			Peak (dB re: 1uPa)	Cumulative SEL[15] (dB re:1uPa-sec2)		RMS (db re:1uPa)
	Level B Harassment	Level A Injury					
	160	**180**	**190**	**206**	**187**	**183**	**150**
72-inch Piles (Pile ID: BD 1-4) Estimated 700 Pile Strikes per Pile							
Modeled Unattenuated	1,970[16]	130	35	30	620	1,065[16]	7,630[16]
Assuming a 10 dB Reduction with Attenuation	510	35	<10	<10	160	275	1,970[16]
48-inch Pile (Pile ID: MD 3) Estimated 520 Pile Strikes							
Modeled Unattenuated	765[16]	50	15	15	155	265	2,955[16]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	40	70	765[16]
42-inch Piles (Pile ID: MD 1&2) Estimated 420 Pile Strikes per Pile							
Modeled Unattenuated	765[16]	50	15	15	135	235	2,955[16]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	35	60	765[16]
30-inch Piles (Pile ID: WB 3-5) Estimated 100 Pile Strikes per Pile							
Modeled Unattenuated	580	40	<10	15	40	70	2,255[16]
Assuming a 10 dB Reduction with Attenuation	150	<10	<10	<10	10	20	580
24-inch Piles (Pile ID: WB 2&6) Estimated 360 Pile Strikes per Pile							
Modeled Unattenuated	510	35	<10	<10	95	160	1,970[16]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	25	40	510
24-inch Pile (Pile ID: WB 1) Estimated 160 Pile Strikes							
Modeled Unattenuated	510	35	<10	<10	60	100	1,970[16]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	15	25	510

[15] Base on the driving of one pile. SEL criteria apply to impact pile driving events that occur during one day. See Table 6 for predicted accumulated SEL for various daily pile driving scenarios.

[16] Distance to underwater noise thresholds is partially constrained by river topography

Table 6 - Cumulative SEL levels at 10 meters and Distances to the 187 dB and 183 dB Cumulative SEL Criterion for Pile Driving

Modeling Scenario	Total Strikes	Attenuation	Cumulative SEL (dB) at 10 Meters	Distance to 187 dB Cumulative SEL (Meters)	Distance to 183 dB Cumulative SEL (Meters)
One 72-inch pile	700	Unattenuated	217	62016	1065[17]
		Attenuated	207	160	275
MD1 (42-inch) & WB1 (24-inch)	580	Unattenuated	207	145	245
		Attenuated	197	40	65
MD2 (42-inch) & WB2 (24-inch)	780	Unattenuated	208	170	290
		Attenuated	198	45	75
BD1 (72-inch) & WB3 (30-inch)	800	Unattenuated	217	585	1005[17]
		Attenuated	207	150	260
WB4 (30-inch) & WB5 (30-inch)	200	Unattenuated	200	60	100
		Attenuated	190	15	25
WB6 (24-inch) & MD3 (48-inch)	880	Unattenuated	209	180	315
		Attenuated	198	50	80
WB5 (30-inch) & WB6 (24-inch)	460	Unattenuated	204	95	165
		Attenuated	194	25	40

[17] Distance to underwater noise thresholds is partially constrained by river topography

V. CONCLUSION

The levels generated during impact driving of all unattenuated piles except the 24-inch piles will exceed the adopted 206 dB peak criteria for injury to fish. The levels generated during impact pile driving of all attenuated piles will not exceed the 206 dB peak criteria. The cumulative SEL will exceed the 187 dB criteria with and without an attenuation system on all piles.

The worst case scenario for impact driving is driving a single 72-inch pile. It is estimated that the 206 dB peak level for an unattenuated 72-inch pile is at 30 meters. The cumulative SEL will exceed the 187 dB criteria out to a distance of approximately 620 meters unattenuated and 160 meters attenuated.

Vibratory pile installation results in much lower amplitude sound levels. The use of vibratory hammers for pile driving in San Francisco Bay is allowed without restrictions on the size of piles or time of year work is performed according to the program level "Not Likely to Adversely

Affect" (NLAA) consultation from the U.S. Army Corps of Engineers (Corps) in 2006. The NLAA consultation was developed jointly between the Corps, USFWS, and NMFS, and was approved by the USFWS on December 6, 2006, and by NMFS on December 21, 2007. The NLAA consultation concluded that use of a vibratory hammer, regardless of pile size, is not likely to exceed underwater sounds level thresholds established by NMFS for impacts to fish. While the application of the NLAA consultation to actions undertaken by non-governmental entities is up to the discretion of the Corps and NMFS, the measures included in that consultation are useful as guidance, and the Action's use of a vibratory hammer is consistent with the NLAA standards.

APPENDIX E – Sediment Toxicity Results

This page intentionally left blank.

Table D-1. Results of Chemical and Physical Analyses of Georgia Pacific Surface Sediments (Weston, 2010)

Analyte		GP-COMP Results	Reference Values								
			SF Bay Ambient Levels[a]	MWP Acceptance Criteria[b]		CalEPA CHSSL[c]		U.S. EPA PRGs[d]		SF Bay RWQCB ESLs[e]	
				Non Cover	Cover	Residential	Industrial/ Commercial	Residential	Industrial/ Commercial	Residential	Industrial/ Commercial
Conventionals											
Grain Size (%)	*Gravel*	2.41	-	-	-	-	-	-	-	-	-
	Sand	85.0	-	-	-	-	-	-	-	-	-
	Silt	7.32	-	-	-	-	-	-	-	-	-
	Clay	5.34	-	-	-	-	-	-	-	-	-
Total Solids (%)		78.5	-	-	-	-	-	-	-	-	-
Metals (mg/kg)											
Arsenic		5.00	15.3	85	33	0.070	0.2	0.39	1.6	0.39	1.6
Cadmium		0.192	0.33	9	0.5	1.7	7.5	70	800	1.7	7.4
Chromium		23.4	112	300	220	17	37	280	1,400	NA	NA
Copper		16.1	68.1	390	90	3,000	38,000	3,100	41,000	230	230
Lead		10.5	43.2	110	50	150	3,500	400	800	200	750
Mercury		0.109	0.43	1.3	0.35	18	180	4.3	24	1.3	10
Nickel		39.2	112	200	140	1,600	16,000	1,500	20,000	150	150
Selenium		0.145	0.64	1.4	0.7	380	4,800	390	5,100	10	10
Silver		0.140	0.58	2.2	1.0	380	4,800	390	5,100	20	40
Zinc		53.5	158	270	160	23,000	100,000	23,000	310,000	600	600
PAHs (µg/kg)											
Acenaphthene		10.7	26.6	NA	NA	NA	NA	3,400,000	33,000,000	19,000	19,000
Acenaphthylene		< 5.96	31.7	NA	NA	NA	NA	NA	NA	NA	NA
Anthracene		16.2	88	NA	NA	NA	NA	17,000,000	170,000,000	2,800	2,800
Benzo (a) anthracene		148	244	NA	NA	NA	NA	150	2,100	380	1,300
Benzo (b) fluoranthene		181	371	NA	NA	NA	NA	150	2,100	380	1,300
Benzo (k) fluoranthene		86.7	258	NA	NA	NA	NA	1,500	21,000	380	1,300
Benzo (ghi) perylene		< 12.4	310	NA	NA	NA	NA	NA	NA	27,000	27,000
Benzo (a) pyrene		49.7	412	NA	NA	38	130	15	210	38	130
Chrysene		188	289	NA	NA	NA	NA	15,000	21,000	23,000	23,000
Dibenz (a,h) anthracene		19.1	32.7	NA	NA	NA	NA	15	210	62	210
Fluoranthene		547	514	NA	NA	NA	NA	2,300,000	22,000,000	40,000	40,000
Fluorene		15.8	25.3	NA	NA	NA	NA	2,300,000	22,000,000	8,900	8,900
Indeno (1,2,3-cd) pyrene		34.9	382	NA	NA	NA	NA	150	2,100	620	2,100
Naphthalene		3.24	55.8	NA	NA	NA	NA	3,900	20,000	1,300	2,800
Phenanthrene		303	237	NA	NA	NA	NA	NA	NA	11,000	11,000
Pyrene		227	665	NA	NA	NA	NA	1,700,000	17,000,000	85,000	85,000
TOTAL PAHs		1,830	3,390	35,000	4,000	NA	NA	NA	NA	NA	NA

NA Not Available, < Indicates concentrations are less than the corresponding method detection limit (MDL),
[a] Ambient Levels reported for fine grained sediment (SFBRWQCB 1998)
[b] Montezuma Wetlands Project WDR Sediment Acceptance Criteria (SFBRWQCB 1999)
[c] California Human Health Screening Levels (CHHSLs) (OEHHA 2009)
[d] Preliminary Remediation Goals (PRGs) U.S. EPA Region 9 (USEPA 2009)
[e] Environmental Screening Levls (ESLs) for sites where groundwater is not drinking water source (SFBRWQCB 2008)

Table D-1 Continued. Results of Chemical and Physical Analyses of Georgia Pacific Surface Sediments (Weston 2010)

Analyte	GP-COMP Results	Reference Values								
		SF Bay Ambient Levels[a]	MWP Acceptance Criteria[b]		CalEPA CHSSL[c]		U.S. EPA PRGs[d]		SF Bay RWQCB ESLs[e]	
			Non Cover	Cover	Residential	Industrial/ Commercial	Residential	Industrial/ Commercial	Residential	Industrial/ Commercial
Organotins (µg/kg)										
Tetrabutyltin	<1.13	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tributyltin	< 1.26	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dibutyltin	< 1.47	NA	NA	NA	NA	NA	NA	NA	NA	NA
Monobutyltin	<0.70	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aroclor PCBs (µg/kg)										
1016	< 2.98	NA	NA	NA	NA	NA	3,900	21,000	NA	NA
1221	< 2.98	NA	NA	NA	NA	NA	170	620	NA	NA
1232	< 2.98	NA	NA	NA	NA	NA	170	620	NA	NA
1242	< 2.98	NA	NA	NA	NA	NA	220	740	NA	NA
1248	< 2.98	NA	NA	NA	NA	NA	220	740	NA	NA
1254	< 2.98	NA	NA	NA	NA	NA	220	740	NA	NA
1260	< 2.98	NA	NA	NA	NA	NA	220	740	NA	NA
Total	< 2.98	30	400	50	178	600	NA	NA	440	1,480
Pesticides (µg/kg)										
Aldrin	< 0.32	NA	NA	NA	33	130	29	100	32	130
Alpha-BHC	< 0.17	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beta-BHC	< 0.27	NA	NA	NA	NA	NA	NA	NA	NA	NA
Gamma-BHC	< 0.22	NA	NA	NA	NA	NA	NA	NA	NA	NA
Delta-BHC	< 0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chlordane (Total)	< 3.03	1.1	1.1	1.1	430	1,700	1,600	6,500	440	1,700
2,4-DDD	< 0.78	NA	NA	NA	NA	NA	NA	NA	NA	NA
4,4-DDD	< 0.31	NA	NA	NA	2,300	9,000	2,000	7,200	2,300	9,000
2,4 DDE	< 0.69	NA	NA	NA	NA	NA	NA	NA	NA	NA
4,4 DDE	< 0.30	NA	NA	NA	1,600	6,300	1,400	5,100	1,600	4,000
2,4 DDT	< 1.27	NA	NA	NA	NA	NA	NA	NA	NA	NA
4,4 DDT	< 0.20	NA	NA	NA	1,600	6,300	1,700	7,000	1,600	4,000
Total DDT	< 0.20	7	100	3	NA	NA	NA	NA	NA	NA
Dieldrin	< 0.30	0.44	0.44	0.44	35	130	30	110	2.3	2.3
Endosulfan I	< 0.27	NA	NA	NA	NA	NA	370,000	3,700,000	4.6	4.6
Endosulfan II	< 0.48	NA	NA	NA	NA	NA	NA	NA	NA	NA
Endosulfan sulfate	< 0.31	NA	NA	NA	NA	NA	NA	NA	NA	NA
Endrin	< 0.31	NA	NA	NA	21,000	230,000	18,000	180,000	0.65	0.65
Endrin aldehyde	< 0.19	NA	NA	NA	NA	NA	NA	NA	NA	NA
Heptachlor	< 0.45	NA	NA	NA	130	520	110	380	14	14
Heptachlor epoxide	< 0.45	NA	NA	NA	NA	NA	53	190	15	15
Methoxychlor	< 0.47	NA	NA	NA	340,000	3,800,000	31	310	19,000	19,000
Toxaphene	< 11.2	NA	NA	NA	460	1,800	440	1,600	0.42	0.42

Table D-2. Results of Georgia-Pacific Sediment Leachate (m-WET) Analyses (Weston, 2010)

Analyte	GP-COMP Results (ug/L)	STLC Limit (ug/L)	Soluble Designated Levels (μg/L)	
			Low[b]	High[c]
Aluminum	14	NA	200	2,000
Antimony	2.0	15,000	6	600
Arsenic	1.14	5,000	0.004	0.04
Barium	64.4	100,000	1,000	10,000
Beryllium	< 0.04	750	1	10
Cadmium	0.520	1,000	0.07	0.7
Chloride	70,000	NA	106,000	1,060,000
Chromium	0.70	5,000	50	500
Chromium (VI)	< 2.0	5,600,000**	21	210
Cobalt	< 0.10	80,000	50	500
Copper	< 9.00	25,000	1,700	17,000
Iron	19.9	NA	300	3,000
Lead	< 0.07	5,000	20	200
Manganese	< 9.0	NA	50	500
Mercury	< 0.30	200	1.2	12
Molybdenum	11.7	350,000	10	100
Nickel	4.35	20,000	12	120
Selenium	0.250	1,000	20	200
Silver	< 0.30	5,000	35	350
Sulfate	1,550,000	NA	250,000	2,500,000
Thallium	< 0.02	7,000	0.1	1
Vanadium	< 2.0	24,000	50	500
Zinc	< 40.0	250,000	20,000	200,000

NA Not Available.

< Indicates concentrations are less than the corresponding method detection limit (MDL)

[a] Soluble Threshold Limit Concentrations (CCR 2009)

[b] Soluble Designated Level = [Water Quality Limit] x [Attenuation Factor] / [Dilution Factor of 10] (CVRWQCB 2007).

[c] Where natural background concentration in groundwater exceed a Water Quality Limit, Soluble Designated Level should be recalculated with Water Quality Limit set equal to background concentration (CVRWQCB 2007).

APPENDIX F – Essential Fish Habitat

This page intentionally left blank.

Supplemental Essential Fish Habitat Information for Georgia-Pacific Antioch Wharf

The proposed Project is located within an area designated as Essential Fish Habitat (EFH) for three Fishery Management Plans (FMPs); the Coastal Pelagic Species, Pacific Groundfish, and Pacific Salmon Management Plans. Details of the location, purpose, and description of the proposed Project, along with minimization and avoidance measures, are discussed in the Biological Assessment. A table of EFH within the Action Area identified in the Biological Assessment, and the anticipated Project effect is provided below.

Essential Fish Habitat	Effect Determination
Coastal Pelagic Species	**Not Likely to Destroy or Adversely Modify**
Pacific Groundfish	**Not Likely to Destroy or Adversely Modify**
Pacific Salmon	**Not Likely to Destroy or Adversely Modify**

<u>Background</u>

The Magnuson-Stevens Act (as amended by the Sustainable Fisheries Act) requires FMPs to "describe and identify essential fish habitat…, minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat" (§303(a)(7)). The Magnuson-Stevens Act defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." NMFS interpreted this definition in its regulations as follows: "waters" include aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include areas historically used by fish where appropriate; "substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities; "necessary" means "the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem"; and "spawning, breeding, feeding, or growth to maturity" covers the full life cycle of a species (§303(a)(7)). A brief description of each FMP for the Action Area is provided below.

The Pacific Coast Groundfish FMP manages 90-plus species over a large and ecologically diverse area (PFMC 2011a). EFH for Pacific Coast Groundfish is defined as the aquatic habitat necessary to allow for groundfish production to support long-term sustainable fisheries for groundfish and a healthy ecosystem.

The Coastal Pelagic Species fishery includes four finfish Pacific sardine (*Sardinops sagax*), Pacific [chub] mackerel (*Scomber australasicus*), northern anchovy (*Engraulis mordax*), and jack mackerel (*Trachurus symmetricus*), along with invertebrates, market squid (*Loligo opalescens*) and all krill (*Euphausiacea* spp) species that occur in the U.S. West Coast exclusive economic zone (EEZ) (PFMC 2011b). EFH for Coastal Pelagic Species includes all marine and estuarine waters from the shoreline along the coasts of California, Oregon, and Washington offshore to the limits of the EEZ and above the thermocline where sea surface temperatures range between 10˚C to 26˚C (PFMC 2011b). The Coastal Pelagic Species FMP also includes two Ecosystem Component Species; jacksmelt (*Atherinopsis californiensis*) and Pacific herring (*Clupea pallasii*).

The Pacific salmon FMP covers two species in California; Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). EFH for Pacific salmon means those waters and substrates necessary for production needed for a health ecosystem and support a sustainable fishery.

Analysis of Effects to EFH

Direct Effects

The Project will require the removal of existing creosote treated pilings and the placement of steel monopoles. The new steel monopoles will result in a permanent impact of 34.63 square feet (0.0008 acres) to shallow water habitat (BA Table 7). This impact will not result in the loss, reduction, or change in habitat features or functions for the three EFH FMPs.

The Project will result in the removal of 150 14-inch diameter creosote treated timber piles and approximately 20 cubic yards less fill than the existing Wharf. Removal of the timber piles will benefit EFH as removing these piles will reduce the amount of creosote potentially leaching into San Joaquin River and the downstream San Francisco Bay-Delta waters (Werme et al 2010). Additionally, the replacement Wharf will result in 157 square feet less over-water shadowing, and the new walkway will be made from a light transmitting material. Because of the reduction in fill, shading, and the removal of creosote treated piles, the Project will have a beneficial effect for EFH within the Action Area.

Indirect Effect

The impact of sea-level rise over the functional lifespan of the Wharf has been evaluated with the Project design, and is not anticipated to affect the Wharf. Additionally, steel components within the splash zone of the Wharf will have coatings or galvanization to protect them from corrosion. Indirect effects will not adversely affect EFH as a result of the Project.

Interrelated and Interdependent Effects

No interrelated or interdependent effects to EFH are expected as a result of the Project.

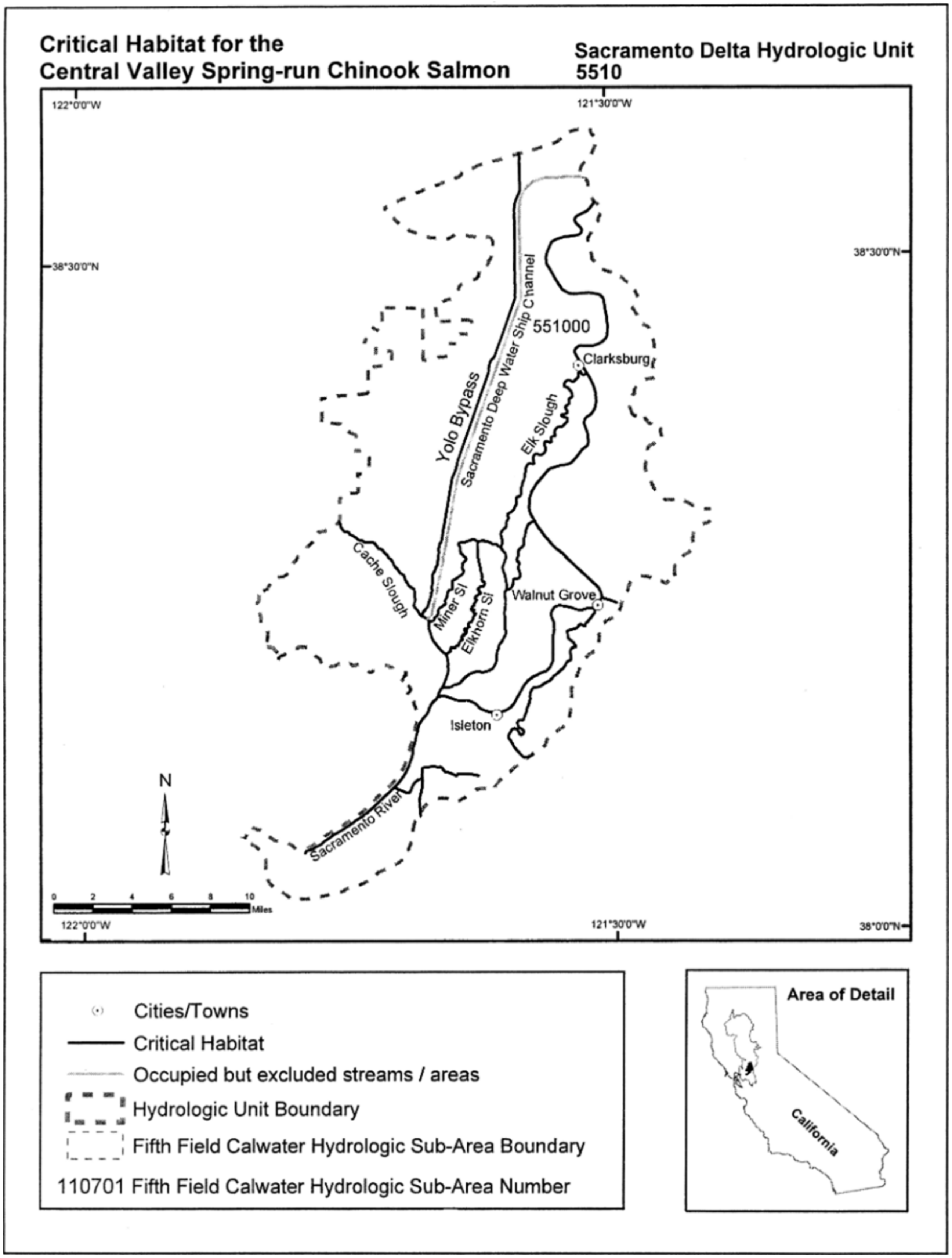
Cumulative Effects

No cumulative effects to EFH are anticipated to occur.

Conclusion

The Project will result in the removal of creosote treated piles and a reduction in both fill and shading, which is anticipated to result in improved aquatic habitat conditions within the Action Area. There will be no adverse change in habitat type or function for EFH within the Action Area as a result of the Project. Furthermore, the Action is not likely to destroy or adversely modify EFH in the Action Area.

EXHIBIT B



Critical Habitat for the
Central Valley Spring-run Chinook Salmon
Sacramento Delta Hydrologic Unit
5510
122°0'0"W
121°30'0"W
38°30'0"N
551000
Sacramento Deep Water Ship Channel
Yolo Bypass
Clarksburg
Elk Slough
Cache Slough
Miner Sl
Elkhorn Sl
Walnut Grove
Isleton
Sacramento River
N
0 2 4 6 8 10 Miles
38°0'0"N
Cities/Towns
Critical Habitat
Occupied but excluded streams / areas
Hydrologic Unit Boundary
Fifth Field Calwater Hydrologic Sub-Area Boundary
110701 Fifth Field Calwater Hydrologic Sub-Area Number
Area of Detail
California

(k) *Central Valley Spring Run Chinook Salmon (O. tshawytscha).* Critical habitat is designated to include the areas defined in the following CALWATER Hydrologic Units:

(1) Tehama Hydrologic Unit 5504—(i) *Lower Stony Creek Hydrologic Sub-area 550410.* Outlet(s) = Glenn-Colusa Canal (Lat 39.6762, Long –122.0151); Stony Creek (39.7122, –122.0072) upstream to endpoint(s) in: Glenn-Colusa Canal (39.7122, –122.0072); Stony Creek (39.8178, –122.3253).

(ii) *Red Bluff Hydrologic Sub-area 550420.* Outlet(s) = Sacramento River (Lat 39.6998, Long –121.9419) upstream to endpoint(s) in: Antelope Creek (40.2023, –122.1275); Big Chico Creek (39.7757, –121.7525); Blue Tent Creek (40.2284, –122.2551); Burch Creek (39.8526, –122.1502); Butler Slough (40.1579, –122.1320); Coyote Creek (40.0929, –122.1621); Craig Creek (40.1617, –122.1350); Deer Creek (40.0144, –121.9481); Dibble Creek (40.2003, –122.2420); Dye Creek (40.0904, –122.0767); Elder Creek (40.0526, –122.1717); Jewet Creek (39.8913, –122.1005); Kusal Slough (39.7577, –121.9699); Lindo Channel (39.7623, –121.7923); McClure Creek (40.0074, –122.1729); Mill Creek (40.0550, –122.0317); Mud Creek (39.7931, –121.8865); New Creek (40.1873, –122.1350); Oat Creek (40.0847, –122.1658); Pine Creek (39.8760, –121.9777); Red Bank Creek (40.1391, –122.2157); Reeds Creek (40.1687, –122.2377); Rice Creek (39.8495, –122.1626); Rock Creek (39.8189, –121.9124); Salt Creek (40.1869, –122.1845); Singer Creek (39.9200, –121.9612); Thomes Creek (39.8822, –122.5527); Toomes Creek (39.9808, –122.0642); Unnamed Tributary (39.8532, –122.1627); Unnamed Tributary (40.1682, –122.1459); Unnamed Tributary (40.1867, –122.1353).

(2) Whitmore Hydrologic Unit 5507—(i) *Inks Creek Hydrologic Sub-area 550711.* Outlet(s) = Inks Creek (Lat 40.3305, Long –122.1520) upstream to endpoint(s) in: Inks Creek 40.3418, –122.1332).

(ii) *Battle Creek Hydrologic Sub-area 550712* Outlet(s) = Battle Creek (Lat 40.4083, Long –122.1102) upstream to endpoint(s) in: Battle Creek (40.4228, –121.9975); North Fork Battle Creek (40.4746, –121.8436); South Fork Battle Creek (40.3549, –121.6861).

(iii) *Inwood Hydrologic Sub-area 550722.* Outlet(s) = Bear Creek (Lat 40.4352, Long –122.2039) upstream to endpoint(s) in: Bear Creek (40.4859, –122.1529); Dry Creek (40.4574, –122.1993).

(3) Redding Hydrologic Unit 5508—(i) *Enterprise Flat Hydrologic Sub-area 550810.* Outlet(s)= Sacramento River (Lat 40.2526, Long –122.1707) upstream to endpoint(s) in: Anderson Creek (40.3910, –122.1984); Ash Creek (40.4451, –122.1815); Battle Creek (40.4083, –122.1102); Churn Creek (40.5431, –122.3395); Clear Creek (40.5158, –122.5256); Cow Creek (40.5438, –122.1318); Olney Creek (40.5262, –122.3783); Paynes Creek (40.2810, –122.1587); Stillwater Creek (40.4789, –122.2597).

(ii) *Lower Cottonwood Hydrologic Sub-area 550820.* Outlet(s) = Cottonwood Creek (Lat 40.3777, Long –122.1991) upstream to endpoint(s) in: Cottonwood Creek (40.3943, –122.5254); Middle Fork Cottonwood Creek (40.3314, –122.6663); South Fork Cottonwood Creek (40.1578, –122.5809).

(4) Eastern Tehama Hydrologic Unit 5509—(i) *Big Chico Creek Hydrologic Sub-area 550914.* Outlet(s) = Big Chico Creek (Lat 39.7757, Long –121.7525) upstream to endpoint(s) in: Big Chico Creek (39.8873, –121.6979).

(ii) *Deer Creek Hydrologic Sub-area 550920.* Outlet(s) = Deer Creek (Lat 40.0144, Long –121.9481) upstream to endpoint(s) in: Deer Creek (40.2019, –121.5130).

(iii) *Upper Mill Creek Hydrologic Sub-area 550942.* Outlet(s) = Mill Creek (Lat 40.0550, Long –122.0317) upstream to endpoint(s) in: Mill Creek (40.3997, –121.5131).

(iv) *Antelope Creek Hydrologic Sub-area 550963.* Outlet(s) = Antelope Creek (Lat 40.2023, Long –122.1272) upstream to endpoint(s) in: Antelope Creek (40.2416, –121.8630); North Fork Antelope Creek (40.2691, –121.8226); South Fork Antelope Creek (40.2309, –121.8325).

(5) Sacramento Delta Hydrologic Unit 5510—(i) *Sacramento Delta Hydrologic Sub-area 551000.* Outlet(s) = Sacramento River (Lat 38.0612, Long –121.7948) upstream to endpoint(s) in: Cache Slough (38.3086, –121.7633); Delta Cross Channel (38.2433, –121.4964); Elk Slough (38.4140, –121.5212); Elkhorn Slough (38.2898, –121.6271); Georgiana Slough (38.2401, –121.5172); Miners Slough (38.2864, –121.6051); Prospect Slough (38.1477, –121.6641); Sevenmile Slough (38.1171, –121.6298); Steamboat Slough (38.3052, –121.5737); Sutter Slough (38.3321, –121.5838); Threemile Slough (38.1155, –121.6835); Yolo Bypass (38.5800, –121.5838).

(ii) [Reserved]

(6) Valley-Putah-Cache Hydrologic Unit 5511—(i) *Lower Putah Creek Hydrologic Sub-area 551120.* Outlet(s) = Yolo Bypass (Lat 38.5800, Long –121.5838) upstream to endpoint(s) in: Sacramento Bypass (38.6057, –121.5563); Yolo Bypass (38.7627, –121.6325).

(ii) [Reserved]

(7) Marysville Hydrologic Unit 5515—(i) *Lower Yuba River Hydrologic Sub-area 551510.* Outlet(s) = Bear River (Lat 38.9398, Long –121.5790) upstream to endpoint(s) in: Bear River (38.9783, –121.5166).

(ii) *Lower Yuba River Hydrologic Sub-area 551530.* Outlet(s) = Yuba River (Lat 39.1270, Long –121.5981) upstream to endpoint(s) in: Yuba River (39.2203, –121.3314).

(iii) *Lower Feather River Hydrologic Sub-area 551540.* Outlet(s) = Feather River (Lat 39.1270, Long –121.5981) upstream to endpoint(s) in: Feather River (39.5203, –121.5475).

(8) Yuba River Hydrologic Unit 5517—(i) *Browns Valley Hydrologic Sub-Area 551712.* Outlet(s) = Dry Creek (Lat 39.2207, Long –121.4088); Yuba River (39.2203, –121.3314) upstream to endpoint(s) in: Dry Creek (39.3201, –121.3117); Yuba River (39.2305, –121.2813).

(ii) *Englebright Hydrologic Sub-area 551714.* Outlet(s) = Yuba River (Lat 39.2305, Long –121.2813) upstream to endpoint(s) in: Yuba River (39.2388, –121.2698).

(9) Valley-American Hydrologic Unit 5519—(i) *Lower American Hydrologic Sub-area 551921.* Outlet(s) = American River (Lat 38.5971, Long –121.5088) upstream to endpoint(s) in: American River (38.5669, –121.3827).

(ii) *Pleasant Grove Hydrologic Sub-area 551922.* Outlet(s) = Sacramento River (Lat 38.5965, Long –121.5086) upstream to endpoint(s) in: Feather River (39.1270, –121.5981).

(10) Colusa Basin Hydrologic Unit 5520—(i) *Sycamore-Sutter Hydrologic Sub-area 552010.* Outlet(s) = Sacramento River (Lat 38.7604, Long –121.6767) upstream to endpoint(s) in: Tisdale Bypass (39.0261, –121.7456).

(ii) *Sutter Bypass Hydrologic Sub-area 552030.* Outlet(s) = Sacramento River (Lat 38.7849, Long –121.6219) upstream to endpoint(s) in: Butte Creek (39.1987, –121.9285); Butte Slough (39.1987, –121.9285); Nelson Slough (38.8901, –121.6352); Sacramento Slough (38.7843, –121.6544); Sutter Bypass (39.1417, –121.8196; 39.1484, –121.8386); Tisdale Bypass (39.0261, –121.7456); Unnamed Tributary (39.1586, –121.8747).

(iii) *Butte Basin Hydrologic Sub-area 552040.* Outlet(s) = Butte Creek (Lat 39.1990, Long –121.9286); Sacramento River (39.4141, –122.0087) upstream to endpoint(s) in: Butte creek (39.7095, –121.7506); Colusa Bypass (39.2276,

–121.9402); Unnamed Tributary (39.6762, –122.0151).

(11) Butte Creek Hydrologic Unit 5521—*Upper Little Chico Hydrologic Sub-area 552130.* Outlet(s) = Butte Creek (Lat 39.7096, –121.7504) upstream to endpoint(s) in Butte Creek (39.8665, –121.6344).

(12) Shasta Bally Hydrologic Unit 5524—(i) *Platina Hydrologic Sub-area 552436.* Outlet(s) = Middle Fork Cottonwood Creek (Lat 40.3314, –122.6663) upstream to endpoint(s) in Beegum Creek (40.3066, –122.9205); Middle Fork Cottonwood Creek (40.3655, –122.7451).

(ii) *Spring Creek Hydrologic Sub-area 552440.* Outlet(s) = Sacramento River (Lat 40.5943, Long –122.4343) upstream to endpoint(s) in: Sacramento River (40.6116, –122.4462)

(iii) *Kanaka Peak Hydrologic Sub-area 552462.* Outlet(s) = Clear Creek (Lat 40.5158, Long –122.5256) upstream to endpoint(s) in: Clear Creek (40.5992, –122.5394).

(13) Maps of critical habitat for the Central Valley Spring Run Chinook ESU follow:

BILLING CODE 3510–22–P

EXHIBIT C

Title:
Biology, History, Status and Conservation of Sacramento Perch, Archoplites interruptus

Journal Issue:
San Francisco Estuary and Watershed Science, 9(1)

Author:
Crain, Patrick K, University of California, Davis
Moyle, Peter B, University of California, Davis

Publication Date:
2011

Permalink:
https://escholarship.org/uc/item/8st5g6df

Keywords:
Endemism, Centrarchidae, invasive species, Central Valley fish, fish conservation, fish translocation, fish life history, Aquaculture and Fisheries

Local Identifier:
jmie_sfews_11025

Abstract:
This paper is a review of the biology of Sacramento perch (Archoplites interruptus) based mainly on recent studies of their distribution, ecology, physiology, and genetics. The Sacramento perch is the only member of the family Centrarchidae that is endemic to California. It is most closely related to the rock basses (Ambloplites spp.) and is thought to have split from its eastern cousins during the Middle Miocene Period (15.5 to 5.2 million years ago, MYA). Their native range includes the Central Valley, Pajaro and Salinas rivers, tributaries to the San Francisco Estuary (e.g., Alameda Creek), and Clear Lake (Lake County). Today, they are most likely extirpated from all of their native range. They are known to persist in 28 waters outside their native range: 17 in California, nine in Nevada, and one each in Utah and Colorado. Disappearance from their native range coincided with massive changes to aquatic habitats in the Central Valley and with the introduction of alien species, including other centrarchids. Unfortunately, many populations established outside their native range have also disappeared and are continuing to do so.

APRIL 2011

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

Sponsored by the Delta Science Program and the UC Davis John Muir Institute of the Environment

Biology, History, Status, and Conservation of Sacramento Perch, *Archoplites interruptus*: A Review

Patrick K. Crain[1] and Peter B. Moyle

Center for Watershed Sciences and Department of Wildlife, Fish, and Conservation Biology

University of California, One Shields Avenue, Davis CA 95616 USA

ABSTRACT

This paper is a review of the biology of Sacramento perch (*Archoplites interruptus*) based mainly on recent studies of their distribution, ecology, physiology, and genetics. The Sacramento perch is the only member of the family Centrarchidae that is endemic to California. It is most closely related to the rock basses (*Ambloplites* spp.) and is thought to have split from its eastern cousins during the Middle Miocene Period (15.5 to 5.2 million years ago, MYA). Their native range includes the Central Valley, Pajaro and Salinas rivers, tributaries to the San Francisco Estuary (e.g., Alameda Creek), and Clear Lake (Lake County). Today, they are most likely extirpated from all of their native range. They are known to persist in 28 waters outside their native range: 17 in California, nine in Nevada, and one each in Utah and Colorado. Disappearance from their native range coincided with massive changes to aquatic habitats in the Central Valley and with the introduction of alien species, including other centrarchids. Unfortunately, many populations established outside their native range have also disappeared and are continuing to do so.

Sacramento perch bones are abundant in Native American middens, and Sacramento perch were common enough in the 19th century to be fished commercially in large numbers. By the late 1800s their decline was evident and by the early 1900s they were rare in fish surveys. Their historic habitats were apparently sloughs, slow-moving rivers, and large lakes, including floodplain lakes. Sacramento perch are adapted to withstand high alkalinities (10.6 to 11.0 pH), are eurythermal—with 16 to 23 °C being their optimal thermal range—and can persist within a wider salinity range (mean 24 to 28 parts per thousand, ppt) than other centrarchid species. Larval and juvenile oxygen consumption increases with age, size, and temperature, except at very low temperatures, where consumption is higher than in their optimal temperature range. In adult Sacramento perch muscle, oxygen consumption significantly increases with temperature. The diet of Sacramento perch varies with size of fish and availability of food by season, but they feed primarily on insect larvae when small, and on fish and macroinvertebrates when large. Growth rates differ in response to population density, diet, gender, water temperature, anthropogenic influences, and presence of alien species. They can grow up to 61 cm total length (TL) and 3.6 kg, with a maximum recorded age of 9 years. Females grow faster than males and have lower mortality rates after the first year of life. Sacramento perch breed for the first time during their second or third year of life. The number of gametes produced is similar to that of

1 Corresponding author: *pkcrain@ucdavis.edu*

Lepomis and *Pomoxis* species (spp.) Spawning is initiated when water temperatures reach 18 to 28 °C from the end of March through as late as October. Males set up territories in littoral areas usually associated with aquatic vegetation, and guard them against other perch and potential egg predators. Courtship behaviors are similar to those of other centrarchid fishes. Sacramento perch eggs are deposited singly or in small clusters, are adhesive, and sink. Embryos hatch in approximately 27 to 72 hours after fertilization, and within 2 to 4 days the larvae are able to swim weakly. Larvae at swim-up are semi–pelagic or pelagic; small juvenile fish (15 - ≈50 mm) tend to shoal together in the littoral zone, moving into deeper water as they grow larger, with individuals becoming solitary or aggregating loosely together. We present two conceptual models of Sacramento perch life history: a reservoir–lake model, which fits their use of most present-day habitats, and a river model, representing their use of historic habitats.

Significant differences in genetic diversity were observed within and among eight Sacramento perch populations. The populations combined had fairly high diversity in genetic structure and were heterozygous for many alleles. However, only three of the eight populations were estimated to have effective population sizes greater than 50 and bottlenecks were detected in all but two of the eight populations. Differences among populations may have resulted from the size of founding populations and/or the genetic diversity of founding populations. Thus, a managed re-introduction strategy that favors genetic diversity should use individuals from all populations.

Our current knowledge of Sacramento perch biology indicates the following characteristics that are important for conservation:

1. They are adapted to using floodplains.
2. The mating behavior of males is divergent from that of their eastern counterparts.
3. Different life stages of Sacramento perch require different habitats.
4. They are presently limited in good part by interactions with alien centrarchid species.
5. Adults are limited by extreme water quality conditions, including high alkalinity.
6. Contaminants may have a major effect on reproduction, growth, and early life history.
7. Adults and juveniles are unable to maintain swimming velocities necessary to avoid being entrained in water diversions.
8. Introduced populations are limited by low genetic diversity.
9. Sacramento perch are exceptionally vulnerable to disease at warmer temperatures.
10. Most today live in artificial habitats, mainly reservoirs and ponds, which are not suitable for long-term survival.

Any strategy for re-establishing Sacramento perch must take multiple factors into account. We propose a conservation strategy that includes:

1. Ensure the future of all remaining populations by establishing backup populations from each source.
2. Establish a genetic management plan.
3. Establish a Sacramento perch experimental rearing facility.
4. Create a dispersed system of ponds for large-scale rearing and reintroduction into the wild.
5. Develop a strategy to build/use floodplain ponds for passive reintroduction.
6. Develop a source-sink reintroduction strategy by locating rearing ponds next to streams or sloughs.
7. Re-introduce fish into all habitats that seem to be suitable in their native range, including ponds and reservoirs.
8. Conduct a thorough search of Clear Lake to see if any Sacramento perch remain, so a special conservation effort for them can be established.
9. Develop and maintain an annual monitoring program for all known Sacramento perch populations.

10. Promote use of Sacramento perch in recreational fisheries.
11. Give Sacramento perch special status to emphasize the urgency of its recovery, beyond its present status as state Species of Special Concern.

KEY WORDS

Endemism, California, Centrarchidae, Sacramento perch, invasive species, Central Valley fish, fish conservation, fish translocation, fish life history

INTRODUCTION

The Sacramento perch (*Centrarchidae: Archoplites interruptus*) is endemic to the Sacramento-San Joaquin watershed, Pajaro and Salinas rivers, and Clear Lake (Lake County) of central California (Moyle 2002). It is listed as a Species of Special Concern by the California Department of Fish and Game (CDFG) and would probably be listed as a Threatened Species under both state and federal endangered species acts had it not been extensively translocated outside of its original range (Moyle 2002). The American Fisheries Society considers it to be a Threatened Species (Jelks and others 2008), whereas NatureServe lists them as Vulnerable (G3). It was included as a declining species in the Delta Native Fishes Recovery Plan (Moyle and others 1996). A priority of the CALFED Ecosystem Restoration Program (ERP) was to reintroduce the Sacramento perch back into its original range within the San Francisco Estuary. This interest resulted in a project that examined the basic biology of the perch, including its status, early life history, physiology, and the genetics of all extant populations (Crain and others 2007). Therefore, the purpose of this paper is to

1. Summarize what is known about the biology of Sacramento perch, including (a) history and taxonomy, (b) distribution and abundance, and (c) ecology and life history and (d) genetics.
2. Provide a conceptual model of Sacramento perch life history.
3. List gaps in our knowledge of Sacramento perch, expressed as a series of hypotheses.
4. Discuss restoration strategies and management, with a list of potential restoration sites.

This review synthesizes information from three major sources: (1) historic literature; (2) literature and personal communications from agency biologists from other states or areas that contain, or that previously contained, translocated populations; and (3) a recent University of California–Davis (UCD) study on their basic biology. Although our knowledge of Sacramento perch has increased greatly in the last few years, many unanswered questions remain as to why they have declined.

HISTORY, DESCRIPTION, AND TAXONOMY

History

The Sacramento perch is the only native member of the family Centrarchidae occurring west of the Rocky Mountains. Its isolation from other centrarchids dates back to the Middle Miocene period (15.5 to 5.2 MYA; Near and others 2005). Its fossil record is sparse, but it is one of the most numerous fish found in Native American middens in the Central Valley (Shultz and Simons 1973). The Sacramento perch was first discussed in Western culture in 1854 (Girard 1854). The following are important dates in the history of Sacramento perch and its habitats in relation to humans:

1852. Antoine Chabot begins hydraulic mining in California, which is the beginning of displacement of historic perch habitat within the Sacramento River and its tributaries (Holliday 1999).

1854. Charles F. Girard, a taxonomist at the Smithsonian Institution, describes the Sacramento perch as *Centrarchus interruptus* (Girard 1854).

1861. The California Legislature authorizes the Reclamation District Act, allowing drainage of Sacramento–San Joaquin –Delta lands and construction of sturdier levees, eliminating vast amounts of habitat previously occupied by perch (CDWR 1995).

1861. T. N. Gill (1861) assigns the Sacramento perch to its own genus, *Archoplites*.

1872. J. A. Poppe introduces common carp (*Cyprinus carpio*) from Germany into a pond in the Sonoma Valley; this species is found to prey on perch eggs and destroy spawning substrates (Dill and Cordone 1997).

1877. H. G. Parker translocates Sacramento perch from the Sacramento River to Washoe Lake, Nevada (Parker 1879).

1880. Further translocations are made within Nevada from Washoe Lake into Pyramid Lake and Walker Lake (Parker 1881).

1884. Fisheries for Sacramento perch are recorded in an early compilation by the United States Commission on Fish and Fisheries (Goode 1884): "It is abundant in the lower part of these [Sacramento and San Joaquin] rivers, large numbers being shipped to the markets in San Francisco. It is there bought and consumed mainly by the Chinese, who value it highly, paying more for it than for any other fish which they consume." (p. 405)

1888–1899. Sacramento perch are noted as an important food fish in San Francisco fish markets with 40,000 to 432,000 pounds of fish harvested per year during this period (Skinner 1962). It is likely that these fish came from the lower Sacramento River and Sacramento–San Joaquin Delta.

1891. Largemouth bass are introduced into the Feather River and are the first non-native centrarchid to be spread throughout the state by anglers and biologists (Dill and Cordone 1997).

1895. Jordan and Gilbert (1895) find Sacramento perch in Clear Lake.

1896. Jordan and Evermann (1896) note that Sacramento perch are declining in abundance.

1908. C. Rutter (1908) finds Sacramento perch rare in surveys of Sacramento-San Joaquin Basin.

1908. Bluegill sunfish are introduced to California (Dill and Cordone 1997).

1913. J. O. Snyder (1913) finds Sacramento perch in the Pajaro River.

1930. Sacramento perch are described as abundant in Clear Lake (Coleman 1930).

1931. Neal (1931) notes that the perch are found "only in the few places where the non-native [fish] species are rare or absent." (p.12)

1947. Clark Hubbs (1947) reports Sacramento perch from the Salinas River.

1950–1960s. Sacramento perch are found to be largely absent from the Delta in surveys by the California Department of Fish and Game (Turner 1966).

1960s. Sacramento perch are translocated to eight western states, with most originating from Nevada's Pyramid Lake (McCarraher and Gregory 1970).

1960s. Sacramento perch are introduced into Crowley Lake (Mono County) (Fuller 2009).

1963. Sacramento perch are extirpated from Nevada's Walker Lake, presumably in response to low water levels, which increased salinities to lethal limits (Cooper and Kock 1984).

1962. S. Mathews finishes his M.S. thesis on the age, growth, feeding, and reproductive habits of Sacramento perch (Mathews 1962), the first study on perch biology.

1965. Mathews (1965) describes reproductive behavior in Sacramento perch.

1966. A large survey of Clear Lake fishes turns up only nine Sacramento perch (Cook and others 1966).

1970. MaCarraher and Gregory (1970) find most introductions of perch into western states have not resulted in permanent populations, so continued stocking programs are needed to maintain the fisheries.

1973. Hopkirk (1973) finds no measurable differences among populations using meristics.

1974. Moyle and others (1974) describe the feeding habits of Sacramento perch.

1976. Sacramento perch are found occupying only a fraction of their original range in California, being limited to 14 small and disjunct bodies of water (Aceituno and Nicola 1976).

1976. *Inland Fishes of California* is published, which summarizes the published literature on Sacramento perch, citing 21 papers (Moyle 1976).

1979. UC Davis students find a remnant population still breeding in Clear Lake near Clear Lake State Park (Fong and Takagi 1979).

1979. Jack Johnson of Carson City, Nevada, catches a Sacramento perch for the California angling record in Crowley Lake, weighing 3 lbs., 10 oz. (CDFG 2008).

1980. Vanicek (1980) describes the decline of the Lake Greenhaven population and speculates that introduced centrarchid fishes (mainly bluegill) are the cause of decline.

1995. CDFG lists the Sacramento perch as a Species of Special Concern (Moyle and others 1995).

1999. Marchetti (1999) demonstrates that competition between bluegill and Sacramento perch can be a problem.

2002. *Inland Fishes of California,* revised and expanded, is published, and further summarizes published literature on Sacramento perch (31 papers cited, 10 published after 1976) (Moyle 2002).

2003. CALFED funds a study on basic biology at UC Davis.

Description and Taxonomy

Sacramento perch morphology is described in Moyle (2002).

Sacramento perch was originally believed to be an ancestral ("primitive") form that split from eastern centrarchid species during the Middle Miocene period (15.5 to 5.2 MYA) (Near and others 2005). The first phylogenetic studies indicated that the Sacramento perch is most closely related to the flyer (*Centrarchus macropterus*) and crappies (*Pomoxis* spp.) (Maybee 1993). However, recent analysis using DNA sequences puts it as most closely related to rock basses (*Ambloplites* spp.) (Near and others 2004), which it resembles. Hopkirk (1973) found little meristic variation among populations of Sacramento perch. Nevertheless, the Clear Lake population was probably distinct because of its long isolation from other populations, a supposition supported by findings that other Clear Lake fishes are distinct (Hopkirk 1973; Aguilar and Jones 2009).

TRENDS IN DISTRIBUTION AND ABUNDANCE

Distribution

California

Sacramento perch are endemic to the Central Valley, the Pajaro and Salinas rivers, tributaries to the San Francisco Estuary (e.g., Alameda Creek), and Clear Lake generally at low elevations (<100 m) except for Clear Lake, which is at an elevation of 402 m. Today Sacramento perch are most likely extirpated from their native range. Moyle (2002) lists 28 localities in California, of which 11 are located in the Central Valley and one in Clear Lake (Table 1). The Central Valley localities consist of reservoirs and small lakes located outside their native valley-floor habitats, and so, presumably, all resulted from introductions. Recent surveys in Calaveras Reservoir (Santa Clara County) and Clear Lake were unsuccessful in finding any perch (P. Crain, UCD, unpublished data). Overall, Sacramento perch are known to still be present in five Central Valley waters, but all populations are small and unlikely to persist over the long term. They are already extirpated from four locations listed in Moyle (2002) and are possibly extirpated (though no recent surveys have been conducted) in two others.

Sixteen populations have been established in California outside their native range, although the status of four populations is unknown (Table 1). Sacramento perch exist in six California watersheds:

1. Clear Lake Reservoir in the upper Klamath basin, from which they have spread into the Lost River and then into the Klamath River from Link Dam down to Copco Reservoir.
2. The Cedar Creek watershed in the South Fork of the Pit River, including Moon and West Valley reservoirs down to the Pit 1 power station, although the only perch found outside the two reservoirs are juveniles representing larval escapes (Reid 2003).

Table 1 Major water bodies containing Sacramento perch in California in the 1990s, with a determination of status in 2008. Populations labeled unknown are most likely extirpated.[a]

Location	County	Watershed (Sub-province)	Status in 2008
Clear Lake	Lake	Clear Lake	Unknown
Calaveras Reservoir	Alameda/Contra Costa	Central Valley	Extirpated
Alameda Creek gravel ponds	Alameda	Central Valley	Extirpated
Lake Anza	Contra Costa	Central Valley	Extirpated
Jewel Lake	Contra Costa	Central Valley	Present
Lagoon Valley Reservoir	Solano	Central Valley	Unknown
Hume Lake	Fresno	Central Valley	Present
Sequoia Lake	Fresno	Central Valley	Present
San Luis Reservoir	Merced	Central Valley	Present
Middle Lake	San Francisco	Central Valley	Extirpated
Almanor Reservoir	Plumas	Central Valley	Present
Butt Valley Reservoir	Plumas	Central Valley	Unknown
Abbotts Lagoon	Marin	North Coast	Present
Sonoma Reservoir	Sonoma	Russian River	Unknown
West Valley Reservoir[b]	Modoc	Pit River	Present
Moon Reservoir	Lassen	Pit River	Present
Honey Lake	Lassen	Lahontan	Unknown
Clear Lake Reservoir	Modoc	Upper Klamath R.	Present
Lost River and Tule Lake	Modoc	Upper Klamath R.	Present
Copco Reservoir	Siskiyou	Upper Klamath R.	Present
Sheepy and Indian Tom lakes	Siskiyou	Upper Klamath R.	Unknown
Bridgeport Reservoir	Mono	Lahontan	Present
East Walker River	Mono	Lahontan	Present
West Walker River	Mono	Lahontan	Unknown
Topaz Lake	Mono	Lahontan	Unknown
Gull, June, Silver, and Grant lakes	Mono	Mono Lake	Present
Crowley Reservoir	Mono	Owens River	Present
Lower Owens River, Pleasant Valley Reservoir	Mono	Owens River	Present

[a] Source: Moyle (2002).

[b] West Valley Reservoir and Moon (Tule) Reservoir are both in the Cedar Creek watershed, so are interconnected. The population was apparently extirpated in the 1980s when water levels were low and the reservoirs became ice-covered in winter. Sacramento perch were subsequently re-introduced (P. Chappell, CDFG, pers. comm.)

3. The Walker River watershed, including Bridgeport Reservoir and the Walker River below it (Moyle 2002).
4. The upper Owens River watershed including Crowley Reservoir, Pleasant Valley Reservoir and the Owens River (S. Parmenter, CDFG, pers. comm., 2005).
5. The Mono Lake watershed including June, Silver, Gull, and Grant lakes.
6. The Abbotts Lagoon watershed including the upper, middle, and lower lagoons.

Sacramento perch apparently were once established in the Russian River, but were extirpated when the river's fishes were poisoned with rotenone by CDFG in the 1950s (Pintler and Johnson 1958). They may have been native to the Russian River, although early records are lacking. An attempt to re-establish them in the watershed was made in Sonoma Reservoir (Dry Creek drainage) when Sacramento perch were stocked from Abbotts Lagoon (Point Reyes National Seashore, Marin County) and Clear Lake from 1985 to 1990 (Rick Macedo, CDFG, pers. comm. 2005). The status of this population is unknown, although anglers reported catching perch in the late 1990s (P. Crain, UCD, unpublished data).

Today, populations in just three California waters are considered to have long-term sustainability: Crowley Reservoir, Abbotts Lagoon, and Clear Lake Reservoir. However, two of these populations exist in reservoirs, which are managed to provide water to public agencies so reservoir waters can be lowered to levels undesirable for perch. In addition, Crowley Reservoir is operated to generate power. Perch populations in Crowley today can be affected by the rapid lowering of water levels during the spawning cycle which leave nests stranded (Steve Parmenter, CDFG, pers. comm. 2005). This phenomenon also seems to be common in reservoirs managed for water storage. For example, lowering water levels in the spring in San Luis Reservoir (Merced County) apparently strands nests. Only when water levels remain high in the spring do good year classes of perch occur (Hess and others 1995).

Outside of California

Arizona. Arizona had only one introduction, made into a borrow pit near Buckeye (Maricopa County) in 1967 (McCarraher and Gregory 1970). It is reported to have spawned once but has not been reported since; it is presumed extirpated (Minckley 1973).

Colorado. Colorado's first Sacramento perch were released into Nee Grande Reservoir (Kiowa County) in 1964, with additional plants made into Newell Lake (Weld County) in 1965 and 1966 (McCarraher and Gregory 1970). Successive plants into small ponds and lakes in the same area (Banner 12 and 13, Lon Hagler Annex waterfowl pond) were made from Newell Lake (Imler and others 1975). Successive years of monitoring in Newall showed the establishment of a reproducing population by 1969 (McCarraher and Gregory 1970). One survey of Nee Grande Reservoir captured no perch and subsequently the lake dried up (McCarraher and Gregory 1970). Two Buttes Reservoir, stocked in the 1960s, has also dried up on several occasions since the introduction and subsequent sampling efforts show no Sacramento perch (Doug Krieger, Colorado Division of Wildlife [CDOW], pers. comm. 1998). Sacramento perch apparently exist in northeast Colorado, but its status is precarious. Fish were moved from the Lon Hagler Annex (Imler and others 1975) in an attempt to establish refuge populations. The first was in Abrams Lake, a privately owned, 50-acre lake near Berthoud. The second was in Gilberts Pond, a private pond south of Hygiene, adjacent to the Pella Crossing Open Space ponds owned by Boulder County. The third and final transplant was to a privately owned gravel pit pond near Fort Lupton. The success of the re-introduction into the first two ponds is unclear; transplanted fish were recaptured, but reproduction was not observed. The third transplant into the gravel pit produced multiple year classes with rapid growth in both juvenile and adult fish (Randy Vanburen, CDOW, pers. comm. 1998). Twelve Sacramento perch were moved from this pond into Milavec Reservoir to initiate a population there, but the status of this translocation is unknown (Harry Crockett, CDOW, pers. comm. 2005); perch are most likely not present.

Table 2 Status of translocated populations of Sacramento perch in Nevada in 2007

Location	County	Watershed (subprovince)	Status
Bassett Lake	White Pine	Steptoe Valley	Extirpated
Big Indian Lake	Churchill	Lahontan	Extirpated
Indian Lakes	Churchill	Lahontan	Rare
Harmon Reservoir	Churchill	East Walker	Rare
Lahontan Reservoir	Churchill/Lyon	Lahontan	Uncommon
Little Meadow Lake	White Pine	Spring Valley	Extirpated
Little Soda Lake	Churchill	Lahontan	Common
Little Washoe Lake	Washoe	Lahontan	Common
Pyramid Lake	Washoe	Truckee River	Uncommon
Rye Patch Reservoir	Pershing	Humboldt River	Uncommon
Sparks Marina	Washoe	Truckee River	Uncommon
Stillwater Marsh	Churchill	Lahontan	Common
Walker Lake	Mineral	Walker River	Extirpated
Washoe Lake	Washoe	Lahontan	Common[a]

[a] Washoe Lake dries up periodically, but during wet years reconnects with Little Washoe Lake which doesn't dry up and restocks Washoe Lake with Sacramento Perch.

Nebraska. Introductions were made into Nebraska from reservoirs in eastern Nevada in 1961 (McCarraher and Gregory 1970). It was thought that Sacramento perch would be well adapted to the highly alkaline waters of the Sand Hills area, but populations had to be maintained by continual stocking. The combination of high alkalinity and temperature limited reproduction. The stocking program at Valentine Hatchery was suspended in 1962. In 1986, the USFWS at Valentine indicated that Sacramento perch no longer existed in local lakes, and that the species was on the verge of extirpation throughout the Sand Hills (Hrabik 1989). The Nebraska Game and Parks Commission (NGPC) regard Sacramento perch as extirpated from Nebraska (Dave Tunink, NGPC, pers. comm. 1998).

Nevada. Introductions were made into other states beginning in 1877 when perch were introduced from the Sacramento River into Washoe Lake, Nevada, then moved to Pyramid and Walker lakes in 1880. Sacramento perch were widely distributed in Washoe, Humboldt, Churchill, Lander, Eureka, and Elko counties (Parker 1881; Miller and Alcorn 1943). Of the 14 known introduction localities (Table 2), populations still persist in 10 of them. However, except for Pyramid and Little Washoe lakes, the long-term status of the populations is tenuous, given the state's emphasis on planting large predatory game fish, including striped bass, striped bass-white bass hybrids, and walleyes, in addition to the traditional warm water species such as centrarchid basses and sunfish (Sigler and Sigler 1987). Even Sacramento perch populations established in alkaline lakes that exclude most other fish species must be regarded as not secure, because if inflows are reduced and the water becomes too alkaline, perch will not reproduce (Woodley 2007).

New Mexico. Sacramento perch were stocked from unknown sources into Tres Lagunas or the Bottomless Lakes (Chaves County) which included Mirror Lake, Lea Lake, and Lazy Lagoon. Subsequent surveys failed to find any perch. They are considered extirpated from the state (Sublette and others 1990).

North Dakota. Introductions were made from Nebraska into North Dakota in 1963 into Round Lake (McHenery County) and Spiritwood Lake (Stutsman

County) (McCarraher and Gregory 1970). In 1964, Clear Lake and Lake Williams were stocked, presumably with fish from Nebraska. However, the transplants failed to establish populations and these lakes today are heavily stocked with other species (F. Ryckman, North Dakota Game and Fish Department [NDG&F], pers. comm. 1998).

Oregon. Sacramento perch were established in Oregon and the Klamath–Lost River System when CDFG introduced them into Clear Lake Reservoir (Modoc County, California) in 1966, using fish from the Central Valley Warm Water Fish Hatchery in Elk Grove (Moyle and others 1974). The perch spread down the Lost River into Tule Lake, and into the Klamath System from Link Dam (Lake Ewauna), downstream to Copco Reservoir in California. The perch are abundant in many areas where found (Roger Smith, Oregon Dept. of Fish and Wildlife [ODFW], pers. comm. 1998).

South Dakota. According to McCarraher and Gregory (1970) an introduction was made into White Lake (Marshall County) sometime in the early 1960s and 2 years of successful reproduction were recorded. However, no records of stocking Sacramento perch were found (records go back to 1941) for White Lake by the South Dakota Game Fish and Parks Department (SDGFP). A retired biologist admitted that wardens made many illegal introductions in that period, and that introductions could have been made by a federal agency with no state record (B. Hanteen SDGFP, retired, pers. comm. 2006). No Sacramento perch exist in South Dakota today (Brian Blackwell, SDGFP, pers. comm. 2006).

Texas. Sacramento perch were stocked in Hamlin Lake (Jones County) in 1966 from unknown sources (probably Nebraska). Fish surveys of the lake in 1969 turned up no perch and the lake was drained in 1971. Sacramento perch are considered extirpated from Texas (Ken Kurzawski, Texas Parks and Wildlife Department, pers. comm. 1998).

Utah. Sacramento perch were moved from one of the early Nevada populations to Utah into Pruess (Garrison) Reservoir (Millard County) and Cutler Reservoir (Box Elder and Cache counties) on the Bear River, although the exact timing is unknown (La Rivers 1962). According to the Utah Division of Wildlife Resources (UDWR), the Garrison Reservoir population is still present, although in small numbers (Dale Hepworth, UDWR, pers. comm. 2006). Young-of-the-year perch were recently found in Minersville Reservoir—apparently the result of an illegal introduction—although the reservoir was largely drained in 2004 during an extended drought, so the perch are presumably extirpated.

Abundance

There are no historical records of Sacramento perch abundance, but the perch is one of the most common fish remains found in Native American middens in Central California (Shultz and Simmons 1973; Broughton 1994), in the Pajaro–Salinas Basin (Gobalet 1990, 1993), and near Clear Lake (Gobalet 1989). They were common enough to be recorded in commercial fish–catch records in San Francisco fish markets (Goode 1884; Skinner 1962). By the late 1800s, Jordan and Evermann (1896) noted that Sacramento perch were declining in abundance in the greater San Francisco Estuary. Rutter (1908) found them to be rare in his fish surveys of the Sacramento-San Joaquin Basin. Walford (1931) reported them as “not very abundant” (p 84). Curtis (1949) noted that the Sacramento perch had “declined greatly in numbers and, while it cannot be called rare, now plays a minor part in the sport fishery” (p. 265). During a year of intensive monthly sampling of the Sacramento–San Joaquin Delta, Turner (1966) reported catching nearly 12,000 centrarchids, of which just one was a Sacramento perch. Subsequent surveys of Delta fishes have produced only two Sacramento perch, one caught just above the junction of Little Potato Slough and the South Fork of the Mokelumne River in 1992 (I. Paulsen, CDFG, pers. comm. 1992) and one caught in Snodgrass Slough opposite the Delta Cross Channel in 2008 (C. Haagen, CDFG, pers. comm. 2008). The latter fish presumably originated from a transplantation experiment made in 2006. Recent surveys that failed to find perch include electrofishing surveys in 2008 aimed largely at centrarchids (L. Conrad, UCD, unpublished data). There is no systematic program of sampling for Sacramento perch in place today and estimates of

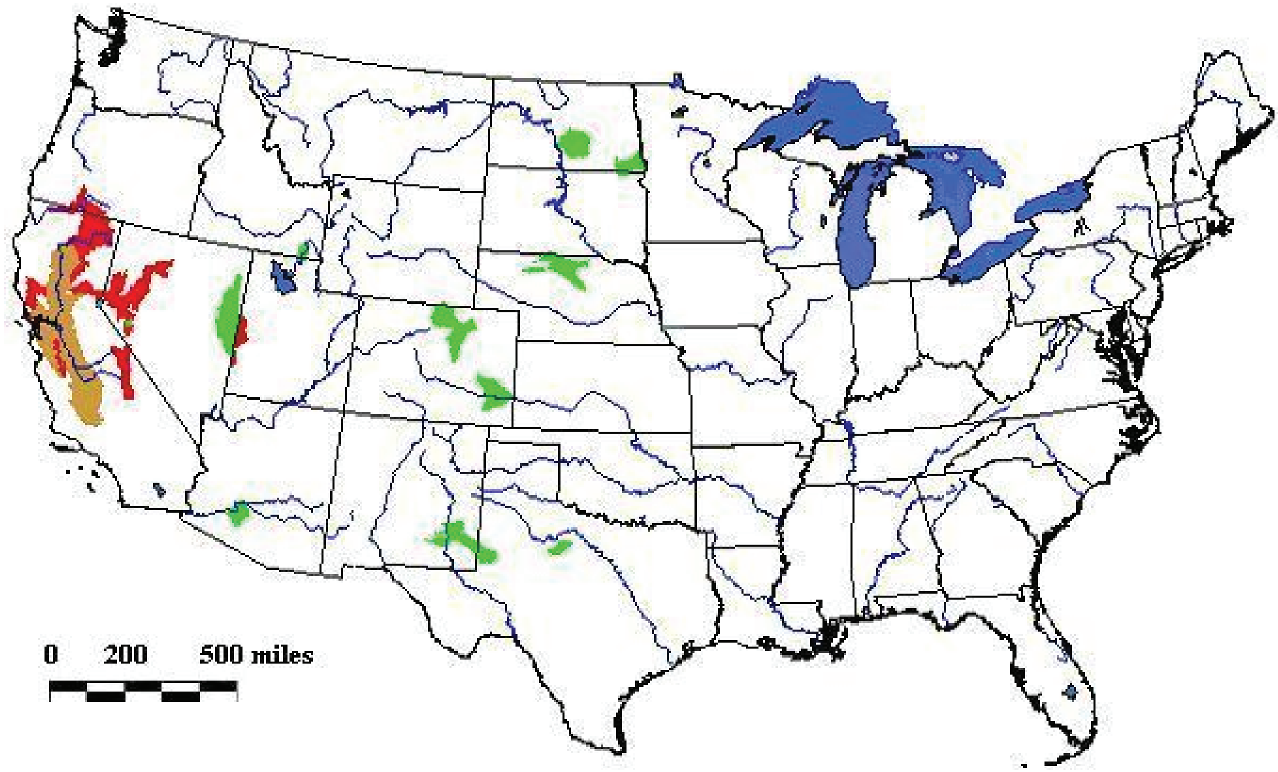


Figure 1 Watersheds into which Sacramento perch have been translocated. Red and green indicate translocations outside the original range (brown). Red translocations are still persisting and green translocations have been extirpated.

their abundance are mainly anecdotal. Crowley Lake has enough Sacramento perch to support an annual fishing derby, but no record exists on numbers of fish caught. Electrofishing surveys by CDFG in Lagoon Valley Reservoir put peak abundance at 1,500 per acre (CDFG 1996), but this reservoir has had no reproduction since 2002 (Wang and Reyes 2008). Recent surveys in Jewel Lake (1.1-ha reservoir) in the East Bay Regional Parks District (EBRPD) have estimated the population of Sacramento perch at 5,435 in 2004, 1,368 in 2005, but only 6 in 2006 (Pete Alexander, EBRPD, unpublished data).

Conclusions

Sacramento perch were once widely distributed and abundant in low elevation habitats in the Central Valley, the Pajaro–Salinas Basin, and in Clear Lake (Moyle 2002). Two populations (Clear Lake and Alameda Creek) that were previously thought to be the only remnants of historic populations are now probably extirpated, although it is still possible a small population exists in Clear Lake. As of 2008, they were known to persist in 28 waters outside their native range: 17 in California, nine in Nevada, and one each in Utah and Colorado (Figure 1), although abundance estimates are lacking. None of the populations that exist in California just outside the peripheries of their native range are likely to persist indefinitely because they are in reservoirs or isolated ponds, subject to drying up, alteration, or introductions of non-native centrarchids. A similar situation exists for populations in other states. Only populations in the Owens River drainage, Walker River drainage, Pyramid Lake (Nevada), and the Klamath basin (Oregon and California), would seem to be large enough to have reasonable potential for persistence through the rest of this century, based on size and permanence of at least portions of the waterways. However, the Pyramid Lake population is not entirely secure because water from the Truckee River is diverted and extirpation could occur (as it did in nearby Walker Lake) from increased alkalinities (Cooper and Koch 1984). Likewise, the other three populations exist in reservoir systems and could be threatened by altered water management practices or lowered water quality. The population in Abbotts Lagoon in Point Reyes National Seashore may also be able to persist, but the lagoon is small and isolated, and subject to large scale natural perturbation because it is located on the San Andreas Fault and connects to the Pacific Ocean.

In the past, it was assumed that Sacramento perch were not in danger of extinction because of translocated populations. However, its long term future is clearly not secure because: (1) it is extirpated from its native range; (2) all populations in California outside its native range are in highly altered or artificial water bodies; (3) all except 10 translocations in other states have failed, with only two populations not in danger of extinction in the near future (Pyramid Lake, Nevada and Lost River basin, Oregon). As in California, most extant populations occur in reservoirs and, thus, are subject to anthropogenic uses of water.

Overall, the Sacramento perch is gone from its native range, and its distribution and abundance outside its native range will continue to shrink as isolated populations become extirpated. Except for Nevada and Oregon, the websites of fisheries agencies in states other than California suggest little interest in Sacramento perch. This portends the continued loss of 'back up' populations and the loss of remaining genetic diversity.

ECOLOGY AND LIFE HISTORY

Habitat

The Sacramento perch was originally one of the dominant piscivorous fishes in the Sacramento-San Joaquin River system. The historic habitats of Sacramento perch were apparently sloughs, slow-moving rivers, and large lakes, including floodplain lakes (Moyle 2002). Many of these habitats became very warm and alkaline during periods of drought (or even in late summer in normal years), which led to the early perception that Sacramento perch could adapt to withstand such conditions. In fact, Sacramento perch generally survive in adverse conditions, which include high alkalinity and salinity (McCarraher and Gregory 1970; Imler 1976; Moyle 2002; Woodley 2007) (Table 3), but this does not mean that these conditions are optimal. This perception, nevertheless, led to perch being translocated into highly alkaline (pH) waters throughout the west as game fish (McCarraher and Gregory 1970). Today, they are found primarily in reservoirs and ponds, and much of what we know about apparent habitat preferences comes from introduced populations in such artificial habitats. Here, we discuss what we can infer about their preferred natural habitats from observations of their basic ecology and physiology.

Structure. The deep body shape of Sacramento perch suggests they require structure for cover, including aquatic plants, downed trees, and submerged objects such as boulders, especially in shallow (<2 to 3 m) water. Presumably, this is both for protection from predators and for ambushing prey. For example, in Crowley Reservoir, they are most commonly found in shallow flat areas among beds of submerged aquatic vegetation as well as along steep slopes among large submerged boulders (P. Crain and Christa Woodley, UCD, unpublished observations). In Pyramid Lake, Sacramento perch are associated with rocky areas (i.e., tufa tufts, rocky ledges, and breakwaters), all in inshore areas (<23 m) (Galat and others 1981). In contrast, in highly turbid reservoirs (e.g., Moon, West Valley and Clear Lake reservoirs) there appears to be little association with structure.

Alkalinity. Because Sacramento perch evolved in the highly variable conditions found in the Central Valley, including severe droughts, they are adapted to withstand high alkalinities (pH) that are associated wtih low lake and river levels, as well as with-estuaries. In experiments with juvenile and larval Sacramento perch, Woodley (2007) found that they can persist in highly alkaline conditions, where critical pH maximum level (where the fish loses equilibrium at 12, 18, 23, and 26 °C) can range from 10.5 to 11.0 pH. This is similar to other California native fish-

Table 3 Water quality (in parts per million) where Sacramento perch have failed to survive translocation for less than one year[a]

Lake	pH	Carbonate	Bicarbonate	Total Alkallinity	Sulfate	Chloride	Calcium	Magnesium	Sodium	Potassium	Tota Solids	Survival (Days)
Colorado												
Nee granda	8.4	8	182	190	8,800	600	644	775	1,600	—	13,825	—
Nebraska												
By-Way	9.3	716	1,505	2,221	20	178	52	8	870	500	3,800	60–80
Diamond	9.8	922	1,163	2,085	106	68	20	—	1,150	950	4,018	1.7–2.5
Goose	9.4	520	1,440	1,960	48	320	45	12	700	510	3,350	65–69
Little Alkali	9.8	987	1,951	2,938	101	155	16	140	728	775	3,450	20–26
McKeel Pond-2	9.2	610	1,470	2,080	40	140	59	1	1,100	1,200	4,300	70–82
Smithys	9.6	680	1,760	2,440	85	182	56	30	743	570	3,350	110–124
Smithys Pond-1	9.3	960	1,850	2,810	72	160	22	20	810	600	3,900	2.2
Smithys Pond-2	9.6	1,140	2,941	4,083	190	240	38	8	2,000	950	5,400	38
W. Long Pond-2	9.3	590	1,480	2,070	60	110	—	—	—	—	2,850	240
New Mexico												
Lazy Lagoon	8.3	0	84	84	5,200	11,200	1,300	792	—	—	25,200	0.5
Lea	8.2	0	120	120	2,200	3,400	960	180	1,500	—	8,300	4–5
Mirror	8.2	0	130	130	3,900	4,800	970	390	3,900	—	15,500	0.2–0.3
North Dakota												
Lake George	9.4	1,026	776	1,802	12,000	2,600	12	770	5,500	—	15,300	4–10
Texas												
Hamlin	8.1	0	40	510	1,400	1,400	1,600	1,000	610	14	3,800	Unknown

[a] McCarraher and Gregory (1970).

es that can live in highly alkaline waters. Sacramento perch were successfully introduced into Clear Lake Reservoir (Klamath Basin) where Klamath Lake tui chub (*Siphatales bicolor*), Klamath largescale sucker (*Catostomus snyderi*), and Klamath shortnose sucker (*Chasmistes brevirostris*) have elevated pH resistance, similar to Sacramento perch (10.8 ± 0.5, 10.7 ± 0.4, and 9.6 ± 0.4, respectively) (Falter and Cech 1991).

Despite their ability to survive high alkalinity, Sacramento perch were extirpated from Walker Lake, Nevada, when total alkalinity reached 2,500 mg L^{-1} (Cooper 1978; Cooper and Koch 1984). McCarraher and Gregory (1970) found that natural reproduction ceased in hatchery ponds in Nebraska when total alkalinity reached ≥2,000 mg L^{-1}. This is supported by the observations of increased tumors, and hardened ovaries and kidneys as total alkalinity increased to 1,500 mg L^{-1} in Pyramid Lake and other areas (Vigg 1978; Woodley 2007).

Water Temperature. Previous studies (Knight 1985) and recent experiments (Woodley 2007) indicate that Sacramento perch are eurythermal, with 16 to 23 °C being the optimal thermal range for growth, depending on age and condition. This temperature range is cooler than for other centrarchid species, but higher than for California native fish species (Woodley 2007). In general, the critical maximum temperatures for larval and juvenile Sacramento perch are similar to those of other centrarchid species, although their endurance range above a given acclimation temperature is higher (Woodley 2007). In tests of critical minimum (CT_{min}) and maximum (CT_{max}) temperature (temperatures at which the fish lose equilibrium), larval Sacramento perch had a CT_{min} of 8.5 ± 1.2 °C and CT_{max} of 36.1 ± 0.5 °C (Woodley 2007). For juveniles, the CT_{min} was 7.0 ± 0.8 °C and the CT_{max} was 36.6 ± 0.6 °C (Woodley 2007). Juveniles show low energetic costs when inhabiting water in the 18 to 23 °C range, which allows them to take advantage of warm littoral areas for foraging (Woodley 2007). Woodley (2007) observed in both Crowley Lake and Abbotts Lagoon that juveniles were found in warmer, littoral areas, whereas adults remained in cooler waters, except when spawning. In the laboratory, adult Sacramento perch reached thermal minima at <10.0 °C and maxima at 29.5 ± 0.4 °C (Woodley 2007). The maximum is lower than that of other centrarchids, which have CT_{max} values of 33.9 to 34.8 °C (Woodley 2007). Adult Sacramento perch maximum thermal resistance is similar to that of other California native fishes, which range from 21 to 29 °C (Woodley 2007). The actual critical minima for adult Sacramento perch is probably lower than that measured in the laboratory because the experimental apparatus was constrained to go no lower than 10˚C (Woodley 2007). An example of this is in Crowley Lake, where perch survive temperatures of 5 to 10 °C in late March through April (Jellison and others 2003).

Behaviorally, adult Sacramento perch prefer temperatures of 18.5 ± 3.1 °C (independent of their acclimation temperature), which is lower than other centrarchid species and similar to other California native species (Woodley 2007). In culture, adults experience increased disease frequency and higher mortality at elevated temperatures (Woodley 2007). In the wild, at elevated temperatures, they presumably have reduced avoidance responses to predators, reduced ability to forage, and reduced resistance to disease compared to other centrarchids living at the same temperatures. One reason for success of Sacramento perch in Abbotts Lagoon is presumably that temperatures hover around preferred values all year around: mean temperature averaged 14.9 to 15.7 °C over a 10-month study (Saiki and Martin 2001) and 14.6 to 15.7 °C over a one-year study (Bliesner 2005).

Salinity. Juvenile and adult Sacramento perch showed greater salinity endurance (mean 24 to 28 ppt in 12 to 16 hrs) than other centrarchid species (Woodley 2007). Salinity resistance of juveniles at 12, 18, 23, and 26 °C was 28 ± 1.1, 27.6 ± 1.0, 26.1 ± 1.5, and 24.3 ± 1.2 ppt, respectively. Salinity resistance generally increased with decreasing temperature and at 12 °C juveniles had greater resistance than adults (26.3 ± 1.5 ppt) (Woodley 2007). Sacramento perch larvae have been raised successfully in waters up to 10 ppt salinity (C. Miller, Contra Costa Vector Control Authority [CCVCA], pers. comm., 2007). Unlike other fishes, the ability to withstand higher salinity does not increase with age in Sacramento perch. Sacramento perch are not an estuarine-dependent species, such as Sacramento splittail (*Pogonichthys macrolepidotus*) and Delta smelt (*Hypomesus transpacificus*), but juveniles can persist in high salinity waters, which could be advantageous for living on floodplains (shallow, littoral regions that might experience high evaporation) or in estuaries (Woodley 2007). In Colorado, Sacramento perch survived and reproduced in chloride-sulfate waters with salinities of 17 ppt and in sodium-potassium carbonate concentrations of over 0.8 ppt. (McCarraher and Gregory 1970). Sacramento perch likely can frequent brackish water habitats, although their ability to survive in elevated salinities may require high energetic costs, so they are not frequently found in such areas (Woodley 2007). For example, Saiki and Martin (2001) found that Sacramento perch in Abbotts Lagoon (with three basins) had access to a wide range of salinities, but were found mainly in freshwater sections.

Dissolved Oxygen. Larval Sacramento perch increase muscle oxygen consumption with age; at 2 hrs post-hatch, 1 day post-hatch (dph), 7 dph at 26 °C, their consumption is 0.26 ± .08, 0.30 ± 0.10, and 0.38 ± .08 mg O_2 $g^{-1}hr^{-1}$, respectively (Woodley 2007). Juvenile muscle oxygen consumption increases with increasing temperature, except at 12 °C at which it is greater than at 18 °C and 23 °C but less than at 26 °C (12 °C, 0.15 ± .03, 18 °C, 0.08 ± 0.01, 23 °C, 0.10 ± 0.01, and 26 °C, 0.18 ± 0.03 mg O_2 $g^{-1}hr^{-1}$) (Woodley 2007). In adult Sacramento perch muscle, oxygen consumption significantly increases with temperature (12 °C, 0.04 ± 0.01; 18 °C, 0.07 ± 0.01; 26 °C, 0.13 ± 0.03 mg O_2 $g^{-1}hr^{-1}$) (Woodley 2007). Overall, oxygen consumption of all life history stages is lower at a given temperature than that of other centrarchid species except for largemouth bass (Woodley 2007). The low oxygen consumption rates are reflected in the ability of Sacramento perch to withstand relatively low dissolved oxygen levels in the water, especially at cool temperatures. This ability is an advantage in escaping stressful high temperatures in littoral areas by moving into deeper, cooler water even if dissolved oxygen levels are low. Movements of this type were observed in Crowley Lake and Abbotts Lagoon where adult Sacramento perch moved inshore to spawn, but then moved into deeper waters afterward (Woodley 2007).

Flow. Sacramento perch have been described as preferring slow, slough-like, or lentic waters (Moyle 2002). Sacramento perch juveniles have a U_{crit} (critical swimming velocity: the maximum velocity a fish can maintain for a specified amount of time) that overlaps with other centrarchid species, but the values are 43% to 58% higher than those of white crappie (*Pomoxis annularis*), a species with similar morphology and size (Woodley 2007). In general U_{crit} increases with fish size, but in Sacramento perch U_{crit} decreases with size (Woodley 2007). During all life stages (larval, juvenile, adult) Sacramento perch swimming performance is affected by temperature (Table 4). At 12 °C the U_{crit} of larval fish is significantly lower than at 23 °C and 18 °C, which is significantly lower than at 23 °C (Woodley 2007). In juvenile Sacramento perch, U_{crit} is significantly lower at 12 °C than at 18 °C and 26 °C (Woodley 2007). Adult Sacramento perch are similar to juveniles in that U_{crit} is significantly lower at 12 °C than at 18 °C and 26 °C (Woodley 2007). This indicates decreased swimming efficiency with elevated temperatures for both life stages and no clear optima as shown by the larvae. The critical swimming speeds for each life stage become thermally stressed when the temperature is above 23 °C (Woodley 2007). These critical swimming speeds are most similar to what a riverine fish might experience. Higher critical swimming speeds displayed by larvae and post-larvae seem to indicate that they could maintain position during high flow periods when some historical spawning probably occurred on floodplains (Woodley 2007).

Table 4 Comparisons of Sacramento perch swimming performance, at different life stages, expressed as U_{crit} (±SD)[a]

Life Stage	Water Temp (°C)	U_{crit} (cm s^{-1})	Body Lengths per sec[b]	Standard Length (cm)
Larvae	12	10.64 (2.10)	5.41 (0.78)	1.58 (0.20)
	18	12.11 (2.17)	7.05 (0.98)	1.52 (0.26)
	23	14.91 (3.22)	8.52 (1.93)	1.46 (0.13)
	26	13.69 (1.73)	7.50 (1.16)	1.49 (0.20)
Juvenile	12	23.67 (1.52)	3.28 (0.12)	7.21 (0.31)
	18	31.53 (2.42)	3.75 (0.19)	8.43 (0.76)
	23	35.43 (2.50)	3.34 (0.94)	10.63 (0.94)
	26	37.04 (4.55)	3.59 (0.34)	10.35 (1.15)
Adults	12	34.50 (4.61)	1.52 (0.30)	23.30 (1.78)
	18	40.28 (4.10)	1.85 (0.41)	21.72 (2.53)
	26	43.70 (6.73)	1.80 (0.31)	24.29 (1.33)

[a] Woodley (2007).

[b] Calculated as the fish's U_{crit} divided by the fish's body length.

Diet

The diet of Sacramento perch varies with fish size and availability of food by season (Table 5), although our understanding of their diet is potentially incomplete because most of our diet data was collected from studies outside their native range (Moyle and others 1974; Imler and others 1975; Aceituno and Vanicek 1976; Bliesner 2005; Crain and others 2007). At the larval stage, Sacramento perch eat prey items corresponding to their gape. This can include rotifers, small zooplankton, and early instars of mosquitoes and midges. Miller (2004) found that Sacramento perch ate mosquito larvae at a higher rate than western mosquitofish (*Gambusia affinis*), which are commonly used in California to control mosquito populations (Linden and Cech 1990). Crain and others (2007) found that in a pond population, cladocerans were the dominant food followed by copepods in diets of ≥8 mm larval fish. In small juveniles, amphipods were the most important food followed by chironomid larvae. Fish <40 mm in Clear Lake fed primarily on copepods; as the fish grew, cladocerans became more prevalent in their diets (Fong and Takagi 1979). As Sacramento perch grow larger, aquatic insect larvae and pupae become increasingly important in the diet, especially chironomids (Moyle and others 1974; Imler and others 1975; Aceituno and Vanicek 1976). In Pyramid and Walker lakes, Nevada, Sacramento perch feed almost entirely on fish by the

Table 5 Stomach contents of different age classes of Sacramento perch from five localities, expressed as percent of total volume (Woodward Pond, Willow Creek, and Curved Pond) or percent of total weight (Pyramid Lake and Kingfish Lake)[a]

Location	Month	Age Class	Length (mm)	Number	Ostracoda	Copepoda	Cladocera	Amphipoda	Chironomidae	Ephemeroptera	Hemniptera	Fish	Gastropoda	Aquat. Larvae	Terr. Insects
Pyramid Lake	7	0	49–77	12	—	—	—	72	4	—	4	<1	—	20	—
Kingfish Lake	9,10	0	98–124	15	—	41	51	—	6	—	—	<1	—	<1	—
Woodward Pond	6	0	13–29	45	—	46	7	—	46	—	1	—	—	—	—
Willow Creek	7	0	50–62	16	—	<1	2	6	26	18	11	—	—	37	—
Cured Pond	4,	0	8–15	39	—	12	64	10	2	—	—	—	—	12	—
Curved Pond	5	0	8–13	24	5	20	70	5	—	—	—	—	—	—	—
Curved Pond	6	0	21–43	64	—	4	5	47	7	9	—	1	—	27	—
Curved Pond	7	0	36–66	18	—	—	1	16	43	40	—	—	—	—	—
Lake Greenhaven	3,4,5	0	50–100	9	tr	10	1	—	61	1	13	—	—	14	—
Lake Greenhaven	7,8,9	0	50–100	10	tr	25	tr	—	75	—	—	—	—	—	—
Lake Greenhaven	11,12,1	0	50–100	17	5	5	44	—	43	—	—	—	—	—	—
Lake Greenhaven	3.4.5	1,2,3,4,5,6	110–305	28	—	tr	tr	—	72	—	tr	5	—	10	—
Lake Greenhaven	7,8,9	1,2,3,4,5,6	110–305	44	tr	5	tr	—	79	—	1	10	—	5	—
Lake Greenhaven	11,12,1	1,2,3,4,5,6	110–305	42	tr	tr	22	tr	38	—	tr	38	—	tr	—
Pyramid Lake	7	1	92–145	13	—	—	—	1	—	—	—	91	—	8	—
Kingfish Lake	4	1	95–129	15	14	72	8	—	1	—	—	1	—	4	—
Woodward Pond	2,3	1	92–144	16	4	<1	5	—	90	<1	<1	—	—	—	—
Woodward Pond	4	1	81–117	35	2	5	5	—	76	—	5	—	—	7	—
Woodward Pond	5	1	91–106	10	—	3	3	—	83	—	6	—	<1	5	—
Woodward Pond	6	1	91–145	79	—	<1	—	—	72	—	19	<1	7	1	—
Clear Lake Res.	7	1	78–141	8	—	—	—	4	4	35	18	26	—	9	3
Pyramid Lake	7	2,3	150–286	20	—	—	—	<1	—	—	—	99	<1	—	—
Pyramid Lake	7	4,5	268–337	10	—	—	—	—	—	—	—	99	1	—	—

[a] Moyle and others (1974); Crain and others (2007).

time they reach 90 mm TL. Their prey is mainly tui chubs (*Siphatales bicolor*) followed by Tahoe suckers (*Catostomus tahoensis*) and smaller Sacramento perch; this diet probably accounts for the large size of perch found in these large lakes (Vigg and Kucera 1981). In smaller lakes and ponds, their diet consists primarily aquatic insect larvae and pupae throughout life, with only occasional fish or crayfish being consumed, although young-of-year may be heavily preyed upon by adults (Moyle and others 1974; Imler and others 1975). The diets of juveniles and adults vary widely by location and season, showing opportunistic feeding (Tables 6, 7, 8). In Lake Greenhaven, chironomid larvae and pupae made up three-fourths of their diet, with fish and copeopods making up the rest (Acietuno and Vanicek 1976). Likewise, in Woodward Pond, the diet was mainly chironomids, followed by water boatmen and snails. In Clear Lake Reservoir, their diet consisted of mayflies, fish, and water boatmen (Moyle and others 1974).

Feeding takes place whenever the opportunity presents itself either day or night, although Sacramento

Table 6 Major prey of Sacramento perch in Abbotts Lagoon, Point Reyes National Seashore. Prey items were collected in June and November of 2001, and in January, April, and June of 2002. Fish stomachs (n = 299) were examined that ranged in size from 68 mm to 323 mm.

	Lower Lagoon Basin			Middle Lagoon Basin			Upper Lagoon Basin		
Prey Item	% Occurrence	% Number	% Weight	% Occurrence	% Number	% Weight	% Occurrence	% Number	% Weight
Hyallela azteca	25.0	0.6	5.0	73.2	18.3	18.2	49.6	29.3	15.6
Chironomidae larvae	0.0	0.0	0.0	52.5	5.2	5.9	74.0	20.6	9.0
Chironomidae pupae	0.0	0.0	0.0	49.5	5.5	6.2	57.0	6.2	6.1
Mysidae	87.5	82.1	4.7	22.2	1.2	0.0	5.4	0.5	0.0
Daphnia	0.0	0.0	0.0	78.3	57.0	25.1	28.0	19.6	7.9
Coenagrionidae	0.0	0.0	0.0	66.3	1.5	25.0	25.8	1.4	17.5
Corophium	25.0	0.7	28.4	53.0	5.5	5.5	2.2	0.2	0.0
Copepoda	0.0	0.0	0.0	19.2	1.6	0.1	34.4	7.3	0.9
Erpobdellidae	0.0	0.0	0.0	8.6	1.5	2.9	37.6	8.8	16.3
Fish	37.5	—	31.3	1.0	—	0.5	1.1	—	0.0
Sphaeromatidae	12.5	12.5	24.8	10.6	0.2	0.2	1.1	0.0	0.0
Asellidae	0.0	0.0	0.0	1.5	0.0	0.1	19.4	3.7	2.4
Other	0.0	4.1	5.8	0.0	2.5	10.3	0.0	2.4	24.3

[a] Bliesner (2004).

Table 7 Percentage by weight (g) of prey consumed by six age classes of Sacramento perch in Abbotts Lagoon[a]

	Age					
Prey Item	0+	1+	2+	3+	4+	5+
Hyallela azteca	27.6	18.8	23.9	19.1	16.9	6.5
Chironomidae larvae	18.9	9.6	5.1	3.2	4.4	11.1
Chironomidae pupae	13.6	11.8	4.3	1.2	7.9	7.0
Daphnia	15.4	6.3	21.8	27.8	24.9	29.4
Coenagrionidae	7.2	14.4	25.9	26.8	22.6	30.2
Corophium	0.0	6.1	4.8	5.4	0.0	3.6
Hirudinea	11.3	28.3	10.9	7.6	14.4	1.5
Other	6.0	4.7	3.3	8.9	8.9	10.7

[a] Bliesner (2004).

Table 8 Comparisons of growth of Sacramento perch from different waters[a]

	Mean Fork Length at Annulus (mm)								
Location	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 6**	**Age 7**	**Age 8**	**Age 9**
California									
Lake Greenhaven[a]	84	163	203	239	286	312			
Lake Almanor[a]	59	122	172	172	217	282			
Lake Anza[b]	86	120	131	138	147	154			
Kingfish Lake[b]	115								
Clear Lake[c]	85	171	196	220					
Colorado									
Newall Lake[d]	94	174	231						
Nebraska									
Big Alkali Lake[d]	85	184							
Clear Lake[d]	129	189	238	278	318	330			
Hudson Lake[d]	117	176	214	236	251				
North Twin Lake[d]	144	186	219	243					
Walgren Lake[d]	130	189	224	278					
Nevada									
Indian Lakes[d]	70	124	176	216	261	303			
Lahontan Reservoir[d]	67	122	166	211	253	286	318	335	355
Walker Lake[e]	102–127	140–190	190–241	229–299	279–318	305-356			
Pyramid Lake[e]	76–127	127–180	178–254	229–305	279–343	305-356	324–368	381–394	394–406
Pyramid Lake[e]	99	158	221	261	299	325	346	371	382
Pyramid Lake[e]	137–224	186–267	219–300	252–333	312–355				
Washoe Lake[d]	67	99	127	154	211	256	278	306	
North Dakota									
Round Lake[d]	79								
South Dakota									
White Lake[d]	70	114							

[a] Acietuno and Vanicek (1976).
[b] Mathews (1962).
[c] Murphy (1948).
[d] McCarraher and Gregory (1970).
[e] Vigg and Kucera (1981).

perch are often most active at dusk and dawn (Moyle and others 1974; Moyle 2002). Sacramento perch exhibit the ability to switch between prey items, and are selective, based in part upon the energetic costs of capturing prey (Vinyard 1982). Their ability to switch prey items is similar to that of pumpkinseed sunfish, whereas the maximum speed and energy production they generate during prey capture are most similar to green sunfish (Webb 1975; Vinyard 1980, 1982). Sacramento perch are more capable than either pumpkinseed or bluegill at efficiently capturing small evasive prey such as copepods (Vinyard 1980, 1982).

Age and Growth

Growth rates of Sacramento perch are highly variable, depending on environmental conditions (Table 8). At the end of years 1, 2, 3, 4, 5, and 6 fish are typically 6 to 13 cm FL, 12 to 19 cm 17 to 25 cm, 20 to 28 cm, 21 to 32 cm, and 28 to 36 cm, respectively (Moyle 2002). The oldest fish known (9 years) were from Pyramid Lake, at 38 to 41 cm FL. The largest perch recorded is 61 cm TL (Jordan and Evermann 1896) and the heaviest fish on record was a 3.6 kg perch from Walker Lake, Nevada (La Rivers 1962). The California angling record, however, is a 1.64 kg fish, from Crowley Reservoir—although a fish measuring 43 cm TL (weighing 1.95 kg) holds the angling record for Utah, and a 43.2-cm (2.22-kg) fish holds the Nevada state record. Growth is more in weight than length, with fish from Abbotts Lagoon having a power regression formula as the best fit for this relationship (Bliesner 2005). The length–weight relationship for Sacramento perch from Abbotts Lagoon is W = 0.00003L2.0 (r^2 = 0.97) (Bliesner 2005). This relationship is similar to growth curves for most fishes, where younger fish tend to have greater growth in length, but older adult fishes grow more in weight. This indicates greater investment in reproduction by adults, as opposed to somatic growth (Crain and Corcoran 2000). Females grow faster than males and suffer lower mortality rates after the first year of life, so fish older than 4 years tend to be females in all populations (Mathews 1962; Aceituno and Vanicek 1976; Vigg and Kucera 1981; Moyle 2002) (Figure 2). This is the opposite of other centrarchids where largest fish are usually males, although small, short-lived males are present in many sunfish species as an alternative life history strategy (Moyle 2002). The increased proportion of females as perch age is presumably explained by the amount of energy expended by males in nest guarding, making them more susceptible to starvation and disease, as well as their increased vulnerability to predation at this time. In Crowley Reservoir, male perch were observed to become emaciated guarding their nests (Christa Woodley, UCD, unpublished observations).

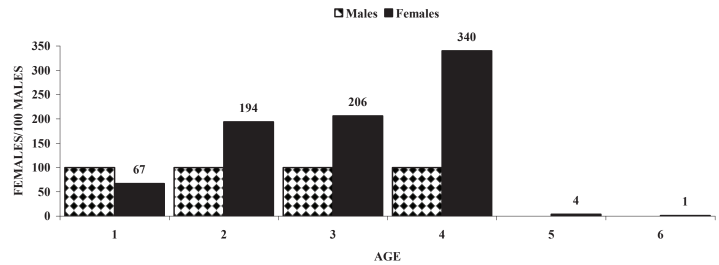


Figure 2 Number of females per 100 males in each age class of Sacramento perch from Pyramid Lake, Nevada. Source: Mathews (1962).

Growth rates differ in response to population density, diet, gender, water temperature, anthropogenic influences, and introduced species. Sacramento perch populations that attain smaller sizes are generally found in small bodies of water in which temperatures exceed 20°C for extended periods of time (Woodley 2007). For example, the largest Sacramento perch in Curved Pond (0.4 ha) on the UC Davis campus was 187 mm FL and was age 4+ years. Pond temperatures averaged 22.6° from May to September (Crain and others 2007). Food for larger perch did not seem to be limiting; the pond also supports a large population of western mosquitofish, eaten by the perch, which peaks during the warmer months. In Lake Anza, perch growth slowed after the second year and six-year-old fish were only 150 mm FL, presumably because of the lack of forage fish for larger adults (Mathews 1962). Small fish size in Clear Lake where fish six to nine years old were 194 to 231 mm FL was attributed to competitive interactions with non-native fishes (Moyle 2002). In Lake Greenhaven, growth rates decreased following invasion of the lake by bluegill, which eventually resulted in the extirpation of the perch (Vanicek 1980).

Table 9 Estimates of fecundity of Sacramento perch females from Lake Anza and Pyramid Lake[a]

Weight (gm)	Length (mm)	Age	Date (1961)	Number of Ova
Lake Anza, California				
37.5	120	II	June 21	9,860
42.7	136	IV	9	10,290
43.3	133	IV	9	9,750
48.5	141	III	May 16	8,820
48.7	140	IV	June 27	9,720
49.8	142	IV	1	8,370
51.0	138	III	21	10,530
51.7	140	III	9	10,270
52.9	132	III	1	13,970
54.2	144	III	May 25	11,000
56.4	144	IV	June 9	11,320
57.8	143	IV	21	16,220
58.0	152	IV	9	16,150
59.0	141	III	21	11,506
65.1	157	VI	21	14,100
71.5	153	III	May16	11,155
Pyramid Lake, Nevada				
108	170	II	June 14	23,550
138	196	II	14	18,100
144	197	III	14	26,860
200	218	III	15	9,666
422	270	IV	15	54,460
425	254	III	15	79,630
435	273	IV	15	40,340
530	281	III	15	70,390
545	283	III	15	64,160
560	286	III	15	72,920
570	288	IV	15	93,090
635	300	IV	15	98,280
686	306	IV	15	94,220
705	312	V	15	90,800
810	331	V	15	124,720
850	337	V	15	121,570

[a]Mathews (1962).

Table 10 Temperature at which Sacramento perch first spawn in different states and localities

Location	Source	Period	Water Temp (°C)
California			
Clear Lake	Murphy 1948	Late May–June	17–28
Curved Pond	Crain and others 2007	Late March–June	18
Kingfish Lake	Mathews 1962	Early April	23
Lagoon Valley	Konyecsni 1962	Late March–mid April Mid May–late July	20–25
Lake Almanor	Aceituno 1976	Late May–early July	20
Lake Anza	Mathews 1962	Early May–mid July	20
Lake Greenhaven	Aceituno 1976	Late April–June	22
Shields Pond	Logan 1997	Late March–June	19
Colorado	Imler 1975	Mid June–August	22
Nebraska	McCarraher and Gregory 1970	June–October	25–28
Nevada			
Pyramid Lake	Vigg and Kucera 1981	June–August	20–24

Reproduction

Sacramento perch in general breed for the first time during their second or third year of life, although the smallest ripe fish found in Lake Greenhaven was a yearling female, 128 mm FL. The number of gametes produced is larger than in most centrarchid species, but similar to that of bluegill and crappie. The number of ova in sixteen females from Lake Anza (120 to 157 mm FL) ranged from 8,370 to 16,210 (mean 11,438); 16 females (196 to 337 mm FL) from Pyramid Lake contained 9,666 to 124,720 eggs (Mathews 1962) (Table 9). Spawning is initiated when water temperatures reach 18 to 28˚C from the end of March through as late as October (Table 10). Males and females cultivated in captivity may spawn multiple times within the same season:

> In one experiment, I had a pair [of Sacramento perch] spawn 18 times in a 148-day spawning trial (first spawn to last). Averaging 14,112 larvae per spawn for a female 158 mm SL, brood size ranged from 6,237 to 23,436. Another female, 162 mm SL, averaged 14,680 with a brood size ranging from 8,732 to 21,924 (seven spawns).

> Another female, 168 mm SL, averaged 20,383 with a brood size 15,309 to 26,271 (six spawns). Temperature ranged from 23 to 29° C with most of the study running at the higher end 26 to 27 °C. The average interbrood interval was 9.6 days ranging from 5 days to 14 days between spawns. (C. Miller, CCVCA, pers. comm., 2010).

Whether or not this happens in the wild depends on several factors. Gonadal indices from Lagoon Valley Reservoir indicate a possible protracted spawning season beginning in late April through the first of August (Hallen, UCD, unpublished data). Older females seemingly spawn earlier in the season (Ridgway and others 1994), although spawning is early in most ponds and small bodies of water, probably a function of earlier warming (Crain and others 2007). When ready to spawn, males become darker than females, especially along the ventral surfaces and gill covers, which turn a purplish color, and distinct silvery spots show through the sides. Moreover, the males are darkest during the most intense periods of spawning (Mathews 1965). By comparison, females remain more uniformly silver. Before spawning, males congregate in shallow areas (15 to 60 cm deep) setting up territories (30 to 45 cm in diameter) before females arrive (Mathews 1962; Moyle 2002). In Crowley Lake males were seen to nest at depths of up to 300 cm (C. Woodley, UCD, unpublished data). These territories are usually associated with some type of aquatic vegetation such as pondweed; surfaces of rocks covered with algae, and submerged terrestrial vegetation (Crain and others 2007). In Clear Lake and Lake Greenhaven perch spawned on algae-covered riprap, but also over clay and mud substrates (Murphy 1948; Acietuno and Vanicek 1976). In Lake Anza and Kingfish Lake, perch spawned in depressions between submerged annual vegetation (grasses and forbs) (Mathews 1962). Sacramento perch seemingly prefer to spawn on or near vegetation, which could be an adaptation to spawning on floodplains.

However, perch are not confined to spawning on plants because they clean away debris and spawn in and around the edges of shallow depressions in a loose colonial fashion in Crowley Reservoir, similar to other centrarchid fishes (Christa Woodley, UCD, unpublished observations). In Kingfish Lake, a low-density population of Sacramento perch spawned at evenly spaced intervals, with nests placed approximately every three meters apart (Mathews 1965). Murphy (1948) commented that in Clear Lake Sacramento perch remained in a shoal during spawning, and that 50 spawning fish were in a 1.2-x-3.7 m area; this would put nest densities at about one spawning pair per 0.2 m^2.

Once a territory (nest) has been set up, a male Sacramento perch guards his area against other male perch by chasing, nipping, and flaring opercular flaps (Mathews 1962; Moyle 2002). Other potential predators are also chased away from nesting areas; a bass placed in the nest was driven away repeatedly, although a hitch was ignored (Mathews 1962). When a salamander was placed in a nest the male perch was initially frightened off, but came back quickly and attempted to nudge the salamander from its nest. When the salamander was held in the nest, the perch attacked it, biting and striking its body, finally grabbing it by the leg and pulling it 30 to 40 cm from the nest (Mathews 1962). Males in territorial defense and courtship display often engage in a rapid burst of tail fanning starting with the head up, but ending with the head perpendicular to the bottom. They also engage in a yawning motion with their opercula as they patrol their nests, a characteristic centrarchid courtship display (Mathews 1962; Moyle 2002). Females also display the yawning behavior and become extremely active, contorting their bodies, rubbing against plants and other objects, and striking at other perch.

As a ripe female first approaches a male, she will be driven off by aggressive thrusts or a nip behind the gill flap. The female persists in her approach and can be attacked repeatedly for as much as an hour before the male accepts her as his mate (Mathews 1965). The pair then may spend approximately 30 minutes on the nest together before spawning occurs. During this time, the male frequently nips or nudges the female just in front of the vent, causing her to turn onto one side or the other. Male and female may nip at the bottom substrate and may pick up gravel or other benthic objects in their mouths, while undulating, contorting the body, gaping, and performing undirected biting (Mathews 1965). Descriptions of spawning are somewhat different for wild fish and fish in aquaria (Mathews 1965). In the wild, both the male and female reclined to about a 45-degree angle, with their ventral surfaces close together and swim in a tight circle, facing in opposite directions; this was performed twice in 10 minutes and eggs were later found within the nest (Mathews 1965). In an aquarium, the female turned on her left side as she was nipped on the belly by the male. The female vibrated her body and fins several seconds before extruding eggs onto some plant roots; she was followed by the quivering male, which immediately turned on his side and fertilized the eggs. This happened four times in the space of 15 minutes, with the fish using both sides of their bodies. This behavior of male and female both turning on their sides is different from other centrarchid fishes where only females engage in this behavior (Mathews 1965). Males guard the nest for 2 to 4 days after spawning, allowing the eggs to hatch, but it is unlikely that all the larvae would be at swim-up stage when the nest is abandoned. This is in contrast to many other centrarchids where males guard postlarvae for a period of time even after they are able to swim (Winkleman 1996).

Early Life History

The eggs of Sacramento perch are spherical, with a mean diameter of 0.33 ± 0.04 mm reported in Leon and others 2008, although sizes of 0.85 mm, 0.9 to 1.1 and .8 to 1.0 mm have also been reported (Wang 1986; Wang and Reyes 2008; C. Miller, CCVCA, pers. comm., 2010). In other centrarchids, egg size varies by species, with rock bass having a mean egg size of 3.07 mm, pumpkin seed 1.50 mm, bluegill 1.47 mm, smallmouth bass 3.11 mm, largemouth bass 2.09 mm, and black crappie 1.27 mm (Cook and others 2006). The yolk is a yellowish to yellowish-white in color and is granular in texture (Wang 1986; Miller 2003). The oil globule is single and large, 0.11 mm in diameter in a 0.33-mm egg, 0.35 mm in a 0.85-mm egg and 0.3 to 0.4 mm in a 0.8- to 1.0-mm egg (Leon and others 2008; Wang and Reyes 2008; C. Miller, CCVCA, pers. comm., 2010). The chorion is transparent and elastic, with the perivitelline space being narrow in all stages (Wang and Reyes 2008). The fertilized eggs are deposited singly or in small clusters and are adhesive to semi-adhesive (Wang 1986; Miller 2003), with the buoyancy being demersal or negative (Murpy 1948; Mathews 1962). Embryos hatch in approximately 19 to 36 hrs after fertilization, depending on temperature and within 5 days the larvae are able to swim weakly (Leon and others 2008). Newly hatched larvae are usually <4.0 mm TL (Wang 1986); 3.4 to 4.0 mm for specimens collected at Lagoon Valley Regional Park by Michael Dege with CDFG; 2.9 to 3.2 mm TL (Leon and others 2008); 2.5 to 3.2 mm TL from eggs obtained from Chris Miller, CCMVCD, and from the Tracy Fish Collection Facility Laboratory (Wang and Reyes 2008). Unlike other centrarchids, Sacramento perch larvae have a small filament that attaches the head of the larvae to the egg capsule, which can last 1 to 4 days. After the filament is absorbed, the larvae cling to the substrate for 2 to 4 days before swim-up (Miller 2004). The larval filament presumably allows larvae to remain attached to the substrate (e.g., submerged terrestrial vegetation) in flowing water (Figure 3).

Larvae at swim-up are semi-pelagic or pelagic; they may stay within inshore beds of aquatic vegetation or off-shore over beds of algae (C. Woodley, UCD,

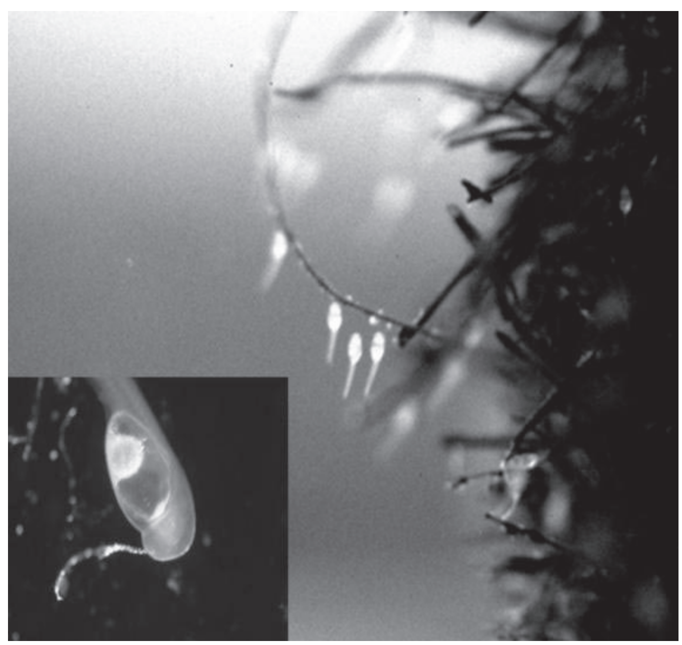


Figure 3 Sacramento perch larvae shown in close-up hanging by Spawntex® filament. Photo courtesy of Chris Miller, Contra Costa Vector Control Authority.

unpublished observations, 2006). Larvae can often be found in association with other fish larvae in macrophyte beds, including those of Sacramento blackfish, golden shiner, green sunfish, and largemouth bass (Matthews 1962; Wang 1986). Small juvenile fish (15 - ≈50 mm) tend to shoal together in the littoral zone, venturing into deeper water as they grow larger (Christa Woodley, UCD, unpublished observations). Eventually, shoaling behavior is replaced by individuals becoming solitary or aggregating loosely together, usually in association with some type of structure.

Causes of Decline

The disappearance of Sacramento perch from its native range coincided with massive changes to aquatic habitats in the Central Valley, combined with the introduction of a host of alien species, including other centrarchids. The mechanism of extirpation is presumably the result of interaction between changes to the environment and alien species. In addition, over-exploitation by 19th century fisheries and water-management practices may have contributed to its decline.

Habitat Change. Historically, Sacramento perch were abundant in major habitats of the Central Valley floor including large rivers, sloughs and floodplain lakes, terminal lakes, and the San Francisco Estuary. These habitats are among the most altered in California, having been drained, filled, rip-rapped, channelized, leveed, polluted, and generally made less suitable for native fishes. Sacramento perch were presumably hard hit by these changes because different life history stages require different but interconnected habitats. Thus the loss of appropriate shallow water habitat for juveniles, the reduction of cool, deep-water habitat for adults, and the loss of floodplain spawning areas helped to accelerate their decline. Some of the major habitats that have been lost include Lake Tulare in the San Joaquin Valley, which was drained for farming; the San Joaquin River, which was dewatered by diversions; and the Sacramento–San Joaquin Delta, which was converted from a vast floodplain-marsh to a complex of diked channels. Nevertheless, physiological studies (summarized in this paper) suggest that Sacramento perch can persist under extreme environmental conditions that occur at least seasonally and our distributional studies indicate that they once lived in a wide variety of habitat conditions.

Alien Species. It is hard to evaluate the historic impacts of alien species on Sacramento perch populations because the perch were under pressure from hydraulic mining, habitat change, and fisheries when introductions were being made. However, even in the 19th century, the decline in Sacramento perch was attributed to alien fishes, especially carp and catfish, which were thought to prey on perch eggs (Jordan and Evermann 1896). This was the explanation usually given as perch continued to decline (Neale 1931; Curtis 1949). The general observation remains that when Sacramento perch are associated with alien fishes (especially centrarchids), their numbers decline, and, in most cases, extirpation occurs (Moyle 2002). For example, Sacramento perch were stocked into Sonoma Reservoir (Sonoma County) and were common in angler catches until bluegill and redear sunfish became abundant (P. Crain, UCD, unpublished observations).

There are a few exceptions to this rule, which is probably related to the kinds of alien fish present with the perch. Sacramento perch co-exist with largemouth bass in both Jewell Lake (EBPRD) and Abbotts Lagoon (Point Reyes National Seashore), in the absence of other sunfish and most other alien fishes. Sacramento perch thrive as an alien species themselves mainly in lakes and reservoirs that are too alkaline to support other centrarchids (see "Habitat," p. 11). But overall, the evidence indicates that Sacramento perch thrive in a diversity of habitats until alien fishes become abundant. The mechanisms responsible for this replacement are some combination of competition, predation, and disease.

Competition. In most places where they exist today, Sacramento perch feed largely on macroinvertebrates (Moyle 2002). Introduced sunfishes have similar diets and spatial needs during parallel life history stages. Marchetti (1999) found that in the presence of bluegill, Sacramento perch gain less weight and show reduced growth, when food is limited. Sacramento perch were found to be less aggressive than bluegill, although larger Sacramento perch were more aggressive than smaller ones. Sacramento perch also shift their use of habitat in the presence of bluegill, tending to move out of deep cover (Marchetii 1999), which would make them more vulnerable to predation. Likewise, Bacon (1980) found that large Sacramento perch are less aggressive than small bluegill. These studies lend support to the hypothesis that aggressive dominance is the specific behavior that drives competition between Sacramento perch and bluegill. When relating the abundance of other centrarchid fishes to that of Sacramento perch, Vanicek (1980) found a significant negative correlation only with black crappie. The evidence overall indicates that where sunfish (*Lepomis* spp.) or crappie (*Pomoxis* spp.) are abundant, Sacramento perch do not persist.

Predation. Non-native predators can have devastating impacts on prey species that haven't co-evolved to resist their particular style of predation (Moyle and Light 1996). With the introduction of striped bass and largemouth bass into the San Francisco Estuary, a new source of predation was imposed upon juvenile and adult perch. However, it seems unlikely that these species preyed heavily on perch because of the abundance of so many other preferred soft-rayed prey species (minnows, shad, smelt). Murphy (1948) proposed egg predation by common carp and other species as a possible cause of perch decline. This hypothesis has still not been tested, and, in fact, carp and Sacramento perch rarely coexist. However, their incompatibility with bluegill (Moyle 2002) brings up the possibility that bluegill could prey on eggs and early life stages of Sacramento perch. Although male Sacramento perch guard their nests vigorously, they do so individually and would be no match for a school of bluegill intent on consuming eggs and fry (small juveniles). Carlander (1977) mentions that large male bluegill can prey on their own eggs and spawn early in the season, thus effectively eliminating early spawns. Bluegill also inhabit shallow beds of aquatic vegetation, which post-hatching Sacramento perch use as cover (Wang 1986); this suggests that bluegill predation on post-larvae and fry could be significant, especially if the bluegill are abundant and their own energetic demands are high (e.g. preparing for spawning). Even if bluegill and other sunfish do not prey directly on Sacramento perch young, they could be a proximate cause of perch decline by driving the young from cover, making them more vulnerable to piscivores. This would not happen to adult Sacramento perch, which spend most of their time offshore in deeper water than bluegill.

Disease. Disease, although not documented within wild populations of perch, has been observed as a major problem when wild fish are brought in for experiments and hatchery production (C. Woodley, UCD, and K. Bliesner, Hayward State University [HSU], unpublished observations). Temperature and stress seem to play key roles in the contraction of disease, to which Sacramento perch may be highly susceptible, especially diseases brought in with introduced fishes. For instance, when adult Sacramento perch were acclimated to temperatures of 23˚C and above, they continually contracted herpes-like viruses and were prone to outbreaks of common parasites such as ich (*Ichthyophthirius multifillis*) (C. Woodley, UCD, pers. comm., 2007). When perch were acclimated back to lower temperatures (15 to 20 °C) and given antibiotics, the outbreaks subsided and eventually stopped; as soon as acclimation temperatures were raised again, the infections reoccurred. Common temperature for ich outbreaks were 15 to 25 °C, indicating that Sacramento perch had immune response difficulties at the elevated temperatures. Temperature-related disease responses may also play a major role in the survival of newly hatched perch. When hatched at 25˚C, fry had a 10% survival rate as compared to 80% at 18 °C (C. Miller, CCVCA, and C. Woodley, UCD, unpublished data.).

Fisheries. Heavy fishing pressure was exerted on Sacramento perch in the middle to late 1800s. Sacramento perch were common in commercial catches, being surpassed only by salmon, white sturgeon and American shad in total catch (Skinner 1962). Heavy fishing pressure coupled with anthropogenic changes in landscape culminated in Sacramento perch being uncommon by the turn of the 19th century (Jordan and Evermann 1896). The only fishery today is a limited sport fishery, which the CDFG does not monitor. At present (2009), there is no limit on take of Sacramento perch in California waters, and there is at least one large fishery within the state, in Crowley Reservoir. Each year thousands of Sacramento perch are taken during a “perch derby” in August. The reason given for the unlimited fishery in Crowley Reservoir is that Sacramento perch are not native to the area and therefore should not receive special protection (S. Parmenter, CDFG, pers. comm., 2007), although the same argument could be made for rainbow trout, the main focus of the fishery. The majority of the fishery occurs while perch are spawning, which generally runs from the end of May through early August. The impact of the fishery could be considerable if large females are removed regularly from the breeding population, thereby lowering egg production and year class recruitment.

Water Management Practices. Clearly reservoirs can support Sacramento perch, but most do not because of the combination of alien species and reservoir operation. Sacramento perch spawn in shallow water (usually 0.6-m to 3.0-m deep) , so if water is drawn down during the spawning period, nests are likely to be stranded. This is why in abundant water years, large year classes of Sacramento perch occasionally develop in reservoirs that normally do not show good recruitment. An example of this phenomenon occurred in San Luis Reservoir in 1995; during a very wet spring, young-of-year perch were very abundant in the Portuguese Arm of the reservoir. This high abundance presumably happened because the reservoir stayed at its maximum capacity for much of the spring, thus allowing adult Sacramento perch access to shallow flats not normally available for spawning (Hess 1995). In most water supply reservoirs, water levels fall extremely fast, stranding nests and the embryos and larvae within them. In addition, rapid reservoir fluctuation eliminates beds of aquatic vegetation needed as cover by perch fry.

LIFE HISTORY MODELS

Here we present two alternative conceptual life history models of Sacramento perch life history, based on existing data and new knowledge gained from recent studies as summarized in this paper. The two models are a reservoir–lake model, representing most present-day habitats and a river model, representing presumed major habitats prior to disruption of Central Valley rivers and their floodplains in the 19th century.

Reservoir–Lake Model

The success of Sacramento perch populations in reservoirs and lakes depends on minimizing their mortality as a result of predation by native and alien species (e.g., from lack of adequate cover), fluctuating water levels, variable food supply (especially insect larvae), poor water quality (especially temperature), and adverse behavioral interactions with alien centrarchids, at all stages of their life cycle. The life cycle is closely tied to their movement from deeper water into the littoral zone for spawning when temperatures reach approximately 16 to 28˚C and daylight hours are approximately equal to nighttime hours. For this movement to work, the offshore areas must provide adequate food resources, protection from predators, and provide high water quality, including cool thermal refuges. The inshore areas must be deep and stable enough to allow for spawning and incubation of embryos, while also providing sufficient food and cover to protect larvae and small juveniles. Adults become mature at two years and live up to nine years, spawning annually. Both fecundity and growth rates are affected by the availability of appropriate prey (fish and macroinvertebrates), and so vary from region to region.

In spring (March through May), males move into the shallows ahead of females to establish territories that they guard vigorously against other males and intruders. They defend either prepared nests or patches of aquatic vegetation. Spawning may be repeated several times during the spawning season, which lasts for several weeks. The fertilized eggs are adhesive and stick to the substrate either singly or in small clusters. Flooded terrestrial vegetation or fairly open beds of aquatic macrophytes are preferred as spawning substrate, but other substrates used include, algae, algae-covered rocks, gravel, and mud. Embryos hatch in approximately 2 days and larvae remain attached to the chorion with a filament for another 4 to 5 days until swim-up occurs. At swim-up the larvae become nektonic and are found, often with other native larval fish, in vegetation or offshore in association with submerged cover. The larval stage lasts approximately 2 weeks at which time the larvae settle to the bottom, shoaling together as fry in the shallows, usually near some type of cover. Juveniles shoal for approximately 2 months then become more solitary, moving out of the littoral zone into deeper water, where they rear until maturity.

River Model

Much like the reservioir–lake model, the river model depends on the same variables for successful year classes to develop, only with river flows setting water levels. The life cycle of Sacramento perch in rivers was presumably once closely tied to adult movement from the main channels and deep sloughs into shallow floodplains for spawning, when temperatures reach approximately 16 to 28˚C and daylight hours are approximately equal to night-time hours. To be effective, river and slough habitat must provide adequate food resources, protection from predators, and high water quality, including cool thermal refuges. Males first move into sloughs adjacent to floodplains, most likely earlier than females, and then set up territories as floods offer the opportunity, similar to splittail (*Pogonichthys macrolepidotus*) (Moyle and others 2004). Spawning occurs on submerged terrestrial vegetation with embryos adhering to the substrate. The chorionic filament allows larvae to remain attached to the substrate in flowing water while yolk absorption is still taking place. At swim-up, the larvae are swept off the floodplain and into river channels or sloughs. After several days, the larvae settle into backwater or edge areas, where they shoal as fry. Alternatively, like splittail, the larvae remain in dense beds of flooded vegetation and leave the floodplain as fry, as flood water recedes. The fry seek out shallow areas that are warmer than the main river, which have beds of aquatic vegetation for cover. Taking advantage of abundant zooplankton and macroinvertebrates, they grow rapidly. As juveniles approach adulthood, they become more solitary and move to deep cool water in pools, oxbow lakes, and sloughs. Rivers and sloughs, with their complex habitats, including numerous fallen trees, historically provided abundant prey (macroinvertebrates, small fish), protection from predators, and good water quality. Floodplains in most years had adequate water levels to allow spawning, incubation of embryos, sufficient food resources, and protection for larvae and small juveniles. However, it is likely that little such habitat was available in dry years, forcing fish to either forgo spawning or to spawn in marginal habitats to maintain minimal populations (as happens in splittail, Moyle and others 2004).

GENETICS

Understanding the genetics of Sacramento perch as a species requires understanding the genetics of isolated populations that resulted from a small number of introductions from limited sources. Schwartz and May (2008) collected genetic samples from eight populations from both California and Nevada and then analyzed genetic variation among populations. Twenty-three polymorphic microsatellite DNA loci were used for the study, based on their ability to be amplified reliably (Schwartz and May 2004). These loci were used to examine genetic variation and effective population size, to evaluate whether bottlenecks occurred during the movement of perch to other areas, and to measure the distinctness of alleles within populations.

Significant differences were observed by Schwartz and May (2008) in genetic diversity within and among populations. The eight populations together had fairly high diversity in genetic structure, being heterozygous for many alleles. Differences among populations may have resulted from the size of founding populations, the original genetic diversity of founding populations, or the number of founding individuals that contributed to the current population (Schwartz and May 2008). Only three of the eight populations—Abbotts Lagoon, Clear Lake Reservoir, and Pyramid Lake—were estimated to have effective population sizes larger than 50 individuals, the minimum recommended to prevent inbreeding depression (Schwartz and May 2008). Not surprisingly, genetic bottlenecks were detected in all but two populations: Abbotts Lagoon and Clear Lake Reservoir. This also suggests that most populations became established from a relatively small number of individuals.

Overall, populations of Sacramento perch collectively show a surprising amount of genetic diversity, indicating multiple introductions from different sources. Abbotts Lagoon and Clear Lake Reservoir populations had the highest genetic diversity and showed the least evidence of inbreeding (i.e., had the largest effective population sizes). Both also showed evidence of having had different origins (i.e., had more unique alleles than other populations). However, these two populations do not contain the entire genetic diversity of the species. Although a population from tiny Jewel Lake in Alameda County had a low overall genetic diversity, it was genetically the most distinctive of the populations.

HYPOTHESES: WHAT WE NEED TO KNOW ABOUT SACRAMENTO PERCH

Although many questions about the biology of Sacramento perch have been at least been partially answered by recent studies, as summarized above, many questions remain to be answered, especially for effective conservation. This section lists a series of hypotheses (questions) under the following categories to show where information is needed to improve management strategies for Sacramento perch: floodplain use, reproductive behavior, life history strategies, effects of alien species, effects of water quality, genetics, and other potentially limiting factors.

Floodplain Use

Hypothesis 1: Adult Sacramento perch are adapted for using floodplains. There is some evidence that Sacramento perch once used floodplains for spawning, as our life history model indicates. It may be coincidence, but sharp declines in Sacramento perch populations occurred as most of California's floodplains became disconnected from their rivers.

Hypothesis 2: Juvenile Sacramento perch grow faster on floodplains than in adjacent sloughs and rivers. Floodplains provide optimal conditions for lower trophic-level production, where large amounts of decomposing vegetation coupled with warm water produce algae, bacteria, and ciliates. These, in turn, are food for rotifers, cladocerans, copepods, and mosquito larvae, which can be fed upon by larval and juvenile fishes (Grosholz and Gallo 2006). Rapid growth on Central Valley floodplains has been demonstrated for Chinook salmon (Sommer and others 2001; Jeffres and others 2008) and other native fishes (Ribeiro and others 2005).

Hypothesis 3: Sacramento perch are preferential floodplain spawners. Without access to available floodplain habitat, they will spawn in other areas (lakes, reservoirs, ponds, rivers). However, it is possible that their greatest spawning success occurred when there were large expanses of floodplain available to them which not only provided space for spawning but food and cover for young. Species that show a similar pattern are Sacramento splittail and common carp.

Hypothesis 4: Sacramento perch have physiological, behavioral, and morphological adaptations to floodplains. The adhesive nature of their eggs, the filament that holds the larvae to the chorion, their preference for spawning in very shallow water, their ability to spawn on flooded annual vegetation, and the timing of their spawning in late March, when floodplains were historically available, all describe a fish adapted for floodplain spawning. In addition, adult perch can use their pectoral fins to maintain position in flow, and seem to respond to flow as a reproductive stimulus (C. Woodley, UCD, unpublished observations). Larvae and juveniles can survive in high salinity, high pH, and low dissolved oxygen—useful early life history strategies—if stranded in shallow floodplain lakes and ponds.

Reproductive Behavior

Hypothesis 5: Sacramento perch reproductive behavior diverges from that of other centrarchids. Sacramento perch males appear not to be as aggressive as their eastern counterparts in protecting their nests. Sacramento perch males do not create depressions for nests, but do clean an area. However, we are not certain if eggs are deposited into the swept area or on debris surrounding the swept area. Thus, the reproductive behavior of Sacramento perch seemingly diverges from that of other centrarchids, but many aspects of the behavior remain poorly documented.

Hypothesis 6: Sacramento perch males display alternative mating strategies. In addition to spawning by large dominant males, bluegill and other colonial nesting sunfishes exhibit alternative male strategies, such as sneaker and streaker males. This type of behavior may be present among loosely colonial nesting Sacramento perch (C. Woodley, UCD, unpublished observations) but needs to be confirmed.

Hypothesis 7: Sacramento perch give less parental care than other centrarchids. The level of parental care invested by Sacramento perch is poorly understood. Males guard the nests against predators and competitors, but seemingly with less vigor than other centrarchids and for shorter periods.

Life History Strategies

Hypothesis 8: Different life stages of Sacramento perch require different habitats. Ontogenetic shifts in perch habitat have been observed but poorly documented. Littoral habitats appear to be used by early life history stages. As they grow, perch seem to move into deeper waters, returning inshore only for reproduction. The reasons for these shifts and their relationships to perch decline are not understood.

Effects of Alien Species

Hypothesis 9: Sacramento perch are limited by interactions with alien (non-native) centrarchids. The gradual disappearance of Sacramento perch populations when forced to co-exist with bluegill, crappie, and other sunfishes indicates that interactions are a major cause of decline. Because adults and large juveniles of these species seem to co-exist, most interaction is likely to occur during early life history stages.

Hypothesis 10: Predation on embryos and juveniles by non-native centrarchids is a major source of mortality. Predation on embryos especially by adult bluegill males has been linked to lack of early recruitment. Sacramento perch, like many other California native fishes spawn early in the year (middle to late spring), so opportunistic predation on embryos and larvae by bluegill, common carp, and other alien fishes may be a major source of mortality.

Hypothesis 11: Juvenile perch are displaced from rearing habitat by adult sunfishes. Juvenile Sacramento perch may be dislodged from littoral habitat by larger adult centrarchid fishes, thus forcing them to use deeper and more open areas, leaving them more vulnerable to predation.

Hypothesis 12: Sacramento perch experience higher stress, slower growth, and lower rates of gonadal development in the presence of alien fishes, especially centrarchids. Sacramento perch may experience high levels of stress when trying to deal with unfamiliar alien fishes, especially large, aggressive species. In particular, competition between Sacramento perch and non-native centrarchids may be a major factor that limits Sacramento perch growth and reproduction. To manage for viable perch populations sources of stress need to be documented.

Effects of Water Quality

Hypothesis 13: Adult Sacramento perch are limited by extreme water quality conditions. Sacramento perch were apparently extirpated by lack of reproduction in Nebraska, New Mexico, and Nevada when alkalinities were at extreme levels. Yet the ability to survive under extreme conditions is the reason Sacramento perch was widely planted. This apparent contradiction needs to be better understood.

Hypothesis 14: Summer temperatures in most present-day Central Valley waters are sub-optimal for Sacramento perch. Adult Sacramento perch prefer water temperatures in the 16 to 20°C range. Temperatures in parts of the present Sacramento-San Joaquin Delta may be too warm for Sacramento perch during summer months (Woodley 2007). Potential changes to the Delta (e.g. island flooding) may improve conditions (Moyle 2008) for them but this needs to be determined.

Hypothesis 15: Physiological responses of larval and juvenile perch to the combined effects of unfavorable salinity, dissolved oxygen, and temperature determine survival rates. Multiple environmental factors affect the physiological responses of Sacramento perch. It is likely that if one factor is optimal, but others are not, perch may have low survival or reduced growth rates.

Hypothesis 16: Sacramento perch are able to maintain growth and reproduction in elevated salinities because of ion-regulation abilities. There is some indication that the perch could live in much of the San Francisco Estuary, suggesting that, like splittail, they are euryhaline and presumably migrated to freshwater areas for spawning. If this is true, they may be able to be re-introduced into brackish waters.

Hypothesis 17: Contaminants (mercury, selenium, pesticides) in the Sacramento–San Joaquin system have a major effect on the reproduction, growth, and early life history of Sacramento perch. Laboratory studies of other fishes suggest that contaminants can be major limiting factors, but they affect survival is not known.

Genetics

Hypothesis 18: Low genetic diversity limits the viability of introduced populations of Sacramento perch. All perch populations today are introduced. Many of the introductions were made with limited numbers of fish radiating out from one initial introduction. Lake Greenhaven and the Elk Grove fish hatchery were the most common source for these initial introductions. How this low genetic diversity affects population viability is not known.

Hypothesis 19: Reintroduced populations established from more than one source exhibit better reproductive success. Genetic studies suggest existing populations come from diverse sources and so have different genetic make-ups. A strategy for taking advantage of this diversity needs to be developed.

Other Limiting Factors

Hypothesis 20: Sacramento perch are unable to maintain swimming velocities necessary to avoid water diversions and pumps. Studies by Woodley (2007) suggest that higher temperatures decrease the ability of perch to swim fast enough to avoid being entrained. The perch's ability to swim for extended periods must be investigated further.

Hypothesis 21: Sacramento perch are exceptionally vulnerable to disease, especially at warmer temperatures. When adult perch were acclimated to 24 °C in experimental conditions they broke out in herpes-like rashes and were highly susceptible to gill parasites. How disease limits Sacramento perch populations is poorly understood, especially diseases fom alien fishes.

DISCUSSION

Our analysis shows that the long-term decline of Sacramento perch is continuing. The species has generally been assumed to be in no danger of extinction because of the presence of multiple populations outside its native range. There are 28 known perch populations today, all isolated from one another. Sacramento perch were introduced into these waters because of its reputation as a game fish that could thrive in waters too alkaline too support other species of game fish. Despite the extraordinary physiological tolerances of the perch, these non-native waters represent sub-optimal conditions for it. The historic record indicates that the isolated, often stressed populations gradually become extirpated from these waters. The future of Sacramento perch is now precarious because no population can be regarded as truly secure. The perch may face severe genetic and demographic limitations.

In many ways, Sacramento perch are like other California-native freshwater fish species in their habitat requirements. The most striking of the habitat requirements is the need for cool water (<20 °C) for adults, reflecting evolution in riverine environments. In general, if water temperatures are optimal, Sacramento perch can persist in waters with high pH, low DO, and high salinity. If temperatures are too warm, their ability to thrive in poor water quality is decreased and growth rates and, presumably, survival declines. However, this ability, no doubt, allowed them to persist under adverse conditions in lakes, sloughs, and estuaries through periods of drought that are characteristic of Central California.

Their diet also reflects adaptability to changing conditions. It is varied and differs with the size of the fish and the availability of food by season. The diet of larval and early juvenile fish changes with the increase in gape as they grow (Crain and others

2007). Under optimal conditions, small perch first feed on aquatic invertebrates, especially abundant insect larvae, but then switch to fish as they grow larger. Growth rates, however, vary in response to population density, diet, gender, water temperature, anthropogenic influences, and alien species.

Sacramento perch generally start breeding during their second or third year of life.

They spawn at different times of the year in different bodies of water, with water temperature being the primary spawning cue that drives these differences. Survival of larvae is dramatically increased if water temperatures are cooler (15 to 22 °C), reflecting adaptation to spring spawning, when large productive littoral areas are likely to be flooded. Sacramento perch juveniles have greater ability to withstand high temperatures than adults, so they are able to use littoral areas and their more abundant food resources well into summer, thereby, avoiding predators in the process. In this respect, they are also like other native fishes.

Although they are usually compared in their adaptations to other centrarchid fishes, Sacramento perch differ from them in many ways. Swimming ability, for example, is higher than in other centrarchids with similar body morphology; this ability increases with size up to young adulthood, then decreases as they grow larger. This suggests adaptation for a life in large variable rivers, including backwater habitats for juveniles as indicated above. Males guard the nest quite vigorously, but apparently for shorter periods of time, and less aggressively than do other species of centrarchid. This behavior is perhaps a reflection of the perch's evolution in the absence of species with similar spawning behavior.

Although they can persist in adverse physical and chemical conditions and have adapted to local environmental conditions, Sacramento perch are severely limited by biotic interactions with alien species, especially other sunfish. In laboratory tests with bluegill, large perch were even less aggressive than small bluegill. Predation of early life history stages of perch by bluegill and other fishes may be the major source of mortality. Disease, perhaps brought in by non-native fishes, could also be a major limiting factor in warm waters. In laboratory experiments, Sacramento perch were extremely vulnerable to disease and common parasites in waters over 18 °C. This suggests that extirpation from their native range was largely the result of the combination of massive habitat change, including diversion of cool water, and establishment of alien species, especially other centrarchids.

The information presented in this paper shows that restoration strategies for Sacramento perch will have to take into account the long isolation of the species from other centrarchids, and its specific adaptations to historic central California environments. A particular problem will be restoring the genetic diversity needed for long-term survival. Genetic diversity has suffered from low numbers of fish used to start populations and a lack of gene flow among populations. Genetic management will have to be part of any restoration plan, presumably by interbreeding fish from multiple locations. However, small initial population sizes and random fluctuations in allele frequencies, combined with unique ecological pressures associated with isolated locations where existing populations of Sacramento perch persist, pose the potential for lower fitness if fish from multiple sites are interbred at reintroduction sites (e.g., Fischer and Matthies 1997; Gharrett and others 1999; Schwartz and May 2008). Two populations are clearly preferred sources for reintroduction: Abbotts Lagoon and Clear Lake Reservoir. These populations had the highest number of alleles and the largest effective population sizes, as well as the greater number of unique alleles. However, these populations do not contain the entire genetic diversity of the species, making it necessary to draw from other populations to retain diversity at reintroduction sites.

All this suggests that the long-term persistence of Sacramento perch will require continual intervention by humans, especially if populations are to be re-established in the perch's native range. A carefully monitored breeding program will be required, along with major habitat restoration programs.

CONCLUSIONS

The following conclusions should be taken into account in the development of a Sacramento perch conservation program.

1. Sacramento perch have been extirpated from natural habitats in their native range, and many populations established outside the native range have disappeared. This indicates that the long-term decline of Sacramento perch is continuing, and that populations outside the native range cannot be depended on for persistence. By most definitions, the Sacramento perch is a Threatened or Endangered species.

2. Sacramento perch are extremely resistant to most environmental conditions as adults, but successful completion of life history requires cool water refuges and diverse habitat conditions.

3. Sacramento perch have diverged from other centrarchids in many respects, including: (a) their high fecundity, (b) their less elaborate reproductive behavior, and (c) their ability to withstand alkaline/saline water.

4. The optimal environment for Sacramento perch appears to be cool riverine habitat, with flooded areas available for spawning. They can survive in extreme environments (high temperatures, alkalinities, etc.) but they will eventually die out through a combination of poor growth, survival, and reproduction if such habitat is all that is available to them.

5. Almost all Sacramento perch today live in human-maintained habitats, mainly reservoirs and ponds, which are not suitable for their long-term survival.

6. Most, but not all, populations of Sacramento perch show signs of genetic bottle-necking (limited genetic diversity), but different populations have different genetic composition.

7. The presence of non-native centrarchids, especially sunfish (*Lepomis*) and crappie (*Pomoxis*), in Sacramento perch habitat is usually associated with their absence, although the exact mechanism of displacement is not fully understood.

8. Sacramento perch seem to be exceptionally vulnerable to disease, especially at warmer temperatures. This could be a result of low genetic heterogeneity due to inbreeding and founder effects, or from the presence of disease organisms.

9. The long-term trajectory for Sacramento perch in all its scattered populations combined is toward increasingly low genetic diversity, the gradual disappearance of populations in isolated ponds and reservoirs, and species extinction.

10. Sacramento perch have repeatedly proven to be a highly desirable food and sport fish, so recovery of fisheries for them should be the goal of long-term management.

MANAGEMENT

Any strategy for re-establishing Sacramento perch must take multiple factors into account. We propose the following as an 11-point conservation strategy, in no particular order of priority.

1. Ensure the future of all existing populations by establishing back-up populations from each source, including those outside of California. Ideally, these would be habitats within the native range of Sacramento perch, but managed ponds or lakes will also be necessary.

2. Establish a genetic management plan and program that brings the genotypes together from isolated populations to re-establish a genetically diverse source population for future planting programs. This would have to be done in a carefully controlled program with genetic monitoring of the fish produced as a source stock.

3. Establish a Sacramento perch rearing facility in the Central Valley, with facilities for selective breeding, and ponds for large-scale rearing of fish for planting, where populations should be established. Realistically, it may be necessary to maintain this facility indefinitely as a source of Sacramento perch to stock recreational ponds and reservoirs and as an insurance policy for wild populations.

4. Re-introduce fish into habitats that seem to be suitable in terms of other species' presence or absence and environmental conditions. Our physiological and ecological studies suggest that there are habitats from which Sacramento perch were extirpated decades ago that have changed enough

so that they may once again be suitable for them. Some of these habitats include:

Suisun Marsh. Sacramento perch have already been introduced (2006) into a pond at the Blacklock restoration site, but the success of this introduction is not known. We think there may be opportunities to re-introduce perch into some of the more natural tidal sloughs in the marsh, but this will require large numbers of fish and some careful evaluation of the potentially suitable sites (e.g., Mallard Slough 1 and 2).

Putah Creek, Solano Reservoir. This is a shallow, weedy run-of-river reservoir into which several hundred perch were introduced in 2005. We have found no sign of their presence since, however.

Wood Duck Slough, Cosumnes River Preserve. This slough has a small dam with a tidal gate across it. Sampling in 2004 indicated that other fishes were relatively scarce in the upper slough, so 700+ Sacramento perch were planted there in 2005. Re-sampling 6 months later showed that the slough had been massively invaded by other centrarchids, and no Sacramento perch were found. A single Sacramento perch of the right size was caught in Snodgrass Slough in September of 2008 by a CDFG crew. It is most likely that this perch originated from the 2005 planting. Presumably sloughs like this could be modified for successful perch introductions.

Barker Slough and Liberty Island Region, Solano County. This freshwater tidal area is likely to be the focus of habitat restoration for native fishes, especially Chinook salmon and splittail, for the Delta region. Sacramento perch should be incorporated into restoration plans.

San Luis Reservoir. This large reservoir apparently contains a small population of Sacramento perch but it has not been studied. It is not a natural habitat but may contain clues as to what conditions are needed to sustain Sacramento perch.

5. Develop a strategy to build/use floodplain ponds that will allow Sacramento perch to become distributed into natural environments during periods of flooding. A successful reintroduction will require a fairly large number of fish stocked and this is one way to achieve that. This strategy would take advantage of our previous studies of restoration of flooded habitat on the McCormick-Williamson Tract (CALFED project #99-B193) and the Cosumnes River Floodplain (CALFED Project #99-N06) (Crain and others 2003; Moyle and others 2007). There may also be potential for using ponds developed in gravel and sand mining operations for this purpose. This strategy should be linked to a more general strategy to develop flow regimes and habitats below dams that are generally more favorable to native fishes.
6. Develop a source-sink strategy by locating rearing ponds next to streams or sloughs so the ponds can 'leak' Sacramento perch on a regular basis into natural habitats. We have had success in developing populations of Sacramento perch in ponds on the UC Davis campus and have observed that small numbers have ended up in Putah Creek via drainage canals.
7. Rear Sacramento perch in large numbers in ponds and other artificial situations for large-scale introduction into the wild. This is the least desirable of the options we have been considering but may be necessary if information indicates that a large introduction size is necessary for re-establishment in the wild. This strategy may be especially important for trying to re-establish or maintain Sacramento perch populations in Clear Lake, Lake County, historically one of the last hold-outs of wild Sacramento perch in their native range.
8. Conduct a thorough search of Clear Lake (Lake County) using trawls, traps and large seines to see if any Sacramento perch remain. Bring fish captured into captivity so they can be propagated.
9. Develop and maintain an annual monitoring program for all known Sacramento perch populations in California. We have observed (e.g., in Lagoon Valley Reservoir) that large Sacramento

perch populations existing for long periods of time can become extirpated in 3 to 4 years. Monitoring will be essential to determine which populations are maintaining themselves, which ones are not, and why. Wild populations should be genetically monitored regularly.

10. Promote the use of Sacramento perch in recreational fisheries, especially farm ponds and city fishing programs. Their recreational and culinary properties are currently under-appreciated, and a program like this would not only acquaint people with an edible native sport fish but increase the likelihood of Sacramento perch being maintained in private ponds and of their escaping to the wild.
11. Give the Sacramento perch special status to emphasize the urgency of its recovery. It is currently a Species of Special Concern in California and could qualify as a state or federal Threatened (or even Endangered) species. It was included as a component of the Delta Native Fishes Recovery Plan (USFWS 1996), but nothing has been done with this. More research on this fish is needed, but its need for conservation is already well justified.

ACKNOWLEDGMENTS

This research was conducted as part of a cooperative research venture managed by the Watershed Sciences Center (WSC) at the University of California, Davis. Jeffrey Mount, Director of the Center, made our lives easier by running the Center's programs so well. We thank Dr. Christa Woodley and Dr. Rachel Schwartz for sharing information and insights from their dissertation work with us, as well as their dissertation advisors, Dr. Joseph Cech and Dr. Bernie May for providing additional insights into the worlds of genetics and physiology. Chris Miller of the Contra Costa County Vector Control Agency shared information and insights from his Sacramento perch rearing program. We thank Ellen Mantalica and Diana Cummings for their help on the often complex budget and management issues of the project. This project was funded by the CALFED Bay-Delta Authority (CALFED, Project # ERP-02-P34).

REFERENCES

Aceituno ME, Nicola SJ. 1976. Distribution and status of the Sacramento perch *Archoplites interruptus* in California. California Fish and Game 62:246–254.

Aceituno ME, Vanicek CD. 1976. Life history studies of the Sacramento perch *Archoplites interruptus* in California. California Fish and Game 62:5–20.

Aguilar A, Jones J. 2009. Nuclear and mitochondrial diversification in two native California minnows: insights into taxonomic identity and regional phylogeography. Molecular Phylogenetics and Evolution 51(2):373–381.

Bacon ME. 1980. An ethological study of the Sacramento perch *Archoplites interruptus* and its interaction with bluegill *Lepomis macrochirus* [M.S. thesis]. Sacramento (CA): California State University. 49 p.

Bliesner KL. 2005. Trophic ecology and bioenergetics modeling of Sacramento perch (*Archoplites interruptus*) in Abbotts Lagoon, Point Reyes National Seashore [M.S. thesis]. Arcata (CA): Humboldt State University. 82 p.

Broughton JM. 1994. Late Holocene resource intensification in the Sacramento Valley, California: the vertebrate evidence. Journal Archaeological Science 21:501–514.

Carlander KD. 1977. The handbook of freshwater fishery biology. Vol. II. Ames (IA): Iowa State University Press. 431 p.

[CDFG] California Department of Fish and Game. 1996. Memo from Fred Meyer to Nick Villa regarding electrofishing results for Lagoon Valley Reservoir [dated April 23, 1996].

[CDFG] California Department of Fish and Game. 2008. State inland angling records. [Internet; updated 2009 May 27]. Sacramento (CA): California Department of Fish and Game. [cited 2009 Jun 3]. Available from: *http://nrm.dfg.ca.gov/AnglingRecords/Default.aspx*

[CDWR] California Department of Water Resources. 1995. Sacramento San–Joaquin Delta Atlas. State of California, Department of Water Resources, Sacramento, California. 121 p.

Coleman GA. 1930. A biological survey of Clear Lake, Lake County. California Fish Game 15:221–227.

Cook SF Jr., Moore RL, Connors JD. 1966. The status of the native fishes of Clear Lake, Lake County, California. Wassmann Journal of Biology 24:141–160.

Cook SJ, Philipp DP, Wahl DH, Weatherhead PJ. 2006. Energetics of parental care in six syntopic centrarchid fishes. Oecologia 148:235–249.

Cooper JJ. 1978. Contributions to the life history of the Lahontan tui chub (*Gila bicolor*) in Walker Lake, Nevada [M.S. thesis]. Reno (NV): University of Nevada, Reno. 98 p.

Cooper JJ, Koch DL. 1984. Limnology of a desertic terminal lake, Walker Lake, Nevada, USA. Hydrobiologia 118:275–292.

Crain PK, Corcoran DM. 2000. Age and growth of tui chub in Eagle Lake, California. California Fish and Game 86:149–155.

Crain PK, Small KM, Moyle PB. 2003. Survey of fish and their diets surrounding the McCormack-Williamson Tract (2001-2002). Final report. CALFED project #99-B193. 34 p.

Crain PK, Woodley CM, Schwartz RS, Moyle PB, May B. 2007. Restoration of the Sacramento perch to the San Francisco Estuary. Final report, CALFED Project #ERP–02–P34. 47 p.

Curtis B. 1949. The warm-water game fishes of California. California Fish and Game 35:255-274.

Dill WA, Cordone AJ. 1997. History and status of introduced fishes in California, 1871–1996. California Department of Fish and Game Fish Bulletin 178. Sacramento (CA): Department of Fish and Game. 414 p.

Falter MA, Cech JJ. 1991. Maximum pH tolerance of three Klamath Basin fishes. Copeia 1991:1109-1111.

Fischer M, Matthies D. 1997. Mating structure and inbreeding and outbreeding depression in the rare plant *Gentianella germanica* (*Gentianaceae*). American Journal of Botany 84:1685-1692.

Fong S, Takagi T. 1979. Competition among four centrarchids in Clear Lake, Lake County, California. Unpublished report. Available from: University of California, Davis. 41 p.

Fuller P. 2009. *Archoplites interruptus*. USGS nonindigenous aquatic species database [Internet]. Gainesville (FL): USGS. Available from: *http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=374> Revision Date: 4/11/2006*.

Galat DL, Lider EL, Vigg S, Robinson SR. 1981. Limnology of a large, deep, North American terminal lake, Pyramid Lake, Nevada, U.S.A. Hydrobiologia 42: 281–317.

Gharrett AJ, Smoker WW, Reisenbichler RR, Taylor SG. 1999. Outbreeding depression in hybrids between odd and even brood year pink salmon. Aquaculture 173:117-129.

Gill TN. 1861. Notes on some genera of fishes of the western coast of North America. Philadelphia (PA): USA Proceedings, Academy of Natural Sciences. 13:164-168.

Girard C. 1854. Descriptions of new fishes, collected by Dr. A L. Heerman, naturalist attached to the survey of the Pacific Railroad Route, under Lieut. R. S. Williamson. Philadelphia (PA): USA Proceedings, Academy of Natural Sciences. 7:129-140.

Gobalet KW. 1989. Remains of tiny fish from a late prehistoric Pomo site near Clear Lake, California. Journal California and Great Basin Anthropology 11:231-239.

Gobalet KW. 1990. Prehistoric status of freshwater fishes of the Pajaro-Salinas River system of California. Copeia 1990:680-685.

Gobalet KW. 1993. Additional archaeological evidence for endemic fishes of California's Central Valley in the coastal Pajaro-Salinas basin. The Southwestern Naturalist 38:218-223.

Goode GB. 1884. The fisheries and fishery industries of the United States. Washington D.C.: United States Commission of Fish and Fisheries. 895 p.

Grosholz E, Gallo E. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. Hydrobiologia 568(1):91-109.

Hess L, Karp C, Wang J. 1995. Sacramento perch, wakasagi, splittail, Sacramento blackfish, and shimofuri goby in San Luis reservoir and O'Neill Forebay. IEP Newsletter. Sacramento (CA): Department of Water Resources. Available from: *http://www.water.ca.gov/iep/products/newsletterPrevious.cfm*.

Holliday JS. 1999. Rush for riches: Gold fever and the making of California. Berkeley (CA): UC Press.

Hopkirk JD. 1973. Endemism in fishes of the Clear Lake Region. University of California Publications in Zoology 96. 160 p.

Hrabik RA. 1989. Fishes. In: Bleed A, Flowerday C, editors. An atlas the Sand Hills. Resource atlas number 5/1989. Reprinted 2005. Lincoln (NA): University of Nebraska, Lincoln, Conservation and Survey Division. p. 143-154.

Hubbs C. 1947. Mixture of marine and freshwater fishes in the lower Salinas River, California. Copeia 1947:147-149.

Imler RL, Weber DT, Fyock OI. 1975. Survival, reproduction, age, growth, and food habits of Sacramento perch *Archoplites interruptus* (Girard), in Colorado. Transactions of the American Fisheries Society 104:232-236.

Jeffres CA, Opperman JJ, Moyle PB. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83:449-458.

Jelks HL, Walsh SJ, Burkhead NM, Contreras-Balderas S, Díaz-Pardo E, Hendrickson DA, Lyons J, Mandrak NE, McCormick F, Nelson JS, Platania SP, Porter BA, Renaud CB, Schmitter-Soto JJ, Taylor EB, Warren ML Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372-407.

Jellison R, Rose K, Melack JM. 2003. Assessment of internal nutrient loading to Crowley Lake, Mono County. Report to State Water Resources Control Board #00-196-160-0.

Jordan DS, Evermann BW. 1896. Fishes of North and Middle America. Bulletin U.S. National Museum 47(1-4):1-3705.

Jordan DS, Evermann BW. 1923. American food and game fishes. New York: Doubleday. 572 p.

Jordan DS, Gilbert CH. 1886. Synopsis of the fishes of North America. Bulletin U.S. National Museum 16:1-1018.

Jordan DS, Gilbert CH. 1894. List of the fishers inhabiting Clear Lake, California. Bulletin of the United States Fish Commission XIV p. 139-140.

Knight NJ. 1985. Microhabitats and temperature requirements of hardhead (*Mylopharodon conocephalus*) and Sacramento squawfish (*Phytochocheilus grandis*), with notes for other native California stream fishes [Ph.D. Dissertation]. Davis (CA): University of California, Davis. 161p.

La Rivers I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Comm. 782 p.

Leon A, Miller CE, Tey SJ. 2008. Early development of the Sacramento perch. North American Journal of Aquaculture 70:27-37.

Linden A, Cech JJ Jr. 1990. Prey selection by mosquitofish (*Gambusia affinis*) in California rice fields: effect of vegetation and prey species. Journal of the American Mosquito Control Association 6:115-120.

Marchetti MP. 1999. An experimental study of competition between native Sacramento perch *Archoplites interruptus* and introduced bluegill *Lepomis macrochirus*. Invasion Biology 1:55-65.

Mathews SB. 1962. The ecology of the Sacramento perch, *Archoplites interruptus*, from selected areas of California and Nevada [M.A. thesis]. Berkeley (CA): University of California, Berkeley. 93 p.

Mathews SB. 1965. Reproductive behavior of the Sacramento perch, *Archoplites interruptus*. Copeia 1965:224–228.

Maybee PM. 1993. Phylogenetic interpretation of ontogenetic change: sorting out the actual and artefactual in an empirical case study of centrarchid fishes. Zoological Journal of the Linnean Society 107:175-291.

McCarraher DB, Gregory RW. 1970. Adaptability and current status of introductions of Sacramento perch, *Archoplites interruptus*, in North America. Transactions of the American Fish Society 100:700-707.

Miller C. 2003. Embryonic development of the Sacramento perch, *Archoplites interruptus*: A preliminary [unpublished] report. Concord (CA): Mosquito and Vector Control Division, Contra Costa County.

Miller C. 2004. 2004 Annual report, fisheries section [unpublished report]. Concord (CA): Mosquito and Vector Control Division, Contra Costa County.

Miller RR, Alcorn JR. 1943. The introduced fishes of Nevada, with a history of their introduction. Transactions of the American Fish Society 73:175-193.

Minckley WL. 1973. Fishes of Arizona. Pheonix (AZ): Arizona Department of Fish and Game.

Moyle PB. 1976. Inland fishes of California. Berkeley (CA): University of California Press. 405 p.

Moyle PB. 2002. Inland fishes of California, revised and expanded. Berkeley (CA): University of California Press. 502 p.

Moyle PB. 2008. The future of fish in response to large-scale change in the San Francisco Estuary, California. In: McLaughlin KD, editor. Mitigating impacts of natural hazards on fishery ecosystems. Bethesda (MD): American Fishery Society, Symposium 64. p 357-374.

Moyle PB, Baxter RD, Sommer T, Foin TC, Matern SA. 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science [Internet]. Available from: *http://www.escholarship.org/uc/item/61r48686*

Moyle PB, Light T. 1996. Biological invasions of fresh water: empirical rules and assembly theory. Biological Conservation 78:149–161.

Moyle PB, Mathews SB, Bonderson N. 1974. Feeding habits of the Sacramento perch, *Archoplites interruptus*. Transactions of the American Fish Society 103:399–402.

Moyle PB, Pine R, Brown LR, Hanson CH, Herbold B, Lentz KM, Meng L, Smith JJ, Sweetnam DA, Winternitz L. 1996. Recovery plan for the Sacramento–San Joaquin Delta native fishes. Portland (OR): U.S. Fish and Wildlife Service. 193 p.

Moyle PB, Yoshiyama RM, Williams JE, Wikramanayake ED. 1995. Fish species of special concern of California. 2nd ed. Sacramento (CA): Department of Fish and Game.

Murphy GI. 1948. A contribution to the life history of the Sacramento perch (*Archoplites interruptus*) in Clear Lake, Lake County, California. California Fish and Game 34:93–100.

Neale G. 1931. Spiny-rayed fresh water game fishes of California inland waters. California Fish and Game 17:1–16.

Near TJ, Bolnick DI, Wainwright PC. 2004. Investigating phylogenetic relationships of sunfishes and black basses (*Actinopterygii: Centrarchidae*) using DNA sequences from mitochondrial and nuclear genes. Molecular Phylogenetic Evolution 32:344–357.

Near TJ, Bolnick DI, Wainwright PC. 2005. Fossil calibrations and molecular divergence time estimates in centrarchid fishes (*Teleostei: Centrarchidae*). Evolution 59:1768–1782.

Parker HG. 1879 First biennial report of the fish commissioner of the State of Nevada, 1877–1878. p. 1–7.

Parker HG. 1881. Biennial report of the Fish Commissioner of the state of Nevada, 1879–1880. p. 1–10.

Pintler HE, Johnson WC. 1958. Chemical control of rough fish in the Russian River drainage, California. California Fish and Game 69:124–128.

Reid SB, Cowan W, Beyers S. 2003. Mainstream upper Pit River fish surveys, including the North and South Fork Pit rivers September 2002. Report to U.S. Fish and Wildlife Service. Klamath Falls (OR): U.S. Fish and Wildlife Service. 38 p.

Ribeiro F, Crain PK, Moyle PB. 2004. Variation and condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Cosumnes River, CA. Hydrobiologia 527:77–84.

Ridgway MS, Shuter BJ, Post EE. 1991. The relative influence of body size and territorial behaviour on nesting asynchrony in male smallmouth bass, *Micropterus dolomieui* (*Pisces: Centrarchidae*). Journal of Animal Ecology 60:665–681.

Rutter C. 1908. The fishes of the Sacramento–San Joaquin basin, with a study of their distribution and variation. Bulletin U.S. Bureau of Fisheries 27:103–152.

Saiki MK, Martin BA. 2001. Survey of fishes and environmental conditions in Abbbotts Lagoon, Point Reyes National Seashore, California. California Fish and Game 87:123–138.

Schulz PD, Simons, D.D. 1973. Fish species diversity in a prehistoric central California Indian midden. California Fish and Game 59:107–113.

Schwartz RS, May B. 2004. Characterization of microsatellite loci in Sacramento perch (*Archoplites interruptus*). Molecular Ecology Notes 4:694–697.

Schwartz R, May B. 2008. Genetic evaluation of isolated populations for use in reintroductions reveals significant genetic bottlenecks in potential stocks of Sacramento perch. Transactions of the American Fish Society 137:1764–1777.

Sigler WF, Sigler JW. 1987. Fishes of the Great Basin: a natural history. Reno (NV): University of Nevada Press. 425 p.

Skinner JE. 1962. An historical view of the fish and wildlife resources of the San Francisco Bay Area. CDFG Water Projects Branch Report 1. 225 p.

Snyder JO. 1913. The fishes of the streams tributary to Monterey Bay, California. Bulletin of the U.S. Bureau of Fisheries 32:49–72.

Sommer TR, Nobriga ML, Harrell WC, Batham W, Kimmerer WJ. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325–333.

Sublette JE, Hatch MD, Sublette M. 1990. The fishes of New Mexico. Albuquerque (NM): University of New Mexico Press. 393 p.

Turner JL. 1966. Distribution and food habits of centrarchid fishes in the Sacramento–San Joaquin Delta. In: Turner JL, Kelley DW, editors. Ecological studies of the Sacramento–San Joaquin Delta. Part II. Fishes of the Delta. California Department of Fish and Game Fish Bulletin 136. Sacramento (CA): California Dept. of Fish and Game. p. 144–153.

Vanicek DC. 1980 Decline of the Lake Greenhaven Sacramento perch population. California Fish and Game 66:178–183.

Vigg S. 1978. Vertical distribution of adult fish in Pyramid Lake, Nevada. Great Basin Naturalist 38:417–428.

Vigg S, Kucera P. 1981. Contributions to the life history of Sacramento perch, *Archoplites interruptus*, in Pyramid Lake, Nevada. Great Basin Naturalist 41:278–289.

Vinyard GL. 1980. Differential prey vulnerability and predator selectivity: effects of evasive prey on bluegill *Lepomis macrochirus* and pumpkinseed *L. gibbosus* predation. Canadian Journal of Fisheries and Aquatic Sciences 37:2294–2299.

Vinyard GL. 1982. Variable kinematics of Sacramento perch *Archoplites interruptus* capturing evasive and nonevasive prey. Canadian Journal of Fisheries and Aquatic Sciences 39:208–211.

Walford LA. 1931. Handbook of common commercial and game fishes of California. Division of Fish and Game of California. Fish Bulletin 28. Sacramento (CA): State Printing Office. 183 p.

Wang JCS. 1986. Fishes of the Sacramento–San Joaquin Estuary and adjacent waters, California: a guide to their early life histories. California Department of Water Resources, Interagency Ecological Program, Technical Report 9, Sacramento (CA): California Dept. of Water Resources. 800 p.

Wang JCS, Reyes RC. 2008. Early life stages and life histories of Centrarchids in the Sacramento–San Joaquin River Delta System, California. Tracy Fish Collection Facility Studies. Vol. 42. U.S. Bureau of Reclamation, Mid Pacific Region, and Denver Technical Service Center. 104 p.

Webb PW. 1975. Acceleration performance of rainbow trout *Salmo gairdneri* and green sunfish *Lepomis cyanellus*. J. Experimental Biology 63:451–465.

Woodley CM. 2007. Using ecological physiology for the conservation and restoration of a declining species: a case study Sacramento perch (*Archoplites interruptus*) [Ph.D. dissertation]. Available from: University of California, Davis. 165 p.