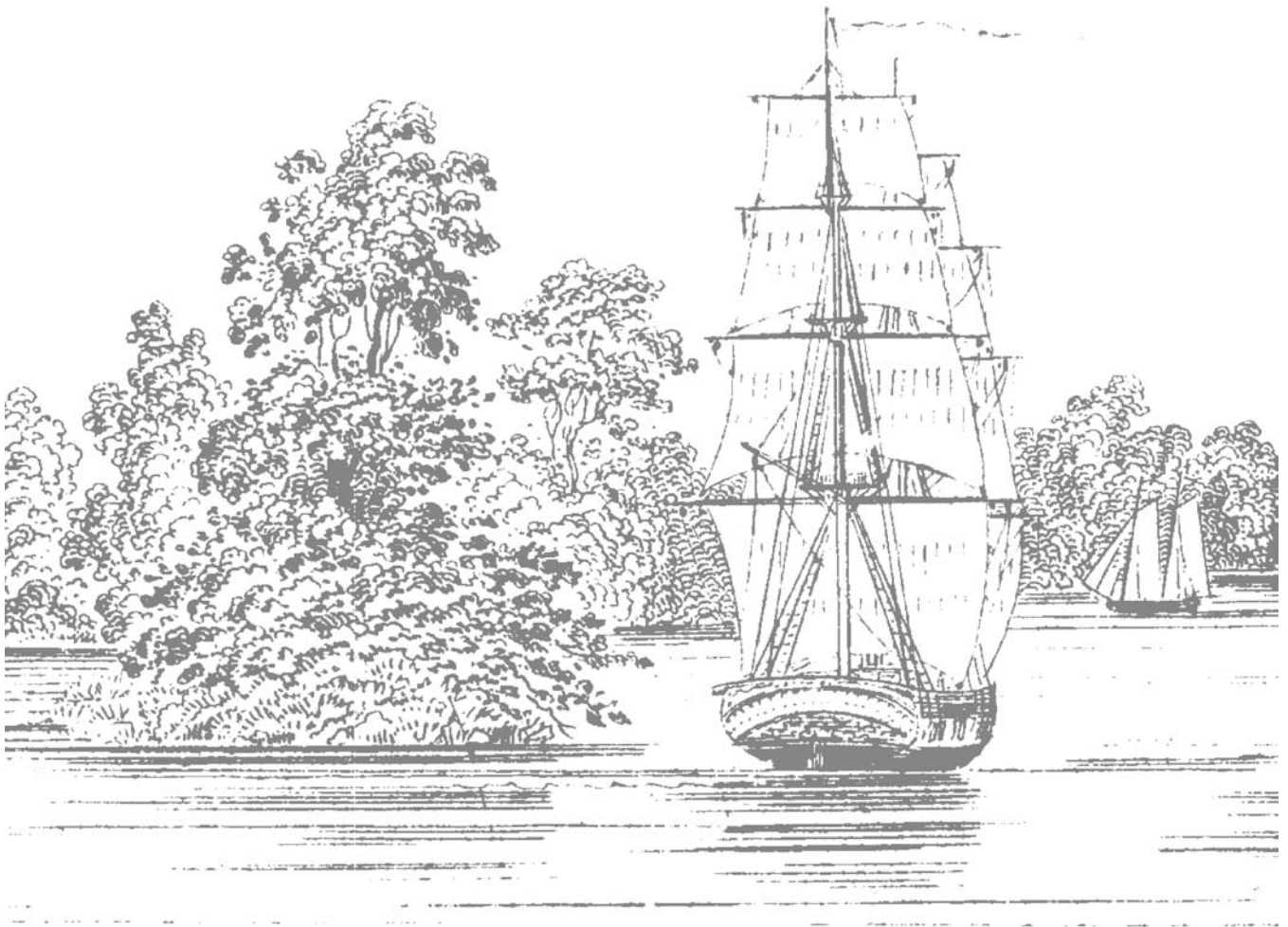


From the Sierra to the Sea

The Ecological History of the
San Francisco Bay-Delta Watershed



Middle Fork



© 1998 The Bay Institute of San Francisco
Second printing, July 2003

The Bay Institute of San Francisco is a non-profit research and advocacy organization which works to protect and restore the ecosystem of the San Francisco Bay/Delta estuary and its watershed. Since 1981, the Institute's policy and technical staff have led programs to protect water quality and endangered species, reform state and federal water management, and promote comprehensive ecological restoration in the Bay/Delta.

Copies of this report can be ordered for \$40.00 (includes shipping and handling) from:

The Bay Institute of San Francisco
500 Palm Drive
Novato, CA 94949
Phone: (415) 506-0150
Fax: (415) 506-0155
www.bay.org

The cover is taken from an engraving showing the entrance to the middle fork of the Sacramento River near modern-day Steamboat Slough, in C. Ringgold's 1852 series of navigational charts and sailing directions for San Francisco Bay and Delta.

Printed on recycled paper

From the Sierra to the Sea

The Ecological History of the
San Francisco Bay-Delta
Watershed

July 1998

The Bay Institute

**FROM THE SIERRA TO THE SEA:
THE ECOLOGICAL HISTORY OF THE
SAN FRANCISCO BAY-DELTA WATERSHED**

Table of Contents

| | <u>Page</u> |
|---|-------------|
| CONTRIBUTORS AND ACKNOWLEDGEMENTS..... | vii |
| EXECUTIVE SUMMARY..... | ES-1 |
| CHAPTER ONE: INTRODUCTION | |
| I. Background..... | 1-1 |
| II. General Approach of the Report..... | 1-1 |
| III. Methods..... | 1-4 |
| IV. Report Organization..... | 1-5 |
| CHAPTER TWO: ECOSYSTEMS OF THE WATERSHED: NATURAL STRUCTURE, FUNCTION AND ORGANIZATION | |
| I. Introduction..... | 2-1 |
| II. Environmental Context..... | 2-2 |
| A. The Geographic Context..... | 2-2 |
| B. The Geologic Context - Formation of the Watershed..... | 2-2 |
| C. The Climatic Context..... | 2-4 |
| D. The Hydrologic Context..... | 2-7 |
| III. Upland (Mountain) River-Riparian Ecosystem..... | 2-8 |
| A. Ecosystem Structure: Habitat Types and Biological Assemblages..... | 2-8 |
| 1. Riverine Habitat..... | 2-8 |
| 2. Riparian Zone..... | 2-12 |
| B. Ecosystem Function: Essential Processes..... | 2-14 |
| 1. Hydrogeomorphic Processes..... | 2-14 |
| 2. Disturbance and Succession..... | 2-16 |
| 3. Community Energetics: The Acquisition and Cycling of Organic Carbon and Nutrients..... | 2-17 |
| IV. Lowland (Alluvial) River-Floodplain Ecosystems..... | 2-19 |
| A. Ecosystem Structure: Habitat Types and Biological Assemblages..... | 2-20 |
| 1. Riverine Habitat..... | 2-20 |
| 2. Riparian Zone..... | 2-27 |
| 3. Wetlands..... | 2-37 |

| | <u>Page</u> |
|---|-------------|
| B. Ecosystem Function: Essential Processes | 2-41 |
| 1. Surface Water Hydrology and Geomorphology | 2-41 |
| 2. Groundwater Hydrology | 2-50 |
| 3. Disturbance and Succession | 2-51 |
| 4. Community Energetics: The Acquisition and Cycling of Organic Carbon and Nutrients | 2-52 |
| V. The Delta | 2-54 |
| A. Ecosystem Structure: Habitat Types and Biological Assemblages | 2-56 |
| 1. Intertidal Wetlands | 2-57 |
| 2. Subtidal Waterways..... | 2-62 |
| 3. Supratidal Landforms | 2-64 |
| 4. Habitat Connectivity | 2-68 |
| 5. Associated Biological Assemblages..... | 2-68 |
| B. Ecosystem Function: Supporting and Integrating Processes | 2-70 |
| 1. Hydrogeomorphic Processes..... | 2-70 |
| 2. Disturbance and Succession | 2-74 |
| 3. Community Energetics: The Acquisition and Cycling of Organic Carbon and Nutrients | 2-74 |
| VI. Greater San Francisco Bay | 2-76 |
| A. Ecosystem Structure: Habitat Types and Biological Assemblages | 2-76 |
| 1. Open Water (Pelagic) Habitat | 2-77 |
| 2. Subtidal Benthic | 2-80 |
| 3. Intertidal Mudflats..... | 2-81 |
| 4. Intertidal (“Tidal”) Marshes | 2-82 |
| 5. Rocky Intertidal..... | 2-85 |
| B. Ecosystem Function: Supporting and Integrating Processes | 2-86 |
| 1. Hydrogeomorphic Processes..... | 2-86 |
| 2. Community Energetics: The Acquisition and Cycling of Organic Carbon and Nutrients..... | 2-87 |
| VII. The Nearshore Ocean | 2-89 |
| A. Ecosystem Structure: Habitat Types and Biological Assemblages | 2-90 |
| 1. Pelagic Subdivision..... | 2-90 |
| 2. Benthic/Demersal Division..... | 2-93 |
| 3. Intertidal (Shoreline) Habitats..... | 2-94 |

| | <u>Page</u> |
|--|-------------|
| B. Ecosystem Function: Supporting and Integrating Processes | 2-95 |
| 1. Physical Processes | 2-95 |
| 2. Community Energetics: The Acquisition and Cycling of Organic Carbon and Nutrients | 2-97 |
| VIII. A Watershed -Scale Perspective..... | 2-98 |
| CHAPTER THREE: TRANSFORMING THE WATERSHED: TWO CENTURIES OF CHANGE | |
| I. Introduction | 3-1 |
| II. Human Interventions in Watershed Ecology | 3-1 |
| A. Harvest..... | 3-2 |
| 1. The Hunting of Large Mammals and Waterfowl..... | 3-2 |
| 2. Fishing | 3-3 |
| 3. Logging..... | 3-6 |
| B. The Introduction of Exotic Species..... | 3-8 |
| C. Livestock Grazing and Dairies | 3-10 |
| D. The Growth of Agriculture | 3-11 |
| 1. Farming the Lowland Floodplains | 3-13 |
| 2. Farming the Delta | 3-16 |
| 3. Farming Near San Francisco Bay..... | 3-20 |
| E. Mining..... | 3-21 |
| F. Urbanization..... | 3-26 |
| G. Water Resource Management..... | 3-31 |
| 1. Surface Water Diversion, Storage and Redistribution..... | 3-31 |
| 2. Groundwater Pumping..... | 3-37 |
| 3. Flood Control..... | 3-39 |
| H. Waterway Navigation..... | 3-40 |
| CHAPTER FOUR: THE WATERSHED: ECOLOGICAL RESPONSE | |
| I. Introduction | 4-1 |
| II. Changes in Hydrogeomorphic Processes..... | 4-1 |
| A. Hydrology | 4-1 |
| 1. Stream Flows | 4-1 |
| 2. Delta Outflow | 4-6 |
| 3. Floods..... | 4-6 |
| 4. Estuarine Circulation..... | 4-7 |
| B. Sedimentology | 4-8 |

| | <u>Page</u> |
|---|-------------|
| III. Changes in Habitats and Biological Communities | 4-10 |
| A. Upland River-Riparian Ecosystems..... | 4-10 |
| 1. Habitat Changes..... | 4-10 |
| 2. Changes in Biological Community Structure and Function..... | 4-12 |
| B. Lowland River Floodplain Systems (Sacramento and San Joaquin) | 4-13 |
| 1. Habitat Changes..... | 4-13 |
| 2. Changes in Biological Community Structure and Function..... | 4-16 |
| C. The Delta..... | 4-17 |
| 1. Habitat Changes..... | 4-17 |
| 2. Changes in Biological Community Structure and Function..... | 4-18 |
| D. San Francisco Bay | 4-19 |
| 1. Habitat Changes..... | 4-19 |
| 2. Changes in Biological Community Structure and Function..... | 4-21 |
| E. The Nearshore Ocean..... | 4-23 |
| 1. Habitat Changes..... | 4-23 |
| 2. Changes in Biological Community Structure and Function..... | 4-24 |
| IV. A Watershed-Scale Perspective..... | 4-25 |

CHAPTER FIVE: APPLICATIONS: BUILDING A PRACTICAL FRAMEWORK FOR ECOSYSTEM RESTORATION AND MANAGEMENT

| | |
|--|-----|
| I. Developing a Practical and Effective Strategic Approach | 5-1 |
| II. Developing Practical Tools for Restoration and Management at the Ecosystem Level..... | 5-5 |
| III. Concluding Recommendations..... | 5-7 |

| | |
|-------------------------|------------|
| REFERENCES | R-1 |
|-------------------------|------------|

APPENDIX A - GEOGRAPHICAL INFORMATION SYSTEM MAPS

List of Figures

| | | <u>Page</u> |
|-------|---|-------------|
| II-A | The Invading Estuary | 2-5 |
| II-B | Annual Precipitation Variability in the Central Valley Watershed (1870-1997) | 2-6 |
| II-C | Average Monthly Unimpaired (Natural) Discharge from the Upland Sacramento and San Joaquin River Watersheds | 2-15 |
| II-D | Characteristic Channel Morphology of a Meandering Reach | 2-23 |
| II-E | Backwater Area | 2-24 |
| II-F | Native Woodlands of the Sacramento Valley, circa 1800..... | 2-31 |
| II-G | Riparian Vegetation Patterns | 2-34 |
| II-H | Waterfowl in Flight..... | 2-42 |
| II-I | Estimated Differences in the Monthly Pattern of Natural Sacramento Valley Inflow versus Outflow | 2-47 |
| II-J | Modifying Effects of Flood Basin and Tributary Inflow on the Lowland Sacramento River Flow | 2-49 |
| II-K | Early View of the Delta | 2-55 |
| II-L | Earliest Map of the Delta and Sacramento Region (ca. 1833) | 2-60 |
| II-M | Delta Vegetation Patterns | 2-61 |
| II-N | Cross-section of the Sacramento River at Freeport | 2-65 |
| II-O | Sketch of Lower Sacramento River in the Delta | 2-67 |
| | | |
| III-A | Egg-hunters on the Farallon Islands | 3-4 |
| III-B | Rate of Introduction of Exotic Species by Period | 3-9 |
| III-C | Impacts of Overgrazing..... | 3-12 |
| III-D | Effects of Pollution..... | 3-17 |
| III-E | “Tule Breakers” | 3-19 |
| III-F | Hydraulic Gold Mine, 1908 | 3-22 |
| III-G | A Sierra Canyon Clogged by Mining Debris, 1908 | 3-24 |
| III-H | Gravel Mining Pits..... | 3-27 |
| III-I | Shasta Dam | 3-33 |
| III-J | Major Central Valley Project (CVP) Facilities | 3-35 |
| III-K | State Water Project Facilities | 3-36 |
| III-L | Reservoir Development in the Central Valley | 3-38 |
| III-M | River-borne Transport..... | 3-41 |
| | | |
| IV-A | Alteration of Median Monthly Inflow into the Lowland Sacramento River at Red Bluff | 4-3 |
| IV-B | Alteration of Median Monthly Inflow into the Lowland Tuolumne and San Joaquin Rivers | 4-4 |
| IV-C | Estimated Alteration of Sacramento River Monthly Outflow Pattern..... | 4-5 |

List of Tables

| | <u>Page</u> |
|--|-------------|
| II-A Annual In-Delta Organic Carbon Contribution to Watershed..... | 2-75 |
| IV-A Summary (by Ecosystem-type) of Major Ecosystem Alterations Over the Last 200 Years..... | 4-29 |
| V-A Delta Ecosystem: Proposed Essential Attributes and Their Indicators..... | 5-10 |
| V-B Upland River-Floodplain Ecosystem: Proposed Essential Attributes and Their Indicators | 5-12 |
| V-C Delta Ecosystem: Sample Reference Values for Selected Indicators | 5-14 |

List of Geographical Information System (GIS) Maps

| | |
|--|--|
| G-1 The San Francisco Bay-Delta Aquatic Ecosystem Distribution | |
| G-2 Historic Connected Waterways of the Central Valley Watershed | |
| G-3 The Transformed Watershed | |
| G-4 Sacramento Valley Historic River Floodplain Ecosystem | |
| G-5 Sacramento Valley Current Aquatic Ecosystem | |
| G-6 San Joaquin Valley Historic River Floodplain Ecosystem | |
| G-7 San Joaquin Valley Current Aquatic Ecosystem | |
| G-8 Tulare Basin Historic Wetland Ecosystem | |
| G-9 Tulare Basin Current Wetland Ecosystem | |
| G-10 The Delta: Historic Aquatic Ecosystem | |
| G-11 The Delta: Current Aquatic Ecosystem | |
| G-12 San Francisco Bay: Historic Aquatic Ecosystem | |
| G-13 The San Francisco Bay: Current Aquatic Ecosystem | |
| G-14 Nearshore Ocean: Habitat and Bathymetry | |

CONTRIBUTORS AND ACKNOWLEDGEMENTS

This report would not have been possible without the generous financial support of the David and Lucile Packard Foundation, the United States Environmental Protection Agency, the CALFED Bay-Delta Program, the Metropolitan Water District of Southern California, the National Fish and Wildlife Foundation, and California Urban Water Agencies. We would also like to acknowledge the Marin Community Foundation, the William and Flora Hewlett Foundation, and the Fred Gellert Family Foundation for their generous contributions to The Bay Institute's general operating budget.

Funding for the second printing was provided by the CALFED Bay-Delta Program in collaboration with the San Joaquin River Parkway and Conservation Trust, Inc. (www.riverparkway.org).

This report is the product of the dedicated effort of many individuals and organizations. We want to acknowledge the patience and perseverance of all the individuals who contributed. Bill Alevizon (formerly Staff Ecologist, The Bay Institute; currently consulting ecologist) was the senior author and editor, and project manager for the early drafts of the report. Peter Vorster (Staff Hydrologist, The Bay Institute) was the project manager for the final report and provided technical editing, GIS and figure preparation, historical conditions research, and water balance development. Alison S. Britton Consulting/Design Services produced the report with the assistance of Kent Sumrall of the Bay Institute. Kate Britton compiled and proofed the references. Ann Dickinson prepared the files for the second printing.

The GIS maps were produced by Brian Cohen of GreenInfo Network with contributions and data provided by John Cain of the Natural Heritage Institute, Steve Greco of the University of California at Davis, Jo Ann Gronberg of the United States Department of the Interior, Robin Grossinger of the San Francisco Estuary Institute, Dave Hanson of the United States Bureau of Reclamation, Dan Scollon of the Bay Institute, Steve Skartvedt of Golden Gate National Recreation Area, Jennifer Vick of Stillwater Sciences, and Paul Viesze of the California Department of Fish and Game.

The final report built upon contributions by the original drafting and research team composed of Bill Alevizon and Nicole Wainwright (The Bay Institute), Jennifer Vick, Michelle Orr, and Phil Williams (Philip B. Williams and Associates), and Rod Fujita and Karen Levy (Environmental Defense Fund). Valuable contributions were also provided by the reviewers of the various drafts of this report. The reviewers included Elaine Archibald (Archibald and Wallberg), Gary Bobker and Grant Davis (The Bay Institute), Richard Denton (Contra Costa Water District), Phyllis Fox (Environmental Management), Robert Nuzum (East Bay Municipal Utilities District), Pete Rhoads (Metropolitan Water District of Southern California), Doug Shields (United States Department of Agriculture, Sedimentation Laboratory), Randy Bailey (Bailey

Environmental), and Charles Simenstad (University of Washington). Bruce Herbold (United States Environmental Protection Agency), Elise Holland (The Bay Institute), Brian Atwater (University of Washington), Judd Monroe (consulting environmental planner), Steve Johnson (the Nature Conservancy), and Fred Nichols (United States Geological Survey) reviewed sections of the report. Several reviewers provided significant additional information and many constructive revisions to the final draft. In particular we wish to acknowledge the efforts of Phyllis Fox and Elaine Archibald in that regard. Although the contributions of all the persons mentioned above were invaluable, none of the foregoing are responsible for the final version of this report.

We also want to acknowledge contributions from the following organizations and individuals who supplied data and other information used in the report: the California Department of Water Resources (Tariq Kadir and others), Roger Putty (Montgomery Watson), David Dawdy, the United States Geological Survey, the Water Resources Archives and the Bancroft Library at the University of California at Berkeley. Phyllis Fox made her extensive personal collection of archival material available. Many other individuals too numerous to list answered our questions and provided information. We thank you.