

CONTAMINANTS IN FISH FROM CALIFORNIA LAKES AND RESERVOIRS, 2007-2008: SUMMARY REPORT ON A TWO-YEAR SCREENING SURVEY

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Concise summary of year 1 results of the SWAMP Lakes Survey: composites or averages at each location

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List of lakes identified for trend analysis



EXECUTIVE SUMMARY **E**

This summary report presents results from a two-year screening survey of contaminants in sport fish in California lakes and reservoirs. This survey was performed as part of the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP). This effort marks the beginning of a new, long-term, statewide, comprehensive bioaccumulation monitoring program for California surface waters. This screening study was the first step in an effort to identify and quantify contaminants in California's lakes to evaluate exposure and risk in humans and wildlife.

This report provides a concise technical summary of the findings of the survey. This report is intended for agency scientists that are charged with managing water quality problems related to bioaccumulation of contaminants in California lakes and reservoirs. Another version of the report is also available (Davis et al. 2010) that provides a more detailed presentation of the methods and findings from the survey.

The Lakes Survey represents a major step forward in understanding the extent of chemical contamination in sport fish in California lakes and reservoirs, and the impact of this contamination on the fishing beneficial use. The study has shown that mercury accumulation in fish is a significant problem throughout much of the state. However, comparison to USEPA's national survey indicate that the degree of mercury contamination in California is not unusual compared to the rest of the country, in spite of the intensive mercury and gold mining that has occurred here. For other contaminants, concentrations were much lower relative to thresholds for human health concern. It should also be noted that this survey focused on the species that accumulate the highest contaminant concentrations. Concentrations in some of the other species can be expected to be substantially lower than observed for the predators and bottom-feeders evaluated in this study.

The Lakes Survey was a preliminary screening of contamination in sport fish. The species selected for sampling (primarily rainbow trout, largemouth bass, and common carp) are known to accumulate high concentrations of contaminants and are therefore good indicators of contamination problems. This screening study did not provide enough information for consumption guidelines – this would require monitoring a broader array of species, larger numbers of fish, and a much higher level of funding.

Fish tissue concentrations were evaluated using thresholds developed by the California Office of Environmental Health Hazard Assessment (OEHHA) for methylmercury, PCBs, dieldrin, DDTs, chlordanes, and selenium, and a State Water Resources Control Board threshold for mercury in tissue that is being used for identification of impaired water bodies.



In 2007 and 2008 the study team collected 4,905 fish representing 23 species from 272 lakes and reservoirs. The survey identified problems in certain areas of the state, with methylmercury and polychlorinated biphenyls (PCBs) being the contaminants of greatest concern.

Methylmercury poses the most widespread potential health risk to persons who consume fish caught in California lakes. Twenty-one percent of the lakes surveyed had at least one fish species with an average methylmercury level high enough (> 0.44 ppm) that OEHHA would consider recommending no consumption of the contaminated species for women between 18 and 45 years of age and children from 1 to 17 years of age. In northern California, the study commonly found low concentrations in high-elevation lakes (above two thousand feet) in the Sierra Nevada and Trinity Alps. Trout were the most frequently caught species in these lakes, and tend to accumulate relatively low methylmercury concentrations. In contrast, methylmercury concentrations in bass were higher than OEHHA's 0.44 ppm threshold in 48% of the lower elevation lakes (below two thousand feet) surveyed in northern California. Southern California had moderate methylmercury contamination, with 15% of the sampled lakes above 0.44 ppm.

Mercury contamination of California water bodies is largely a legacy of historic mercury and gold mining, but can also reach lakes from local and global emissions to the atmosphere. In spite of the extensive mining activity in California, however, the degree of mercury contamination in the state's lakes is not that unusual and comparable to the average condition observed across the U.S. in a recent national lakes survey.

PCBs were second to methylmercury as a potential health concern to consumers of fish caught from California lakes. However, only 1% of the lakes sampled had a species with an average concentration that exceeded OEHHA's threshold for considering a recommendation of no consumption (120 ppb). PCBs are persistent chemicals that are now banned, but were commonly used in electrical, industrial and other applications. Concentrations of other pollutants (dieldrin, DDT, chlordane, and selenium) were generally low, and infrequently exceeded OEHHA thresholds.

This screening survey has raised many questions, and left other questions unanswered. Several areas where additional information would be of great value in addressing management issues are listed below.

1) Data for additional species at lakes with high contaminant concentrations to support development of consumption guidelines.

High priority waters in this regard with elevated concentrations were discussed in the mercury and PCB sections. Development of consumption guidelines requires data from a broader spectrum of species, so anglers can be directed to cleaner species if they are present (as is often the case). Significant funding would be needed to perform this follow-up work at the many lakes with concentrations above thresholds.



2) Focused evaluations of selected lakes to identify sources, controlling factors, and likely outcomes

Distinguishing the relative importance of legacy contamination from mining, atmospheric deposition, and other sources is critical to effective management of methylmercury contamination. More detailed, site-specific field work could be performed to assess the contributions from different sources. Identifying and sampling lakes without mining influence could yield valuable insights. Other controlling factors that can be important in determining accumulation in the food web, such as food web structure and limnology, also need to be understood as a basis for management.

3) Assessment of risks to wildlife from bioaccumulative contaminants

Although this study did not focus on risks to wildlife due to funding limitations, they are likely to be a significant concern. Exposures and risks to wildlife, including fish and fish-eating birds (Sandheinrich and Wiener 2009), are likely to be substantially higher than for humans in some instances. The best approach would be to conduct monitoring targeted at addressing this question.

4) Emerging contaminants

Again due to funding limitations, this study did not evaluate emerging contaminants. Two of these contaminants, polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs), are known to accumulate in fish. Human health thresholds for these chemicals in fish are anticipated (PBDEs) or available (PFC screening values have been developed by the state of Minnesota). These and other emerging contaminants accumulate in fish and should be tracked to provide information that managers need in order to act before they become the legacy contaminants of tomorrow.

5) Trends

Lake and reservoir food webs are contaminated with mixtures of contaminants, some with declining concentrations, some rising, and some not changing appreciably. Tracking these trends is essential to effective management of water quality in these ecosystems. Large-scale processes such as climate change can influence trends. Contaminant trends in lakes are affected by a host of sources and processes operating at global (e.g., atmospheric deposition) and local scales. An effective program to monitor trends is needed.



SECTION 1 INTRODUCTION

This summary report presents results from a two-year screening survey of contaminants in sport fish in California lakes and reservoirs. This survey was performed as part of the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP). This effort marks the beginning of a new long-term, statewide, comprehensive bioaccumulation monitoring program for California surface waters.

This report provides a concise technical summary of the findings of the survey. This report is intended for agency scientists that are charged with managing water quality problems related to bioaccumulation of contaminants in California lakes and reservoirs. Another version of the report (Davis et al. 2010) has also been prepared that provides more technical detail on the survey and was the basis for scientific peer review of the work.

Oversight for this project is being provided by the SWAMP Roundtable. The Roundtable is composed of State and Regional Board staff and representatives from other agencies and organizations including US Environmental Protection Agency (USEPA), the California Department of Fish and Game, and the California Office of Environmental Health Hazard Assessment (OEHHA). Interested parties, including members of other agencies, consultants, or other stakeholders also participate.

The Roundtable has formed a subcommittee, the Bioaccumulation Oversight Group (BOG) that specifically guides SWAMP bioaccumulation monitoring. The BOG is composed of State and Regional Board staff and representatives from other agencies and organizations including USEPA, the Department of Fish and Game, OEHHA, and the San Francisco Estuary Institute. The members of the BOG possess extensive experience with bioaccumulation monitoring.

The BOG has also convened a Bioaccumulation Peer Review Panel that is providing evaluation and review of the bioaccumulation program. The members of the Panel are internationally-recognized authorities on bioaccumulation monitoring.

The BOG has developed and begun implementing a plan to evaluate bioaccumulation impacts on the fishing beneficial use in all California water bodies. Sampling of sport fish in lakes and reservoirs was conducted in the first two years of monitoring (2007 and 2008). In 2009 and 2010, sport fish from the California coast, including bays and estuaries are being sampled. Sport fish from rivers and streams will be sampled in 2011. In 2012 the plan is to again begin a two year effort on lakes and begin another five-year cycle of sampling these water body types.



THE LAKES SURVEY

Management Questions for This Survey

Three management questions were articulated to guide the design of the Lakes Survey. These management questions are specific to this initial monitoring effort; different sets of management questions will be established to guide later efforts.

Management Question 1

What is the condition of California lakes with respect to bioaccumulation in sport fish?

Answering this question has been the goal of assessments related to Section 305(b) of the federal Clean Water Act (CWA). In the past, 305(b) reports have provided water quality information to the general public and served as the basis for USEPA's National Water Quality Inventory Report to Congress. The report provided a statewide, comprehensive assessment of the status of California water bodies with respect to support of designated beneficial uses (e.g., SWRCB [2003]). Beginning in 2010, an Integrated Report provides the recommendations of the staff of the State Water Board for changes to the Clean Water Act Section 303(d) List of impaired water bodies and the Clean Water Act Section 305(b) report on the quality of waters in California (CWA Section 303(d) is discussed further below). Answering this question also provides the state and the public with information that helps describe the magnitude, spatial dimensions, and significance of the bioaccumulation problem relative to other environmental and societal problems.

The information needed to answer this question is the representative, average concentration of contaminants in sport fish indicator species in each lake for an adequately large sampling of lakes.

Management Question 2

Should a specific lake be considered for inclusion on the 303(d) List due to bioaccumulation of contaminants in sport fish?

Answering this question is critical to determining the need for 303(d) listing and cleanup actions to reduce contaminant exposure in specific water bodies. Total Maximum Daily Load evaluations (TMDLs) are required for water bodies placed on the 303(d) list. This is the principal regulatory mechanism being used by the State Water Board, the Regional Water Boards, and USEPA to establish priorities for management actions.

The State Board has established a Listing Policy for placing water bodies on the CWA Section 303(d) list. The Listing Policy establishes a standardized approach and includes California listing and de-listing factors. The fish tissue information needed to make a listing determination depends on the type of data and the pollutant. The more representative the samples are of the water body, the better. The goal in addressing Management Question 2 in this survey was to assist the Regional Boards and State Board by providing the data needed for listing decisions. Actual 303(d) listing determinations will be made by the Regional Boards using the data generated in the Lakes Survey.



Management Question 3

Should additional sampling of bioaccumulation in sport fish at a lake be conducted for the purpose of developing consumption guidelines?

Answering this question is essential as a first step in developing consumption guidelines. Consumption guidelines provide a mechanism for reducing human exposure to problematic contaminants in the near-term. The information requirements for consumption guidelines are more extensive than for 303(d) listing. OEHHA, the agency responsible for issuing consumption guidelines in California, needs samples representing at least nine or more fish from a variety of species abundant in a water body in order to issue guidance. It is useful to have information not only on the species with high concentrations, but also the species with low concentrations so anglers and other consumers of wild fish can be encouraged to target the low species.

Overall Approach

The overall approach taken to answer these three questions was to perform a statewide screening study of bioaccumulation in sport fish. The highest priority for SWAMP in the short term is to answer Management Questions 1 and 2. Answering these questions will provide a basis for decision-makers to understand the scope of the bioaccumulation problem and will provide regulators with information needed to establish priorities for cleanup actions. In the longer term, developing consumption guidelines that inform the public on ways to reduce their exposure is also a high priority. This initial monitoring effort was a cost effective way to establish a foundation for developing consumption guidelines by identifying lakes that are candidates for additional sampling

This screening study is already leading to more detailed follow-up investigations of many water bodies that are candidates for the 303(d) List or where consumption guidelines are needed.



SECTION 2 METHODS

SAMPLING DESIGN

The sampling plan was developed to address the three management questions for the project. In 2007 and 2008, sampling was conducted at 272 fishing lakes and reservoirs across California (Figures 1a-d, Tables 1a,b). Fish were collected from lakes across the state from June through November in 2007 and 2008 (Figures 1a-d, Tables 1a,b). Cruise reports with detailed information on locations are available at: http://www.swrcb.ca.gov/water_issues/programs/swamp/docs/lakes_study/bog_07lakes_monplan.pdf.

Targeted sampling of “popular” lakes comprised the bulk of the effort (222 of 272 lakes), with a random sampling of 50 lakes. In addition to the statewide targeted sampling of popular lakes, this report also includes data obtained from a coordinated targeted sampling of lakes in Region 4 (Figures 1a,c,d). The Region 4 Water Board augmented the statewide effort with funds to provide for sampling of 22 additional lakes, including a more thorough analysis of replicate samples than was feasible in the statewide effort.

The second major emphasis of the survey was to provide an evaluation of statewide lake condition. A randomized sampling of 50 lakes from the entire population of California lakes was conducted to provide an unbiased statewide assessment, and a valuable frame of reference for interpreting bias in the targeted sampling. The Sampling Plan (Davis et al. 2007a) provides more details on the design.

TARGET SPECIES

The overall goal of this screening study was to determine whether sport fish in California lakes have concentrations of contaminants that are above thresholds for protection of human health. Therefore, the study focused on sampling of indicator species that tend to accumulate the highest concentrations of the contaminants of concern. Primary target species were selected that are popular for human consumption (e.g., rainbow trout [*Oncorhynchus mykiss*]), and/or are effective at documenting spatial trends in methylmercury (e.g., largemouth bass [*Micropterus salmoides*]) or organics (e.g., common carp [*Cyprinus carpio*]).

Methylmercury biomagnifies primarily through its accumulation in muscle tissue, so top predators such as largemouth bass tend to have the highest methylmercury concentrations. In contrast, organic contaminants are biomagnified through accumulation in lipid. Bottom-feeding species such as common carp and channel catfish (*Ictalurus punctatus*) tend to have the highest lipid concentrations in their muscle tissue, and therefore usually have the highest concentrations of organics.



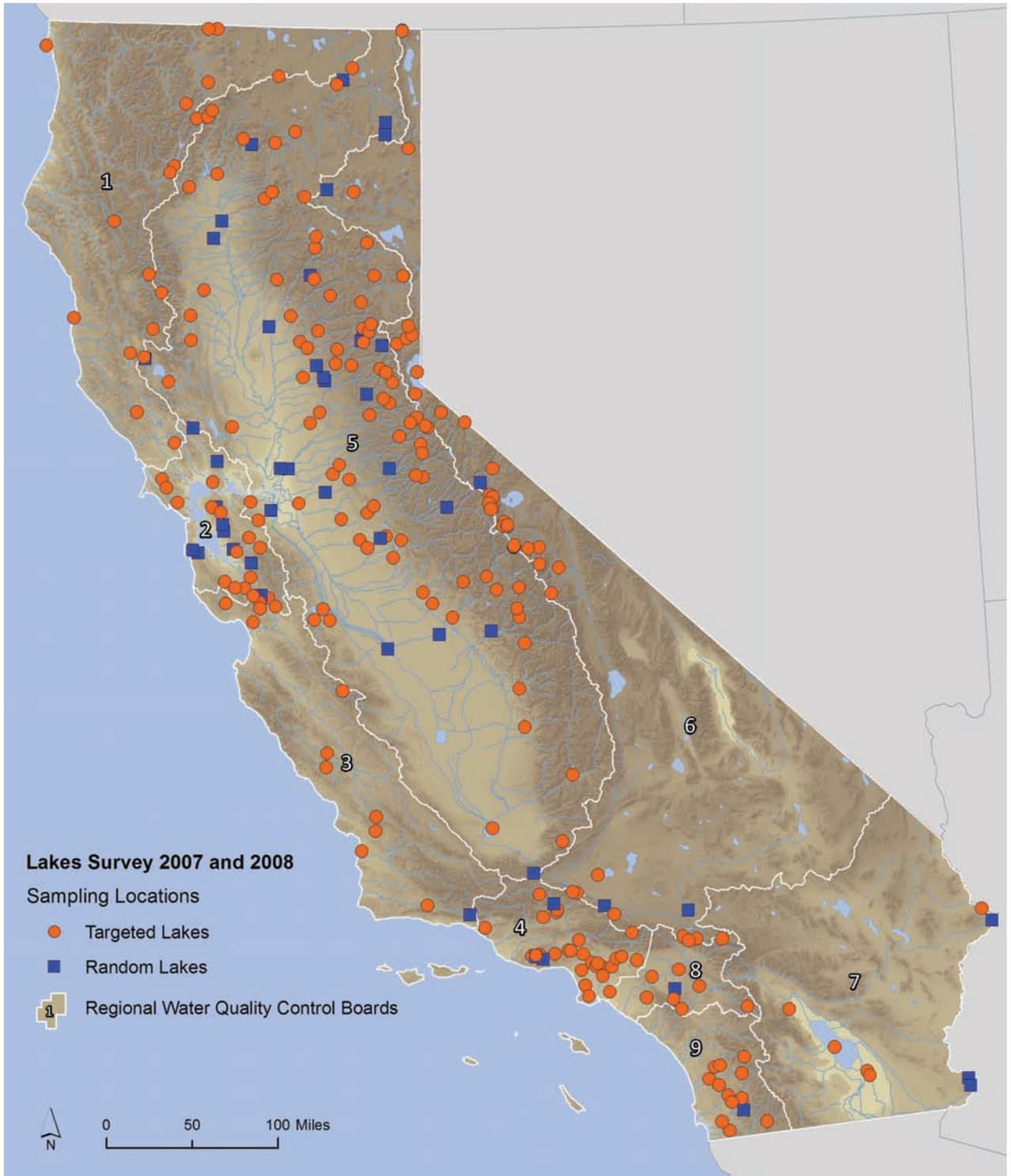


Figure 1a. Lakes sampled in the Lakes Survey. Circles represent 222 lakes that were targeted and squares represent 50 lakes sampled randomly. Lakes are sparse in large areas of Regions 1, 6, and 7.

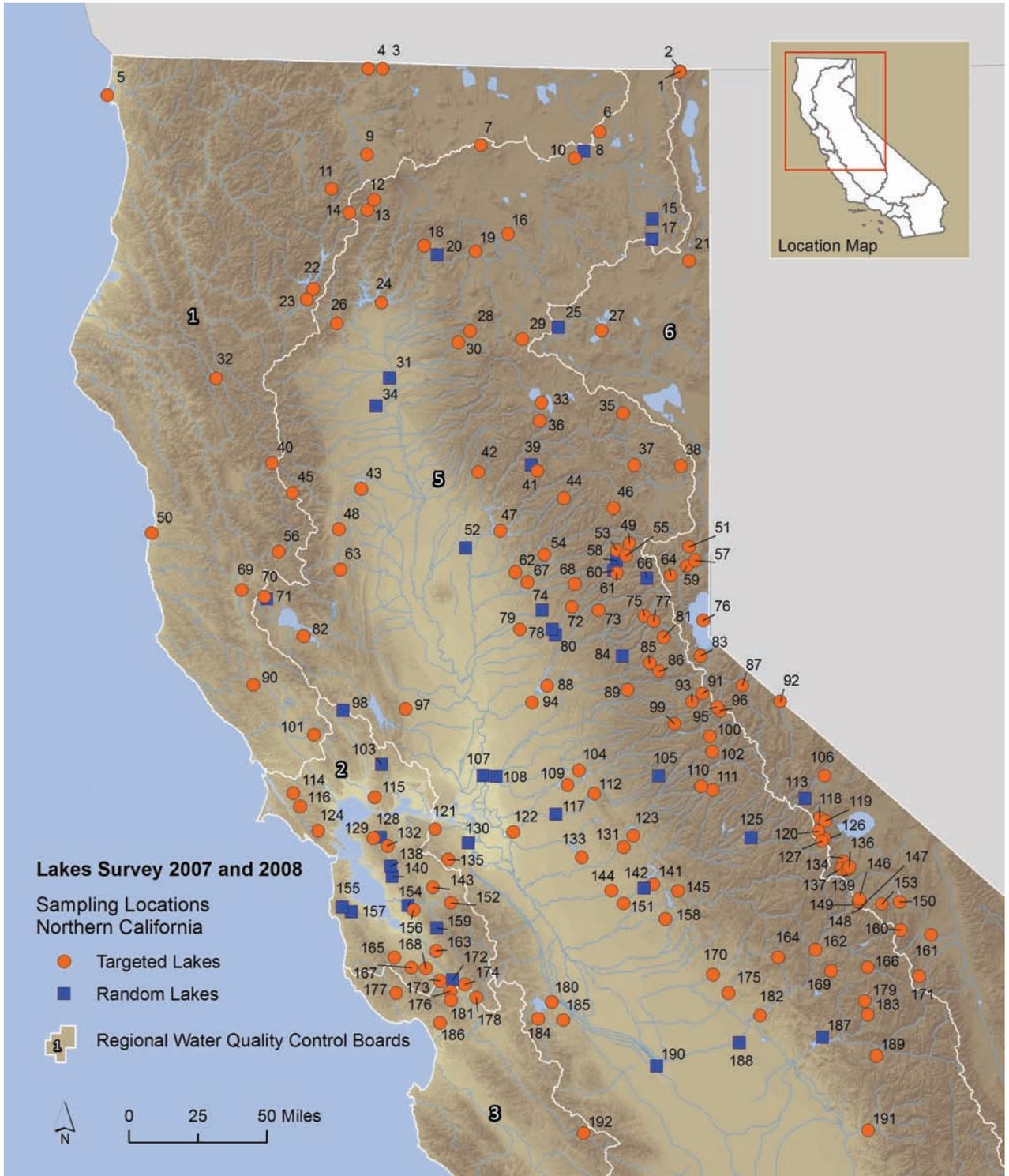


Figure 1b. Northern California lakes sampled in the Lakes Survey. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1. Lakes are sparse in much of Region 1.

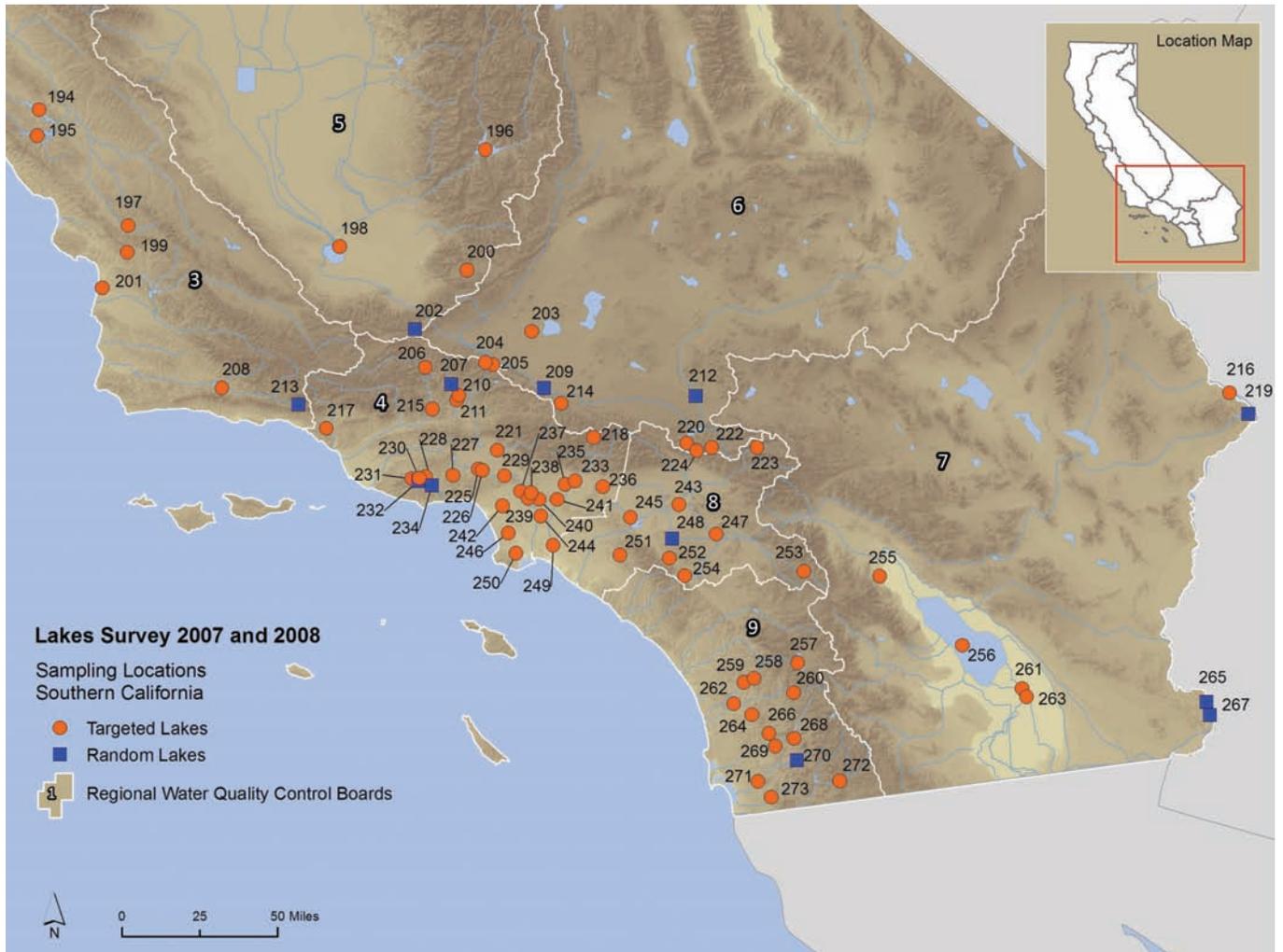


Figure 1c. Southern California lakes sampled in the Lakes Survey. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1. Lakes are sparse in large areas of Regions 6 and 7.

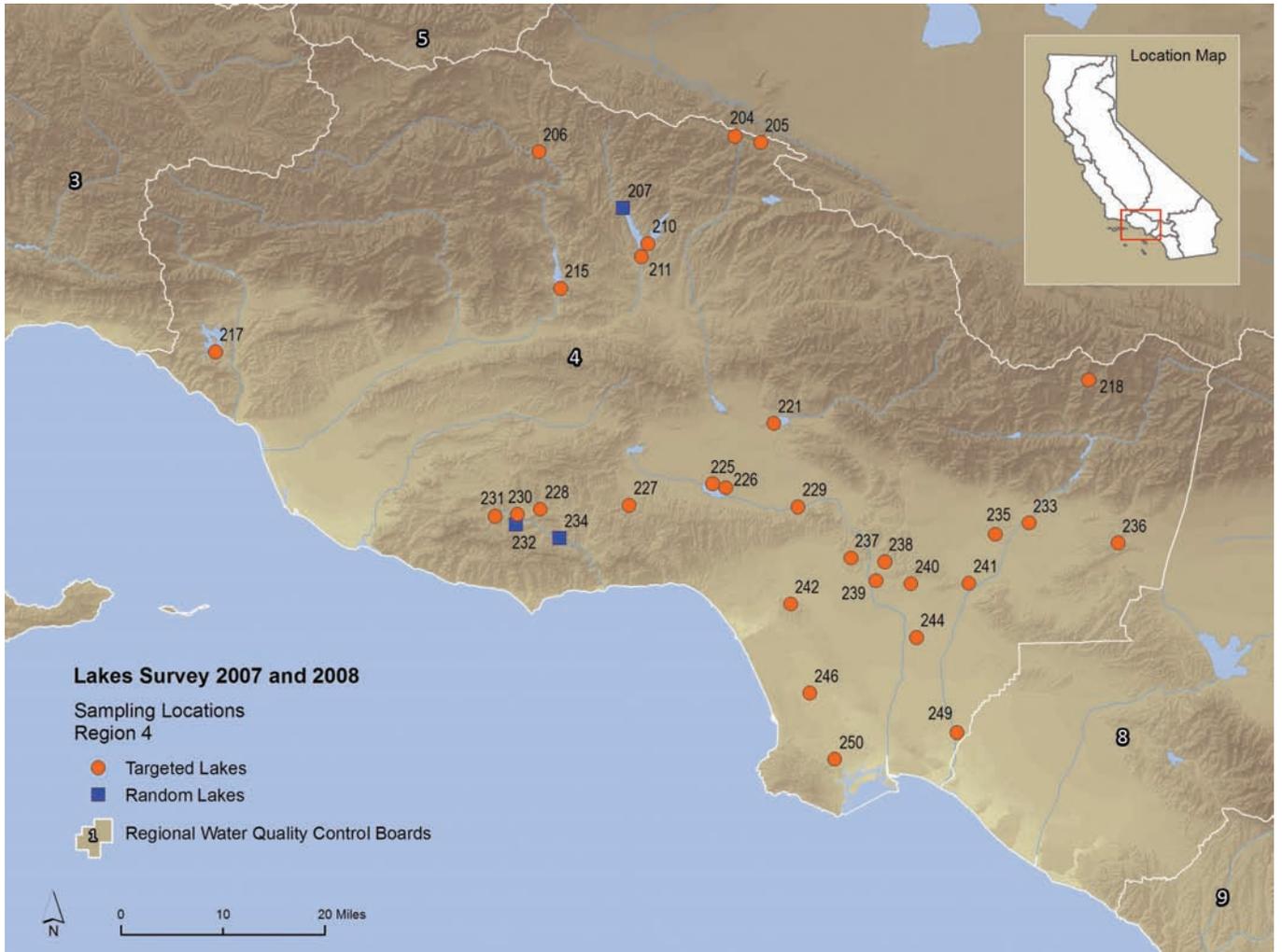


Figure 1d. Region 4 lakes sampled in the Lakes Survey. The Region 4 Water Board augmented the Survey with additional funding to sample a larger number of lakes in their Region. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1.

Table 1a
Lakes sampled, ordered by station number.

Note: These station numbers were assigned only for the purpose of identification on these maps. These are not related to the official station identification numbers in the database.

Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
1	Cave Lake	5	X					X
2	Lily Lake	5	X					X
3	Copco Lake	1	X					X
4	Iron Gate Reservoir	1	X					X
5	Dead Lake	1	X					X
6	Reservoir C	5	X					X
7	Medicine Lake	5	X					X
8	Reservoir F	1	X				X	
9	Lake Shastina	1	X					X
10	Duncan Reservoir	5	X					X
11	Kangaroo Lake	1	X					X
12	Siskiyou Lake	5	X					X
13	Castle Lake	5	X					X
14	Gumboot Lake	5	X					X
15	West Valley Reservoir	5	X				X	
16	Big Lake	5	X					X
17	Moon Lake	5			X		X	
18	Iron Canyon Reservoir	5	X					X
19	Lake Britton	5	X					X
20	Tunnel Reservoir	5	X				X	
21	Dodge Reservoir	6	X					X
22	Trinity Lake	1				X		X
23	Lewiston Lake	1	X					X
24	Shasta Lake	5				X		X
25	Crater Lake	6	X				X	
26	Whiskeytown Lake	5			X			X
27	Eagle Lake	6				X		X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
28	North Battle Creek Reservoir	5	X					X
29	Butte Lake	5	X					X
30	McCumber Reservoir	5	X					X
31	Lake California	5	X				X	
32	Ruth Lake	1	X					X
33	Lake Almanor	5				X		X
34	Finger Lake	5	X				X	
35	Antelope Lake	5	X					X
36	Butt Valley Reservoir	5		X				X
37	Lake Davis	5			X			X
38	Frenchman Lake	5		X				X
39	Lower Bucks Lake	5	X				X	
40	Howard Lake	1	X					X
41	Bucks Lake	5		X				X
42	Paradise Lake	5	X					X
43	Black Butte Lake	5			X			X
44	Little Grass Valley Reservoir	5		X				X
45	Plaskett Lake	1	X					X
46	Gold Lake	5	X					X
47	Lake Oroville	5				X		X
48	Stony Gorge Reservoir	5		X				X
49	Jackson Meadow Reservoir	5	X					X
50	Cleone Lake	1	X					X
51	Stampede Reservoir	6			X			X
52	Thermalito Afterbay	5		X			X	
53	Bowman Lake	5	X					X
54	New Bullards Bar Reservoir	5			X			X
55	Faucherie Lake	5	X					X
56	Lake Pillsbury	1		X				X
57	Boca Reservoir	6	X					X
58	Feeley Lake	5	X				X	
59	Prosser Creek Reservoir	6	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
60	Fuller Lake	5	X				X	
61	Lake Spaulding	5	X					X
62	Collins Lake	5	X					X
63	East Park Reservoir	5		X				X
64	Donner Lake	6	X					X
66	Kidd Lake	5	X				X	
67	Harry L Englebright Lak	5	X					X
68	Scotts Flat Reservoir	5	X					X
69	Lake Mendocino	1		X				X
70	Blue Lakes	5	X					X
71	Lower Blue Lake	5	X				X	
72	Rollins Reservoir	5	X					X
73	Big Reservoir	5	X					X
74	Zayak/Swan Lake	5	X				X	
75	French Meadows Reservoir	5		X				X
76	Lake Tahoe	6				X		X
77	Hell Hole Reservoir	5		X				X
78	Lake of the Pines	5	X				X	
79	Camp Far West Reservoir	5		X				X
80	Lake Combie	5	X				X	
81	Loon Lake	5	X					X
82	Clear Lake	5				X		X
83	Fallen Leaf Lake	6		X				X
84	Stump Meadow Lake	5	X				X	
85	Union Valley Reservoir	5		X				X
86	Ice House Reservoir	5	X					X
87	Indian Creek Reservoir	6	X					X
88	Folsom Lake	5			X			X
89	Jenkinson Lake	5	X					X
90	Lake Sonoma	1		X				X
91	Caples Lake	5	X					X
92	Topaz Lake	6	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
93	Silver Lake	5	X					X
94	Lake Natomas	5	X					X
95	Upper Blue Lake	5	X					X
96	Lower Blue Lake (Alpine County)	5	X					X
97	Lake Berryessa	5				X		X
98	Lake Henne	2	X				X	
99	Lower Bear River Reservoir	5	X					X
100	Lake Alpine	5	X					X
101	Spring Lake	1	X					X
102	Spicer Meadow Reservoir	5	X					X
103	Lake Madigan	2	X				X	
104	Lake Amador	5	X					X
105	White Pines Lake	5	X				X	
106	Bridgeport Reservoir	6		X				X
107	Meadows Slough	5	X				X	
108	Cosumnes River	5	X				X	
109	Camanche Reservoir	5			X			X
110	Beardsley	5	X					X
111	Pinecrest	5	X					X
112	New Hogan Lake	5			X			X
113	Upper Twin Lake	6	X				X	
114	Soulejoule Lake	2	X					X
115	Lake Chabot (Vallejo)	2	X					X
116	Nicasio Lake	2	X					X
117	Unnamed Lake 2	5	X				X	
118	Virginia Lakes	6	X					X
119	Lundy Lake	6	X					X
120	Saddlebag Lake	6	X					X
121	Contra Loma Reservoir	5	X					X
122	Yosemite Lake	5	X					X
123	New Melones Lake	5		X				X
124	Bon Tempe Lake	2	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
125	Hetch Hetchy Reservoir	5		X			X	
126	Ellery Lake	6	X					X
127	Tioga Lake	6	X					X
128	Briones Reservoir	2	X				X	
129	San Pablo Reservoir	2	X					X
130	Discovery Bay	5	X				X	
131	Tulloch Reservoir	5	X					X
132	Lafayette Reservoir	2	X					X
133	Woodward Reservoir	5		X				X
134	Grant Lake	6	X					X
135	Los Vaqueros Reservoir	5		X				X
136	June Lake	6	X					X
137	Silver Lake (Region 6)	6	X					X
138	Upper San Leandro Reservoir	2	X				X	
139	Gull Lake	6	X					X
140	Lake Chabot (San Leandro)	2	X				X	
141	Don Pedro Reservoir	5			X			X
142	La Grange Reservoir	5	X				X	
143	Shadow Cliffs Reservoir	2	X					X
144	Modesto Reservoir	5		X				X
145	Lake McClure	5			X			X
146	Twin Lakes	6	X					X
147	Lake Mamie	6	X					X
148	Lake Mary	6	X					X
149	Lake George	6	X					X
150	Lake Crowley	6			X			X
151	Turlock Lake	5			X			X
152	Lake del Valle	2	X					X
153	Convict Lake	6	X					X
154	Lago Los Osos	2	X				X	
155	Pilarcitos Lake	2	X				X	
156	Lake Elizabeth	2	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
157	Lower Crystal Springs Reserv	2	X				X	
158	Lake McSwain	5	X					X
159	Calaveras Reservoir	2		X			X	
160	Rock Creek Lake	6	X					X
161	Pleasant Valley Reservoir	6	X					X
162	Mammoth Pool Reservoir	5	X					X
163	Lake Cunningham	2	X					X
164	Bass Lake	5	X					X
165	Stevens Creek Reservoir	2	X					X
166	Florence Lake	5	X					X
167	Lake Vasona	2	X					X
168	Almaden Lake	2	X					X
169	Huntington Lake	5		X				X
170	Eastman Lake	5		X				X
171	Lake Sabrina	6	X					X
172	Oiger Quarry Ponds	2	X				X	
173	Calero Reservoir	2	X					X
174	Anderson Lake	2	X					X
175	Hensley Lake	5		X				X
176	Chesbro Reservoir	3	X					X
177	Loch Lomond Reservoir	3	X					X
178	Coyote Lake	2	X					X
179	Courtright Reservoir	5		X				X
180	O'Neill Forebay	5		X				X
181	Uvas Reservoir	3	X					X
182	Millerton Lake	5			X			X
183	Wishon Reservoir	5	X					X
184	San Luis Reservoir	5				X		X
185	Los Banos Reservoir	5	X					X
186	Pinto Lake	3	X					X
187	Pine Flat Lake	5			X		X	
188	Unnamed Lake 1	5	X				X	



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
189	Hume Lake	5	X					X
190	Marsh in Fresno Slough	5	X				X	
191	Lake Kaweah	5		X				X
192	Hernandez Reservoir	3	X					X
193	Success Lake	5			X			X
194	Lake San Antonio	3			X			X
195	Lake Nacimiento	3			X			X
196	Isabella Lake	5			X			X
197	Santo Margarita Lake	3	X					X
198	Lake Webb	5	X					X
199	Lopez Lake	3	X					X
200	Brite Valley Lake	5	X					X
201	Little Oso Flaco Lake	3	X					X
202	Castac Lake	5	X				X	
203	Apollo Lake	6	X					X
204	Lake Hughes	4	X					X
205	Elizabeth Lake	4	X					X
206	Pyramid Lake	4		X				X
207	Elderberry Forebay	4	X				X	
208	Lake Cachuma	3			X			X
209	Palmdale Lake	6	X				X	
210	Castaic Lake	4		X				X
211	Castaic Lagoon	4	X					X
212	Spring Valley Lake	6	X				X	
213	Jameson Lake	3	X				X	
214	Little Rock Reservoir	6	X					X
215	Lake Piru	4	X					X
216	Lake Havasu	7				X		X
217	Lake Casitas	4		X				X
218	Crystal Lake	4	X					X
219	Gene Wash Reservoir	7	X				X	
220	Silverwood Lake	6	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
221	Hansen Lake	4	X					X
222	Lake Arrowhead	6	X					X
223	Big Bear Lake	8			X			X
224	Lake Gregory	6	X					X
225	Balboa Lake	4	X					X
226	Sepulveda Lake	4	X					X
227	Lake Calabasas	4	X					X
228	Lake Lindero	4	X					X
229	Toluca Lake	4	X					X
230	Westlake Lake	4	X					X
231	Lake Sherwood	4	X					X
232	Las Virgenes Reservoir	4	X				X	
233	Santa Fe Reservoir	4	X					X
234	Malibou Lake	4	X				X	
235	Peck Road Water Conservation Park	4	X					X
236	Puddingstone Reservoir	4	X					X
237	Echo Lake (Reg 4)	4	X					X
238	Lincoln Park Lake	4	X					X
239	Hollenbeck Park Lake	4	X					X
240	Belvedere Park Lake	4	X					X
241	Legg Lake	4	X					X
242	Ken Hahn Park Lake	4	X					X
243	Lake Evans	8	X					X
244	John Ford Park Lake	4	X					X
245	Prado Lake	8	X					X
246	Alondra Park Lake	4	X					X
247	Perris Reservoir	8		X				X
248	Lake Mathews	8			X		X	
249	El Dorado Lakes	4	X					X
250	Harbor Lake (Lake Machado)	4	X					X
251	Irvine Lake	8	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
252	Lee Lake/Corona Lake	8	X					X
253	Lake Hemet	8	X					X
254	Lake Elsinore	8		X				X
255	Lake Cahuilla	7	X					X
256	Salton Sea	7				X		X
257	Lake Henshaw	9		X				X
258	Lake Wohlford	9	X					X
259	Dixon Lake	9	X					X
260	Lake Sutherland	9	X					X
261	Ramer Lake	7	X					X
262	Lake Hodges	9	X					X
263	Wiest Lake	7	X					X
264	Lake Poway	9	X					X
265	Ferguson Lake	7	X				X	
266	San Vicente Reservoir	9	X					X
267	Senator Wash Reservoir	7	X				X	
268	El Capitan Lake	9		X				X
269	Lake Jennings	9	X					X
270	Loveland Reservoir	9	X				X	
271	Sweetwater Reservoir	9	X					X
272	Morena Reservoir	9	X					X
273	Lower Otay Reservoir	9	X					X



Table 1b
Lakes sampled, ordered by name.

Note: These station numbers were assigned only for the purpose of identification on these maps. These are not related to the official station identification numbers in the database.

Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
168	Almaden Lake	2	X					X
246	Alondra Park Lake	4	X					X
174	Anderson Lake	2	X					X
35	Antelope Lake	5	X					X
203	Apollo Lake	6	X					X
225	Balboa Lake	4	X					X
164	Bass Lake	5	X					X
110	Beardsley	5	X					X
240	Belvedere Park Lake	4	X					X
223	Big Bear Lake	8			X			X
16	Big Lake	5	X					X
73	Big Reservoir	5	X					X
43	Black Butte Lake	5			X			X
70	Blue Lakes	5	X					X
57	Boca Reservoir	6	X					X
124	Bon Tempe Lake	2	X					X
53	Bowman Lake	5	X					X
106	Bridgeport Reservoir	6		X				X
128	Briones Reservoir	2	X				X	
200	Brite Valley Lake	5	X					X
41	Bucks Lake	5		X				X
36	Butt Valley Reservoir	5		X				X
29	Butte Lake	5	X					X
159	Calaveras Reservoir	2		X			X	
173	Calero Reservoir	2	X					X
109	Camanche Reservoir	5			X			X
79	Camp Far West Reservoir	5		X				X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
91	Caples Lake	5	X					X
202	Castac Lake	5	X				X	
211	Castaic Lagoon	4	X					X
210	Castaic Lake	4		X				X
13	Castle Lake	5	X					X
1	Cave Lake	5	X					X
176	Chesbro Reservoir	3	X					X
82	Clear Lake	5				X		X
50	Cleone Lake	1	X					X
62	Collins Lake	5	X					X
121	Contra Loma Reservoir	5	X					X
153	Convict Lake	6	X					X
3	Copco Lake	1	X					X
108	Cosumnes River	5	X				X	
179	Courtright Reservoir	5		X				X
178	Coyote Lake	2	X					X
25	Crater Lake	6	X				X	
218	Crystal Lake	4	X					X
5	Dead Lake	1	X					X
130	Discovery Bay	5	X				X	
259	Dixon Lake	9	X					X
21	Dodge Reservoir	6	X					X
141	Don Pedro Reservoir	5			X			X
64	Donner Lake	6	X					X
10	Duncan Reservoir	5	X					X
27	Eagle Lake	6				X		X
63	East Park Reservoir	5		X				X
170	Eastman Lake	5		X				X
237	Echo Lake (Reg 4)	4	X					X
268	El Capitan Lake	9		X				X
249	El Dorado Lakes	4	X					X
207	Elderberry Forebay	4	X				X	



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
205	Elizabeth Lake	4	X					X
126	Ellery Lake	6	X					X
83	Fallen Leaf Lake	6		X				X
55	Faucherie Lake	5	X					X
58	Feeley Lake	5	X				X	
265	Ferguson Lake	7	X				X	
34	Finger Lake	5	X				X	
166	Florence Lake	5	X					X
88	Folsom Lake	5			X			X
75	French Meadows Reservoir	5		X				X
38	Frenchman Lake	5		X				X
60	Fuller Lake	5	X				X	
219	Gene Wash Reservoir	7	X				X	
46	Gold Lake	5	X					X
134	Grant Lake	6	X					X
139	Gull Lake	6	X					X
14	Gumboot Lake	5	X					X
221	Hansen Lake	4	X					X
250	Harbor Lake (Lake Machado)	4	X					X
67	Harry L Englebright Lak	5	X					X
77	Hell Hole Reservoir	5		X				X
175	Hensley Lake	5		X				X
192	Hernandez Reservoir	3	X					X
125	Hetch Hetchy Reservoir	5		X			X	
239	Hollenbeck Park Lake	4	X					X
40	Howard Lake	1	X					X
189	Hume Lake	5	X					X
169	Huntington Lake	5		X				X
86	Ice House Reservoir	5	X					X
87	Indian Creek Reservoir	6	X					X
18	Iron Canyon Reservoir	5	X					X
4	Iron Gate Reservoir	1	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
251	Irvine Lake	8	X					X
196	Isabella Lake	5			X			X
49	Jackson Meadow Reservoir	5	X					X
213	Jameson Lake	3	X				X	
89	Jenkinson Lake	5	X					X
244	John Ford Park Lake	4	X					X
136	June Lake	6	X					X
11	Kangaroo Lake	1	X					X
242	Ken Hahn Park Lake	4	X					X
66	Kidd Lake	5	X				X	
142	La Grange Reservoir	5	X				X	
132	Lafayette Reservoir	2	X					X
154	Lago Los Osos	2	X				X	
33	Lake Almanor	5				X		X
100	Lake Alpine	5	X					X
104	Lake Amador	5	X					X
222	Lake Arrowhead	6	X					X
97	Lake Berryessa	5				X		X
19	Lake Britton	5	X					X
208	Lake Cachuma	3			X			X
255	Lake Cahuilla	7	X					X
227	Lake Calabasas	4	X					X
31	Lake California	5	X				X	
217	Lake Casitas	4		X				X
140	Lake Chabot (San Leandro)	2	X				X	
115	Lake Chabot (Vallejo)	2	X					X
80	Lake Combie	5	X				X	
150	Lake Crowley	6			X			X
163	Lake Cunningham	2	X					X
37	Lake Davis	5			X			X
152	Lake del Valle	2	X					X
156	Lake Elizabeth	2	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
254	Lake Elsinore	8		X				X
243	Lake Evans	8	X					X
149	Lake George	6	X					X
224	Lake Gregory	6	X					X
216	Lake Havasu	7				X		X
253	Lake Hemet	8	X					X
98	Lake Henne	2	X				X	
257	Lake Henshaw	9		X				X
262	Lake Hodges	9	X					X
204	Lake Hughes	4	X					X
269	Lake Jennings	9	X					X
191	Lake Kaweah	5		X				X
228	Lake Lindero	4	X					X
103	Lake Madigan	2	X				X	
147	Lake Mamie	6	X					X
148	Lake Mary	6	X					X
248	Lake Mathews	8			X		X	
145	Lake McClure	5			X			X
158	Lake McSwain	5	X					X
69	Lake Mendocino	1		X				X
195	Lake Nacimiento	3			X			X
94	Lake Natomas	5	X					X
78	Lake of the Pines	5	X				X	
47	Lake Oroville	5				X		X
56	Lake Pillsbury	1		X				X
215	Lake Piru	4	X					X
264	Lake Poway	9	X					X
171	Lake Sabrina	6	X					X
194	Lake San Antonio	3			X			X
9	Lake Shastina	1	X					X
231	Lake Sherwood	4	X					X
90	Lake Sonoma	1		X				X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
61	Lake Spaulding	5	X					X
260	Lake Sutherland	9	X					X
76	Lake Tahoe	6				X		X
167	Lake Vasona	2	X					X
198	Lake Webb	5	X					X
258	Lake Wohlford	9	X					X
232	Las Virgenes Reservoir	4	X				X	
252	Lee Lake/Corona Lake	8	X					X
241	Legg Lake	4	X					X
23	Lewiston Lake	1	X					X
2	Lily Lake	5	X					X
238	Lincoln Park Lake	4	X					X
44	Little Grass Valley Reservoir	5		X				X
201	Little Oso Flaco Lake	3	X					X
214	Little Rock Reservoir	6	X					X
177	Loch Lomond Reservoir	3	X					X
81	Loon Lake	5	X					X
199	Lopez Lake	3	X					X
185	Los Banos Reservoir	5	X					X
135	Los Vaqueros Reservoir	5		X				X
270	Loveland Reservoir	9	X				X	
99	Lower Bear River Reservoir	5	X					X
71	Lower Blue Lake	5	X				X	
96	Lower Blue Lake (Alpine County)	5	X					X
39	Lower Bucks Lake	5	X				X	
157	Lower Crystal Springs Reserv	2	X				X	
273	Lower Otay Reservoir	9	X					X
119	Lundy Lake	6	X					X
234	Malibou Lake	4	X				X	
162	Mammoth Pool Reservoir	5	X					X
190	Marsh in Fresno Slough	5	X				X	
30	McCumber Reservoir	5	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
107	Meadows Slough	5	X				X	
7	Medicine Lake	5	X					X
182	Millerton Lake	5			X			X
144	Modesto Reservoir	5		X				X
17	Moon Lake	5			X		X	
272	Morena Reservoir	9	X					X
54	New Bullards Bar Reservoir	5			X			X
112	New Hogan Lake	5			X			X
123	New Melones Lake	5		X				X
116	Nicasio Lake	2	X					X
28	North Battle Creek Reservoir	5	X					X
172	Oiger Quarry Ponds	2	X				X	
180	O'Neill Forebay	5		X				X
209	Palmdale Lake	6	X				X	
42	Paradise Lake	5	X					X
235	Peck Road Water Conservation Park	4	X					X
247	Perris Reservoir	8		X				X
155	Pilarcitos Lake	2	X				X	
187	Pine Flat Lake	5			X		X	
111	Pinecrest	5	X					X
186	Pinto Lake	3	X					X
45	Plaskett Lake	1	X					X
161	Pleasant Valley Reservoir	6	X					X
245	Prado Lake	8	X					X
59	Prosser Creek Reservoir	6	X					X
236	Puddingstone Reservoir	4	X					X
206	Pyramid Lake	4		X				X
261	Ramer Lake	7	X					X
6	Reservoir C	5	X					X
8	Reservoir F	1	X				X	
160	Rock Creek Lake	6	X					X
72	Rollins Reservoir	5	X					X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
32	Ruth Lake	1	X					X
120	Saddlebag Lake	6	X					X
256	Salton Sea	7				X		X
184	San Luis Reservoir	5				X		X
129	San Pablo Reservoir	2	X					X
266	San Vicente Reservoir	9	X					X
233	Santa Fe Reservoir	4	X					X
197	Santo Margarita Lake	3	X					X
68	Scotts Flat Reservoir	5	X					X
267	Senator Wash Reservoir	7	X				X	
226	Sepulveda Lake	4	X					X
143	Shadow Cliffs Reservoir	2	X					X
24	Shasta Lake	5				X		X
93	Silver Lake	5	X					X
137	Silver Lake (Region 6)	6	X					X
220	Silverwood Lake	6	X					X
12	Siskiyou Lake	5	X					X
114	Soulejoule Lake	2	X					X
102	Spicer Meadow Reservoir	5	X					X
101	Spring Lake	1	X					X
212	Spring Valley Lake	6	X				X	
51	Stampede Reservoir	6			X			X
165	Stevens Creek Reservoir	2	X					X
48	Stony Gorge Reservoir	5		X				X
84	Stump Meadow Lake	5	X				X	
193	Success Lake	5			X			X
271	Sweetwater Reservoir	9	X					X
52	Thermalito Afterbay	5		X			X	
127	Tioga Lake	6	X					X
229	Toluca Lake	4	X					X
92	Topaz Lake	6	X					X
22	Trinity Lake	1				X		X



Station Number	Station Name	Lake Size				Lake Selection		
		Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
131	Tulloch Reservoir	5	X					X
20	Tunnel Reservoir	5	X				X	
151	Turlock Lake	5			X			X
146	Twin Lakes	6	X					X
85	Union Valley Reservoir	5		X				X
188	Unnamed Lake 1	5	X				X	
117	Unnamed Lake 2	5	X				X	
95	Upper Blue Lake	5	X					X
138	Upper San Leandro Reservoir	2	X				X	
113	Upper Twin Lake	6	X				X	
181	Uvas Reservoir	3	X					X
118	Virginia Lakes	6	X					X
15	West Valley Reservoir	5	X				X	
230	Westlake Lake	4	X					X
26	Whiskeytown Lake	5			X			X
105	White Pines Lake	5	X				X	
263	Wiest Lake	7	X					X
183	Wishon Reservoir	5	X					X
133	Woodward Reservoir	5		X				X
122	Yosemite Lake	5	X					X
74	Zayak/Swan Lake	5	X				X	



Consequently, this study targeted two indicator species in each lake – a top predator (e.g., black bass) as a methylmercury indicator and a high lipid, bottom-feeding species (e.g., common carp or channel catfish) as an organics and selenium indicator. This approach is recommended by USEPA (2000). Some high elevation lakes only had one abundant high trophic level species (i.e., a trout species). In these cases, the one species still represented a worst-case indicator for methylmercury and organics and was sampled and analyzed for all of the pollutants on the analyte list. The species sampled most frequently were the primary target species: largemouth bass, common carp, and rainbow trout (Table 2). Other species were collected where the primary targets could not be obtained.

Black bass (including largemouth, smallmouth [*Micropterus dolomieu*], and spotted bass [*Micropterus punctulatus*]) and Sacramento pikeminnow (*Ptychocheilus grandis*) were the key methylmercury indicators. These species have a high trophic position and a strong size:methylmercury relationship. For these species, fish were sampled across a wide range of lengths and analyzed as individuals to facilitate estimation of size-standardized methylmercury concentrations. For other species methylmercury was analyzed in composites of 5 individuals.

Channel catfish and common carp were the primary targets for high lipid bottom-feeders. These species were analyzed for organics, selenium, and methylmercury. Organics and selenium were expected to be highest in these species (Davis et al. 2007b, SFEI 2008).

LOCATIONS TARGETED

Lakes and reservoirs in California vary tremendously in size, from hundreds of small ponds less than 10 ha to Lake Tahoe at 50,000 ha. For larger lakes it is necessary to sample more than one location to obtain a representative characterization of the water body. For small lakes less than 500 ha in size, one sampling location covered a significant fraction of the surface area of the lake and was considered adequate to characterize the lake. However, for larger lakes, sampling of additional locations was performed. For lakes of medium size (500 – 1000 ha), two locations were generally sampled. For lakes in the large category (1000 – 5000 ha) and extra large category (> 5000 ha), two to four locations were sampled.

ARCHIVING STRATEGY

Due to the large number of water bodies to be sampled, the relatively high cost of organics analysis, and an expectation that some of these would be below thresholds for concern, an archiving strategy was developed for composite samples of the bottom-feeder species. The strategy varied somewhat by the size of lake. The basic approach was to begin by analyzing one representative sample from each lake, and then proceed to other samples if the first sample exceeded a threshold. The threshold for this follow-up analysis was designated as 75% of the threshold for concern (Tables 3 and 4). This approach avoided expenditure of funds on organics analysis where it was not needed.



Table 2
Scientific and common names of fish species collected, the number of lakes in which they were sampled, their minimum, median, and maximum total lengths (mm), and whether they were analyzed as composites or individuals.

Species Name	Common Name	Number of Lakes Sampled	Minimum Length (mm)	Median Length (mm)	Maximum Length (mm)	Analyzed as Composites	Analyzed as Individuals
<i>Pomoxis nigromaculatus</i>	Black Crappie	3	225	289.5	335	x	
<i>Lepomis macrochirus</i>	Bluegill	2	117	134.5	165	x	
<i>Salvelinus fontinalis</i>	Brook Trout	2	200	263.5	308	x	
<i>Ameiurus nebulosus</i>	Brown Bullhead	13	149	292	417	x	
<i>Salmo trutta</i>	Brown Trout	12	203	347	485	x	x
<i>Ictalurus punctatus</i>	Channel Catfish	12	386	509	766	x	
<i>Cyprinus carpio</i>	Common Carp	78	290	551	886	x	x
<i>Oncorhynchus mykiss aquilarum</i>	Eagle Lake Trout	1	448	503.5	547	x	
<i>Carassius auratus</i>	Goldfish	1	309	332.5	350	x	
<i>Mylopharodon conocephalus</i>	Hardhead	1	140	147.5	161	x	
<i>Lavinia exilicauda</i>	Hitch	1	204	239.5	292	x	
<i>Oncorhynchus nerka</i>	Kokanee	2	326	343	359		x
<i>Salvelinus namaycush</i>	Lake Trout	2	356	408	460	x	x
<i>Micropterus salmoides</i>	Largemouth Bass	143	157	350	623	x	x
<i>Lepomis gibbosus</i>	Pumpkinseed	1	120	135	150	x	
<i>Oncorhynchus mykiss</i>	Rainbow Trout	79	140	301	598	x	x
<i>Lepomis microlophus</i>	Redear Sunfish	1	206	220	242	x	
<i>Ptychocheilus grandis</i>	Sacramento Pikeminnow	2	354	406.5	493	x	x
<i>Catostomus occidentalis</i>	Sacramento Sucker	15	211	431	564	x	
<i>Micropterus dolomieu</i>	Smallmouth Bass	10	151	309	529	x	x
<i>Micropterus punctulatus</i>	Spotted Bass	2	126	248	480		x
<i>Morone saxatilis</i>	Striped Bass	1	486	534	582	x	x
<i>Tilapia leucosticta</i>	Tilapia	1	253	276	299	x	



Table 3
Thresholds selected for triggering follow-up analysis of archived composite samples. Triggers were 75% of a threshold for concern (see Davis et al. 2007a). All samples were analyzed for mercury, so a threshold for follow-up analysis was not needed.

Pollutant	Threshold for Follow-up Analysis (ppb wet weight)
PCBs	22
DDTs	622
Dieldrin	18
Chlordanes	225
Selenium	2,947

Aliquots from all composites were archived whether they were analyzed or not, in case of any analytical problems or other circumstances calling for analysis or re-analysis at a later time. In addition, aliquots of some samples were selected for long-term archiving. This will provide an integrative, representative sample for each lake that can be reanalyzed in later years to confirm earlier analyses, look for new chemicals of concern, provide material for application of new analytical methods, provide material for other ecological research, and other purposes. In addition,

each Regional Board identified lakes they were interested in sampling more often and establishing a baseline for trend analysis. A list of trend lakes can be found in Appendix 2. For trend lakes individual archives were retained for all species and all locations, and where sufficient tissue was present, location and lakewide archives were also retained.

Table 4
Thresholds for concern based on an assessment of human health risk from these pollutants by OEHA (Klasing and Brodberg, 2008). All values given in ng/g (ppb). The lowest available threshold for each pollutant is in bold font. One serving is defined as 8 ounces (227 g) prior to cooking. The FCG and ATs for mercury are for the most sensitive population (i.e., women aged 18 to 45 years and children aged 1 to 17 years).

Pollutant	Fish Contaminant Goal	Advisory Tissue Level (3 servings/week)	Advisory Tissue Level (2 servings/week)	Advisory Tissue Level (No Consumption)
Chlordanes	5.6	190	280	560
DDTs	21	520	1000	2100
Dieldrin	0.46	15	23	46
Mercury	220	70	150	440
PCBs	3.6	21	42	120
Selenium	7400	2500	4900	15000



SAMPLE PROCESSING

Dissection and compositing of muscle tissue samples were performed following USEPA guidance (USEPA 2000). All fish were dissected skin-off, and only the fillet muscle tissue was used for analysis.

CHEMICAL ANALYSIS

Nearly all (> 95%) of the mercury present in fish is methylmercury (Wiener et al. 2007). Consequently, monitoring programs usually analyze total mercury as a proxy for methylmercury, as was done in this study. USEPA (2000) recommends this approach, and the conservative assumption be made that all mercury is present as methylmercury to be most protective of human health. Total mercury and selenium in muscle tissue were measured by Moss Landing Marine Laboratory (Moss Landing, CA). Detection limits for total mercury and all of the other analytes are presented in Table 5.

Trace organics in muscle tissue were measured by the California Department of Fish and Game Water Pollution Control Laboratory (Rancho Cordova, CA). PCBs are reported as the sum of 55 congeners (Table 5). Concentrations in many lakes were near or below limits of detection (Table 5). The most abundant congeners were detected in 65-69% of the 364 samples analyzed for PCBs. Frequencies of detection and reporting were lower for the less abundant PCB congeners.

QUALITY ASSURANCE

The samples were analyzed in multiple batches. QA/QC analyses for SWAMP Data Quality Objectives (DQOs) (precision, accuracy, recovery, completeness, and sensitivity) were performed for each batch as required by the SWAMP BOG QAPP (Bonnema 2007). The Technical Report for this study (Davis et al. 2009) contains a complete description of the QA results.

There were 55,598 sample results for individual constituents including tissue composites, composite blind duplicates, and laboratory QA/QC samples. Overall, all data with the exception of 865 results were considered usable for the intended purpose. A 98% completeness level was attained which met the 90% project completeness goal specified in the Lakes QAPP.

ASSESSMENT THRESHOLDS

This report compared fish tissue concentrations to two types of thresholds for concern for pollutants in sport fish that were developed by OEHHA (Klasing and Brodberg 2008): Fish Contaminant Goals (FCGs) and Advisory Tissue Levels (ATLs) (Table 4).

Table 5
Analytes included in the study, detection limits, and frequencies of detection and reporting.
 Frequency of detection includes all results above detection limits. Frequency of reporting includes all results that were reportable (above the detection limit and passing all QA review).

Class	Analyte	MDL	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)
Metals/Metalloids	Mercury	0.01	3158	99%	99%
	Selenium	0.12	209	86%	86%
Cyclodienes	Dieldrin	0.42	360	29%	29%
Chlordanes	Nonachlor, cis-	0.30	360	36%	36%
	Chlordane, cis-	0.39	360	44%	33%
	Nonachlor, trans-	0.19	360	68%	59%
	Chlordane, trans-	0.44	360	41%	28%
	Oxychlordane	0.46	360	6%	6%
DDTs	DDE(o,p')	0.17	360	8%	8%
	DDE(p,p')	0.47	360	93%	92%
	DDT(o,p')	0.21	360	4%	4%
	DDT(p,p')	0.15	360	19%	19%
	DDD(o,p')	0.09	360	30%	30%
	DDD(p,p')	0.12	360	71%	71%
PCB Congeners	PCB 008	0.14	364	3%	3%
	PCB 018	0.13	364	15%	15%
	PCB 027	0.11	364	5%	5%
	PCB 028	0.16	364	27%	27%
	PCB 029	0.11	364	0%	0%
	PCB 031	0.15	364	23%	23%
	PCB 033	0.15	364	12%	12%
	PCB 044	0.15	364	32%	32%
	PCB 049	0.11	364	40%	40%
	PCB 052	0.17	364	40%	38%
	PCB 056	0.10	364	38%	23%
	PCB 060	0.11	364	29%	27%
	PCB 064	0.10	364	25%	24%
	PCB 066	0.13	364	48%	41%
	PCB 070	0.19	364	45%	35%
PCB 074	0.12	364	38%	36%	
PCB 077	0.11	364	15%	15%	
PCB 087	0.15	364	51%	39%	



Class	Analyte	MDL	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)
PCB Congeners	PCB 095	0.18	364	54%	41%
	PCB 097	0.11	364	45%	38%
	PCB 099	0.12	364	58%	55%
	PCB 101	0.18	364	66%	54%
	PCB 105	0.15	364	40%	39%
	PCB 110	0.21	364	59%	43%
	PCB 114	0.10	364	10%	7%
	PCB 118	0.24	364	54%	49%
	PCB 126	0.11	364	2%	2%
	PCB 128	0.11	364	44%	43%
	PCB 137	0.10	364	23%	23%
	PCB 138	0.19	364	64%	63%
	PCB 141	0.11	364	36%	36%
	PCB 146	0.10	364	35%	35%
	PCB 149	0.12	364	60%	57%
	PCB 151	0.09	364	45%	45%
	PCB 153	0.18	364	69%	68%
	PCB 156	0.11	364	30%	29%
	PCB 157	0.10	364	10%	10%
	PCB 158	0.10	364	38%	37%
	PCB 169	0.10	364	6%	3%
	PCB 170	0.12	364	32%	32%
	PCB 174	0.11	364	32%	32%
	PCB 177	0.09	364	32%	32%
	PCB 180	0.10	364	65%	64%
	PCB 183	0.10	364	38%	38%
	PCB 187	0.11	364	55%	55%
	PCB 189	0.10	364	4%	4%
	PCB 194	0.10	364	30%	30%
PCB 195	0.11	364	12%	12%	
PCB 198/199	0.09	364	14%	2%	
PCB 200	0.10	364	9%	9%	
PCB 201	0.11	364	37%	37%	
PCB 203	0.09	364	38%	38%	
PCB 206	0.11	364	26%	23%	
PCB 209	0.09	364	15%	15%	



FCGs, as described by Klasing and Brodberg (2008), are “estimates of contaminant levels in fish that pose no significant health risk to humans consuming sport fish at a standard consumption rate of one serving per week (or eight ounces [before cooking] per week, or 32 g/day), prior to cooking, over a lifetime and can provide a starting point for OEHHA to assist other agencies that wish to develop fish tissue-based criteria with a goal toward pollution mitigation or elimination. FCGs prevent consumers from being exposed to more than the daily reference dose for non-carcinogens or to a risk level greater than 1×10^{-6} for carcinogens (not more than one additional cancer case in a population of 1,000,000 people consuming fish at the given consumption rate over a lifetime). FCGs are based solely on public health considerations without regard to economic considerations, technical feasibility, or the counterbalancing benefits of fish consumption.” For organic pollutants, FCGs are lower than ATLS.

ATLS, as described by Klasing and Brodberg (2008), “while still conferring no significant health risk to individuals consuming sport fish in the quantities shown over a lifetime, were developed with the recognition that there are unique health benefits associated with fish consumption and that the advisory process should be expanded beyond a simple risk paradigm in order to best promote the overall health of the fish consumer. ATLS provide numbers of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are used to provide consumption advice to prevent consumers from being exposed to more than the average daily reference dose for non-carcinogens or to a risk level greater than 1×10^{-4} for carcinogens (not more than one additional cancer case in a population of 10,000 people consuming fish at the given consumption rate over a lifetime). ATLS are designed to encourage consumption of fish that can be eaten in quantities likely to provide significant health benefits, while discouraging consumption of fish that, because of contaminant concentrations, should not be eaten or cannot be eaten in amounts recommended for improving overall health (eight ounces total, prior to cooking, per week). ATLS are but one component of a complex process of data evaluation and interpretation used by OEHHA in the assessment and communication of fish consumption risks. The nature of the contaminant data or omega-3 fatty acid concentrations in a given species in a water body, as well as risk communication needs, may alter strict application of ATLS when developing site-specific advisories. For example, OEHHA may recommend that consumers eat fish containing low levels of omega-3 fatty acids less often than the ATL table would suggest based solely on contaminant concentrations. OEHHA uses ATLS as a framework, along with best professional judgment, to provide fish consumption guidance on an ad hoc basis that best combines the needs for health protection and ease of communication for each site.” For methylmercury and selenium, the 3 serving and 2 serving ATLS are lower than the FCGs.

Consistent with the description of ATLS above, the assessments presented in this report are not intended to represent consumption advice.

For methylmercury, results were also compared to a 0.3 ppm threshold that is being used by the State and Regional Water Boards in the current round of 303(d) listing.

DATA ANALYSIS

For individual largemouth bass, regression equations were used to estimate methylmercury concentrations (mean and 95% confidence interval) in a 350 mm (total length) largemouth bass for each lake. The 350 mm value was selected to represent the middle of the typical size distribution above the legal limit of 305 mm (12 in) for largemouth bass in California.

Candidates for 303(d) Listing

One of the objectives of this survey was to provide information that could be used in evaluating whether a given lake should be included on the 303(d) List for each pollutant. The sampling design was developed specifically to address this objective. To meet listing requirements in a cost-effective manner, all available samples were analyzed for lakes where an initial analysis of a lakewide composite sample showed that concentrations approached a threshold. This report does not, however, present an assessment for the purposes of 303(d) listing determinations. These determinations were left to the discretion of the Regional Boards.



SECTION 3

RESULTS AND DISCUSSION

In this screening study, 4,905 fish representing 23 species were collected from 272 lakes and reservoirs in California (Figure 1a-c, Tables 1a,b). A concise summary of the data for each lake is provided in Appendix 1. Excel files containing these tables are available from SFEI (contact Jay Davis, jay@sfei.org). All data collected for this study are maintained in the SWAMP database which is managed by the data management team at Moss Landing Marine Laboratories (<http://swamp.mpsl.mlml.calstate.edu>). The complete dataset, which will be used for 303(d) listing determinations, includes QA data (quality control samples and blind duplicates) and additional ancillary information (specific location information, fish sex, weights, etc). It is anticipated that by the fall of 2010, the complete dataset from this study will also be available on the web at <http://www.ceden.org>. Finally, data from this study are available on the web through the California Water Quality Monitoring Council's "My Water Quality" portal (www.CaWaterQuality.net). This site is designed to present data from the Lakes Survey and other studies in a nontechnical manner to the public, and allows mapping and viewing of summary data from each lake.

METHYLMERCURY

Comparison to Thresholds

Methylmercury is the pollutant that poses the most widespread potential health risks to consumers of fish caught from California lakes. Methylmercury was the only pollutant that frequently reached concentrations high enough that OEHHA would consider recommending no consumption of the contaminated species (0.44 ppm wet weight). This degree of contamination was quite prevalent across the state. Overall, 56 of the 272 lakes surveyed (21 %) had a species with an average concentration exceeding 0.44 ppm (Table 6, Figure 2). For the random lakes, 23 % had a species above 0.44 ppm (Figure 3a). The 95 % confidence interval for this estimate was ± 11 %. Expressed on an areal basis, an estimated 18% of California lake area had fish with concentrations above 0.44 ppm (Figure 3a). For the targeted lakes, 20% had concentrations above the 0.44 ppm threshold (Figure 3b). The occurrence of these high mercury lakes showed distinct regional variation. Only 2% of the northern California trout lakes were above 0.44 ppm (Table 6). In contrast, 48% of the lower elevation lakes in northern California were above 0.44 ppm. In southern California, the overall degree of contamination was less severe than in the low elevation lakes of northern California, but the fraction of lakes above 0.44 ppm was still substantial (16%).



Table 6
Percentages of lakes in methylmercury concentration categories by region.
 Concentrations in ppm. Note: Some lakes did not fall into these three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Concentration Category					
		< 0.07	0.07-0.15	0.15-0.22	0.22 – 0.3	0.3 -0.44	>0.44
California (All Data)	272	32	13	13	7	14	21
Northern California Trout Lakes	87	71	16	6	2	2	1
Northern California Lower Elevation (<2000 ft)	82	2	5	11	12	22	48
Southern California	83	27	12	20	7	18	16

The State and Regional Boards are applying a methylmercury threshold of 0.3 ppm in fish tissue in the current round of 303(d) listing of impaired water bodies. Many lakes across the state had fish tissue concentrations above this threshold. Overall, 95 of the 272 lakes surveyed (35%) had a species with an average methylmercury concentration exceeding 0.30 ppm (Table 6, Figure 2). The occurrence of lakes with concentrations above this threshold showed distinct regional variation. Only 3% of the northern California trout lakes were above 0.30 ppm (Table 6). In contrast, 70% of the lower elevation lakes in northern California were above 0.30 ppm. In southern California, 34% of lakes were above 0.30 ppm.

Most of the lakes surveyed had some degree of methylmercury contamination. Methylmercury concentrations measured in this study were frequently higher than the lowest OEHHA threshold for methylmercury – 0.07 ppm – a concentration at which OEHHA would consider recommending consumption of less than three servings of fish per week. Overall, 68% of the 272 lakes sampled had a fish species with methylmercury concentrations above the lowest threshold for methylmercury (the 0.07 ppm three serving ATL) (Table 6, Figure 2). Most (71%) of the northern California trout lakes were below 0.07 ppm (Table 6). This was in sharp contrast to lower elevation lakes (below 2000 ft) in northern California, which had only 2% below 0.07 ppm. Concentrations in Southern California lakes were intermediate, with 27% below 0.07 ppm.

Variation Within and Among Species

As expected, relatively high methylmercury concentrations were observed in species that are high trophic position predators, including largemouth, smallmouth, and spotted bass and Sacramento pikeminnow (Table 7). For some of these species, however, the averages are based on small sample sizes and therefore are imprecise estimates. Statewide average concentrations in smallmouth and largemouth bass (0.42 and 0.41 ppm, respectively) approached OEHHA's no consumption ATL of 0.44 ppm. Other warmwater species such as common carp, channel catfish, black crappie, and bluegill had moderate methylmercury contamination.

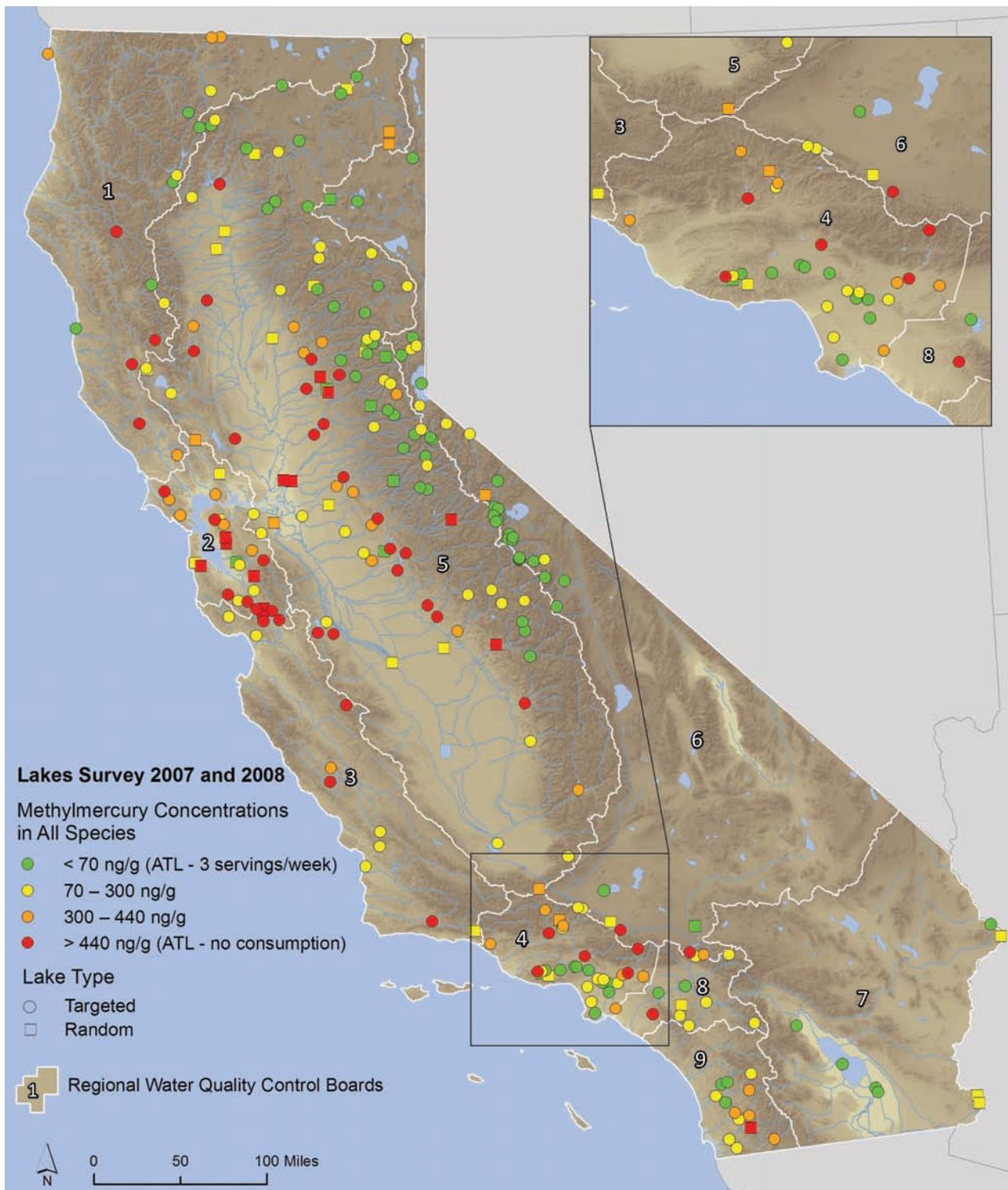


Figure 2. Spatial patterns in methylmercury concentrations (ng/g wet weight) in lakes sampled in the Lakes Survey, 2007-2008. Each point represents the highest average methylmercury concentration among the species sampled in each lake. Concentrations based on location composites and individual fish, from both targeted (circles) and random (squares) lakes.

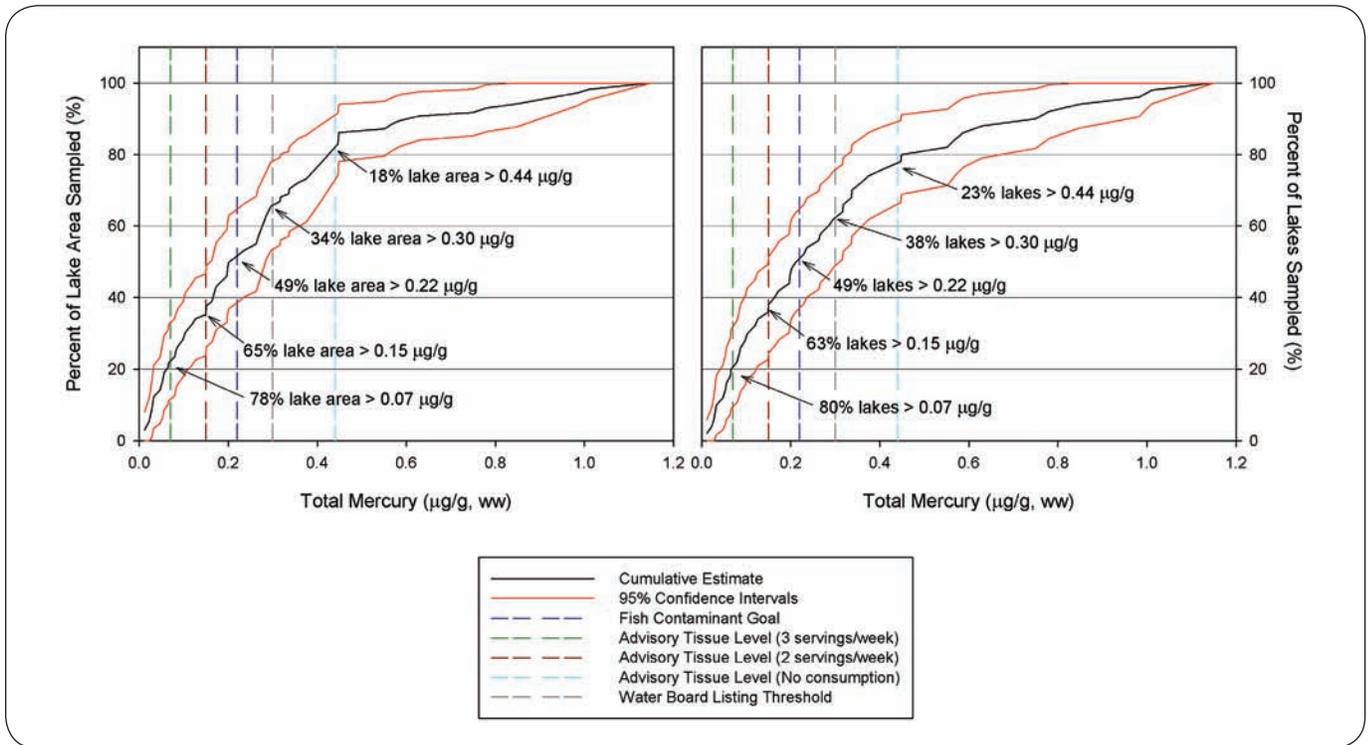


Figure 3a. Cumulative distribution function (CDF) plot for mercury in random lakes, shown as percent of lake area (left) and percent of lakes (right). Concentrations are the highest species average (ug/g wet weight) for each lake, based on location composites and individual fish at randomly sampled lakes in the Lakes Survey. Vertical lines are threshold values. Data in µg/g, or ppm.

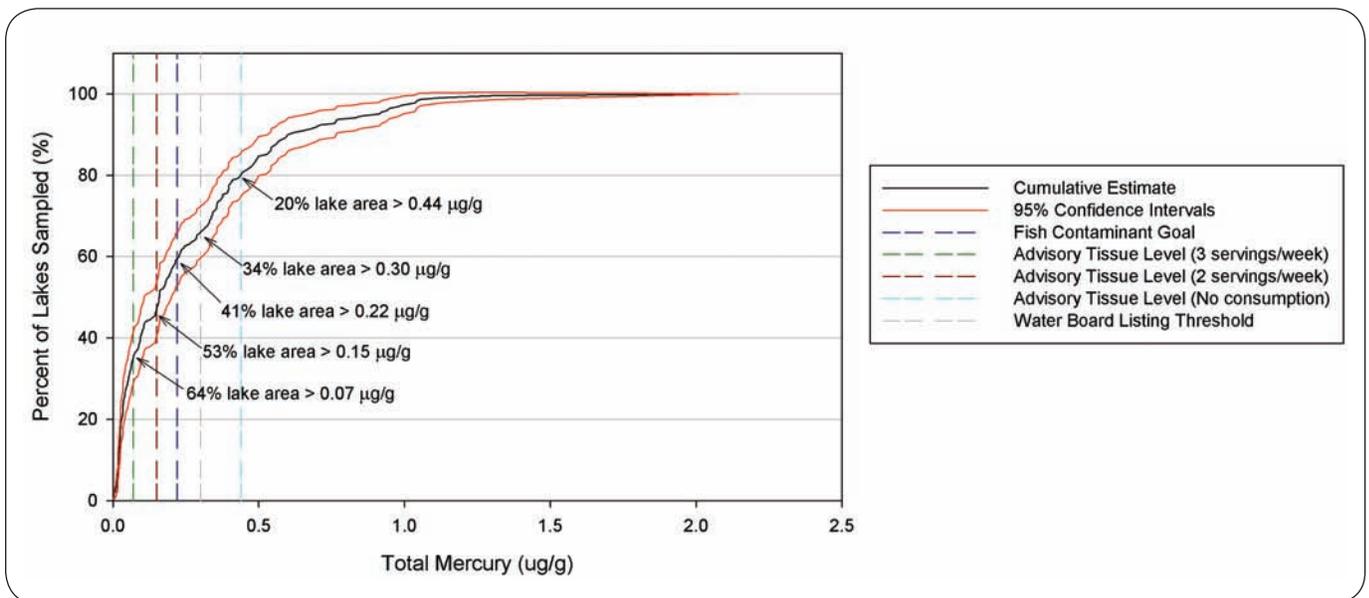


Figure 3b. Cumulative distribution function (CDF) plot for mercury at targeted lakes, shown as percent of lakes sampled. Concentrations are the highest species average (ug/g wet weight) for each lake, based on location composites and individual fish at targeted lakes in the Lakes Survey. Vertical lines are threshold values. Data in µg/g, or ppm.

Table 7

Average concentrations of mercury (ppm wet weight) in each species sampled in this survey. Averages are based on the total number of composites or estimated averages for all locations (i.e., all of the data points shown in Appendix 1). Concentrations in ppm. Averages by species are shown for the entire statewide dataset, and for each region. Almaden Lake in Region 2 had high concentrations and a large influence on the Region 2 averages for largemouth and common carp. Without the data from Almaden Lake, the average was 0.23 ppm for common carp, 0.58 ppm for largemouth bass, and 0.36 ppm for Region 2 as a whole. N=number of samples; S.E.=standard error of the mean.

Species	California		Region 1		Region 2		Region 3		Region 4		Region 5		Region 6		Region 7		Region 8		Region 9																					
	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.																			
BlackCrappie	4	0.04	0.02									1	0.08			3	0.03	0.01																						
Bluegill	3	0.08	0.02		2	0.10	0.01			1	0.04																													
Brook Trout	4	0.13	0.04									4	0.13	0.04																										
Brown Bullhead	24	0.08	0.01	1	0.13					8	0.14	0.03	15	0.05	0																									
Brown Trout	19	0.20	0.05									17	0.21	0.06	2	0.05	0																							
Channel Catfish	20	0.17	0.04		7	0.12	0.04			3	0.10	0.03	6	0.36	0.10	2	0.06	0	1	0.01		1	0.05																	
Common Carp	172	0.18	0.01	2	0.08	0.01	0.07	13	0.32	0.04	31	0.05	0.01	61	0.22	0.01	4	0.21	0.11	14	0.03	0.01	13	0.11	0.02	14	0.14	0.03												
Eagle Lake Trout	4	0.06	0.01																																					
Goldfish	2	0.07	0					2	0.07	0																														
Hardhead	2	0.11	0.01	2	0.11	0.01																																		
Hitch	2	0.03	0					2	0.03	0																														
Kokanee	3	0.08	0.01																																					
Lake Trout	2	0.16	0.01																																					
Largemouth Bass	199	0.41	0.02	13	0.58	0.10	0.09	14	0.43	0.08	26	0.31	0.04	93	0.42	0.03	5	0.41	0.14	3	0.11	0.02	8	0.15	0.05	15	0.25	0.04												
Pumpkinseed	1	0.19	0								1	0.19																												
Rainbow Trout	152	0.05	0	12	0.04	0.01	0.01	2	0.23	0.04	1	0.03	76	0.04	0	58	0.04	0					1	0.03																
Redear Sunfish	2	0.02	0								2	0.02	0																											
Sac. Pike/minnow	2	0.27	0.07										2	0.27	0.07																									
Sacramento Sucker	28	0.27	0.04		2	0.29	0.02	2	0.09	0																														
Smallmouth Bass	22	0.42	0.06					3	1.00	0.03																														
Spotted Bass	6	0.32	0.11																																					
Striped Bass	3	0.21	0.02																																					
Tilapia	4	0.01	0																																					
Overall	680	0.15	0.02	30	0.19	0.03	0.04	38	0.31	0.03	73	0.11	0.02	319	0.22	0.05	85	0.14	0.04	25	0.04	0.01	25	0.12	0.03	30	0.15	0.03												



Rainbow trout generally had low concentrations of methylmercury, with a statewide average (0.05 ppm) below the lowest OEHHA threshold (the 0.07 ppm three serving ATL).

Trout generally occupy a lower trophic position and accumulate lower concentrations of methylmercury and other pollutants, though exceptions to this pattern occur and were observed in this study (discussed further below). Another factor that probably contributes to lower observed concentrations in trout is that, in many lakes, recently planted hatchery fish are part of the catch. A previous study found that hatchery trout consistently had very low concentrations of methylmercury (rainbow trout from four hatcheries all had less than 0.023 ppm – Grenier et al. 2007).

It is important to note that resident, self-sustaining trout populations in these lakes are likely to have higher concentrations than the hatchery fish that are most readily collected. The results from Hetch Hetchy Reservoir, which has a self-sustaining population of brown trout, illustrate this point. Hetch Hetchy Reservoir was anomalous among the trout lakes with methylmercury concentrations of 0.96 and 0.54 ppm in composites of brown trout from two distinct locations (Figure 4). One other lake (Loon Lake, which also has a self-sustaining population of brown trout) also had relatively high concentrations in two composites of brown trout (0.50 and 0.30 ppm). Brown trout from the other nine lakes where they were collected generally had low concentrations (all around 0.10 ppm or less, except for one composite from Hell Hole Reservoir at 0.28 ppm).

Larger size fish from self-sustaining trout populations are particularly likely to accumulate high concentrations of methylmercury. A second factor that could contribute to the high concentrations in brown trout from Hetch Hetchy Reservoir and Loon Lake is that brown trout are known to switch to from a diet of invertebrates to a diet of fish as they get older (Moyle 2002). The brown trout samples with high methylmercury were all above 400 mm in average length, while the samples with lower methylmercury were all below 400 mm (Figure 4).

Rainbow trout showed less variation in methylmercury concentrations than brown trout. The highest concentrations of methylmercury in rainbow trout were observed in two composites from Pilarcitos Lake in Region 2 (0.26 and 0.27 ppm). Other lakes with relatively high concentrations in rainbow trout were Jameson Lake in Region 3 (0.19 and 0.27 ppm in two composites) and Mammoth Pool Reservoir in Region 5 (0.10 and 0.22 in two composites).

Very few California lakes contain predatory fish, such as largemouth bass, with low concentrations of methylmercury (Figure 5). Only 8 of the 143 lakes where largemouth bass were sampled (6%) had average largemouth concentrations of 0.07 ppm or lower. The average (size-adjusted) concentrations observed in lakes with largemouth bass that were below the lowest OEHHA threshold were 0.07 ppm in Lake of the Pines (Region 5), 0.03 ppm in Lake Calabassas and 0.01 ppm in Toluca Lake (Region 4), 0.07 ppm in Prado Lake and 0.03 ppm in Lake Evans (Region 8), and 0.05 ppm in each of three Region 9 lakes (Dixon Lake, Lake Poway, and Lake Wohlford). These lakes stand out as having exceptionally low methylmercury contamination. These low concentrations may be due to variation in ecosystem factors such as water



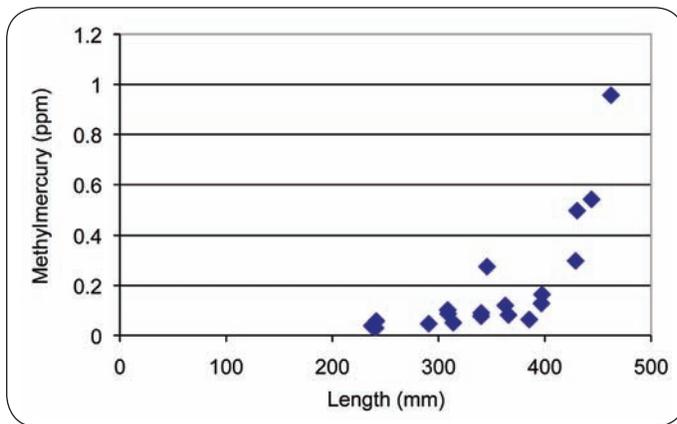


Figure 4. Methylmercury concentration (ug/g wet weight) versus average length (total) for brown trout composites. Data from 11 lakes in the Sierra Nevada.

chemistry, productivity, trophic dynamics, wetland presence, or others; or due to variation in sources, such as an absence of mining influence. The influence of these factors was explored in further detail in a companion paper (Negrey et al. 2010). The low concentrations observed at these lakes indicate that it is indeed possible for lakes in the California landscape, even those with self-sustaining populations of predators, to not have excessive bioaccumulation of methylmercury, and that a realistic management goal for at least some lakes may be to attain concentrations of this magnitude.

A much higher percentage of the low elevation lakes where predators (black bass, Sacramento pikeminnow, striped bass) were not collected had methylmercury concentrations below the 0.07 ppm threshold: 16 of 23 (70%). The species sampled at these lakes (e.g., common carp, channel catfish, black crappie, and bluegill) tend to accumulate lower concentrations of methylmercury.

Limited evaluation of correlations among species could be evaluated with this dataset (Figure 6). The largest sample size was available for largemouth bass and common carp. A fairly strong correlation was observed between these species ($R^2 = 0.59$), with bass averaging 1.6 times higher concentrations than carp. Considerable variation around the regression line was observed, especially toward the higher end of the distribution of concentrations. Although sample sizes were small, concentrations in largemouth bass also appeared to have consistent relationships with Sacramento sucker, brown bullhead, and channel catfish.

Spatial Patterns

Methylmercury concentrations across the state varied at a regional scale (Table 6, Figure 2). In northern California, low concentrations were commonly observed in fish from high elevation lakes in the Sierra Nevada and Trinity Alps. The highest species averages observed in most of these lakes were below the three-serving ATL (0.07 ppm). Trout (mostly rainbow trout, but a few lakes had brown trout, brook trout, lake trout, or Eagle Lake trout) were the most commonly caught species in these lakes, and, as discussed above, tend to accumulate lower methylmercury concentrations than largemouth bass. For the 87 northern California trout lakes sampled, 71% had a maximum species average below 0.07 ppm, another 16% were between 0.07 and 0.15 ppm, and only one of these lakes (1%) had a species average above 0.44 ppm – Hetch Hetchy Reservoir with brown trout at 0.75 ppm (Table 8). Photodemethylation in the very clear water column of high-elevation lakes may be a mechanistic process that contributes to the low methylmercury concentrations in these areas.

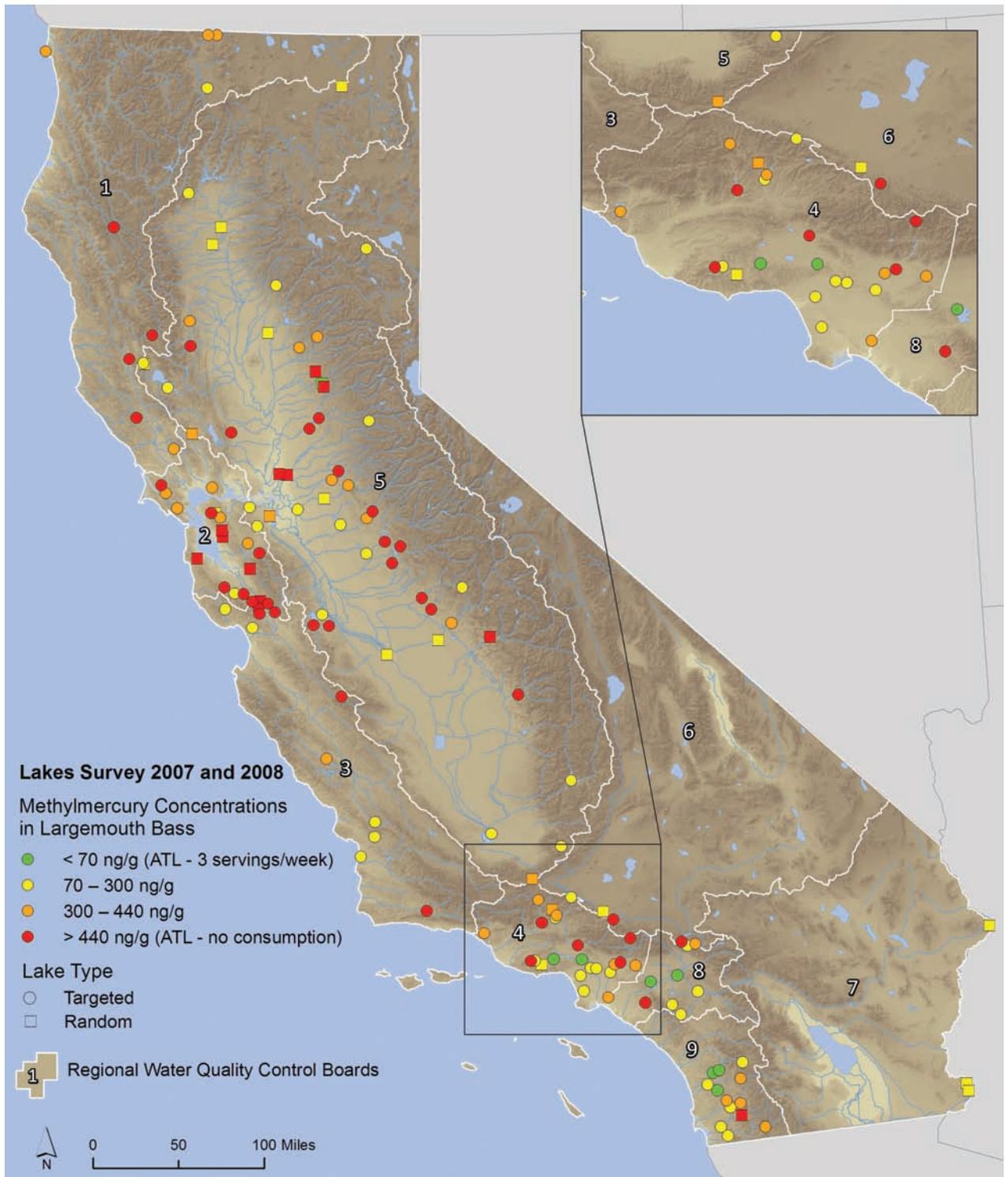


Figure 5. Spatial patterns in methylmercury concentrations (ug/g wet weight) in standard-sized (350 mm) largemouth bass at lakes sampled in the Lakes Survey, from both targeted (circles) and random (squares) lakes.

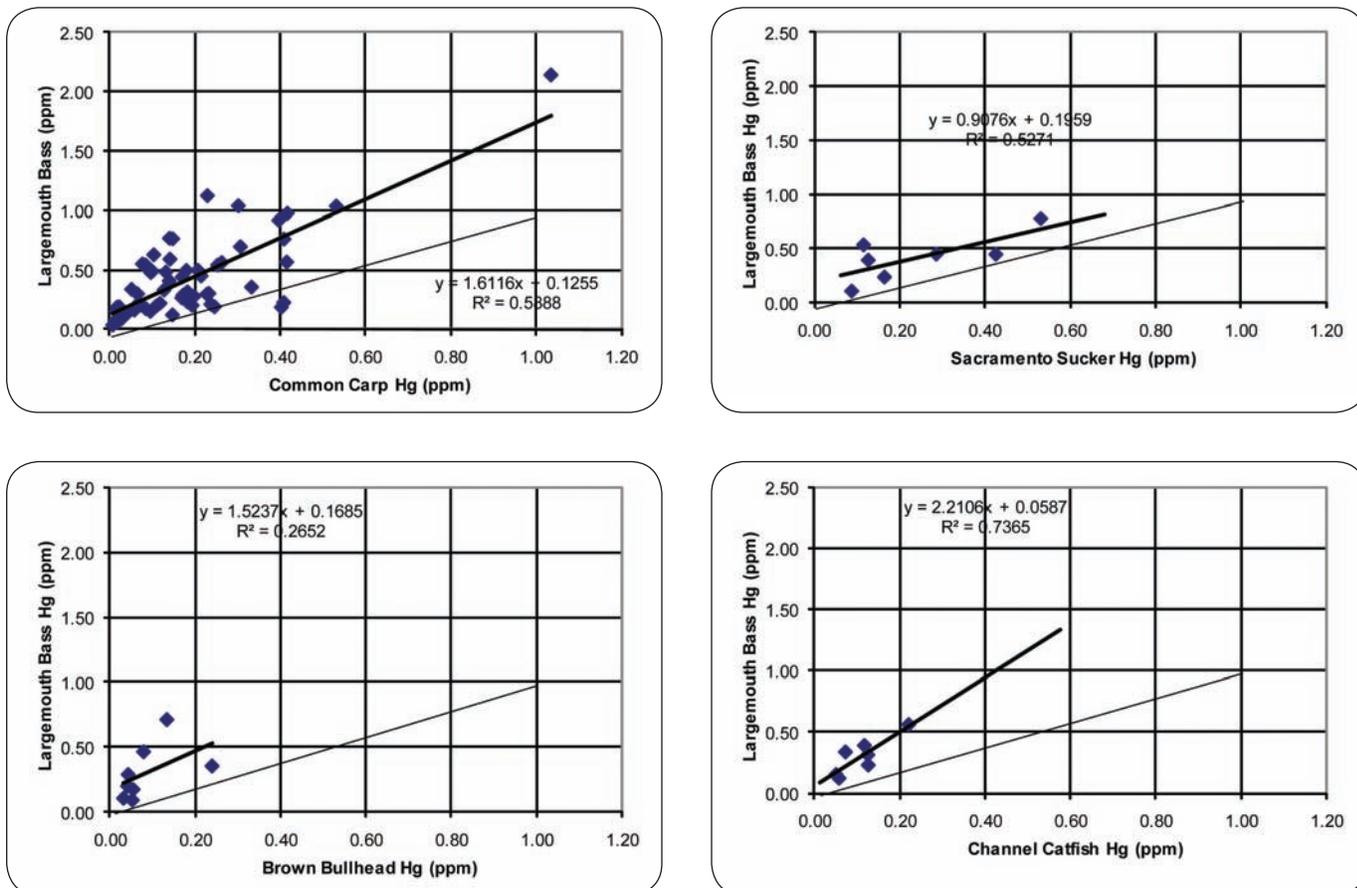


Figure 6. Correlations of methylmercury concentrations (ug/g wet weight) in largemouth bass with concentrations in other species.

In contrast to the northern California trout lakes, methylmercury concentrations in fish from lower elevation (below 2000 ft) lakes in northern California (Table 6, Figure 2) were almost always higher than the three-serving per week ATL (0.07 ppm), and frequently higher than the no consumption ATL (0.44 ppm). Of the 82 lower elevation lakes sampled in northern California, 48% had a maximum species average above 0.44 ppm, another 34% were between 0.22 and 0.44 ppm, and only two (2%) lakes in this region had a species average below 0.07 ppm. The two lakes that had a methylmercury concentration at or below 0.07 ppm were Lago Los Osos in Region 2 and Lake of the Pines in Region 5. Largemouth bass were not caught at Lago Los Osos – only channel catfish were collected. Lake of the Pines was the only lake in northern California where largemouth bass were collected that had an average concentration at a standard size of 350 mm of 0.07 ppm or lower. Interestingly, the average concentration measured at this lake was in sharp contrast to concentrations in 350 mm largemouth at two adjacent lakes: Lake Combie immediately to the south at 0.78 ppm, and Zayak/Swan Lake to the north at 0.98 ppm.

Table 8
Lakes with methylmercury above 0.44 ppm (wet weight) OEHA threshold in average concentrations or composite samples. Data are sorted by region. Data for samples of individual fish are not included in this table.

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
1	Lake Pillsbury	Year1	medium	targeted	Largemouth Bass	350	1.34	L1	NA	11	350 mm Standard Size
1	Lake Pillsbury	Year1	medium	targeted	Largemouth Bass	350	1.29	L2	NA	11	350 mm Standard Size
1	Lake Sonoma	Year1	medium	targeted	Largemouth Bass	350	0.71	L2	NA	11	350 mm Standard Size
1	Lake Sonoma	Year1	medium	targeted	Largemouth Bass	350	0.64	L1	NA	11	350 mm Standard Size
1	Ruth Lake	Year2	small	targeted	Largemouth Bass	350	0.71	L1	NA	11	350 mm Standard Size
1	Ruth Lake	Year2	small	targeted	Brown Bullhead	323.8	0.13	L1	1	5	Location Composite
1	Lake Mendocino	Year1	medium	targeted	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size
1	Lake Mendocino	Year1	medium	targeted	Largemouth Bass	350	0.54	L2	NA	11	350 mm Standard Size
1	Lake Mendocino	Year1	medium	targeted	Common Carp	491.6	0.10	L2	1	5	Location Composite
1	Lake Mendocino	Year1	medium	targeted	Common Carp	479	0.07	L1	1	5	Location Composite
2	Almaden Lake	Year2	small	targeted	Largemouth Bass	350	2.15	L1	NA	11	350 mm Standard Size
2	Almaden Lake	Year2	small	targeted	Common Carp	669.4	1.05	L1	1	5	Location Composite
2	Almaden Lake	Year2	small	targeted	Common Carp	668.4	1.02	L1	2	5	Location Composite
2	Calero Reservoir	Year2	small	targeted	Largemouth Bass	350	1.05	L1	NA	16	350 mm Standard Size
2	Upper San Leandro Reservoir	Year1	small	random	Largemouth Bass	350	1.01	L1	NA	11	350 mm Standard Size
2	Anderson Lake	Year1	small	targeted	Largemouth Bass	350	0.98	L1	NA	11	350 mm Standard Size
2	Anderson Lake	Year1	small	targeted	Common Carp	501.2	0.52	L1	2	5	Location Composite
2	Anderson Lake	Year1	small	targeted	Common Carp	502.6	0.32	L1	1	5	Location Composite



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Soulejoule Lake	Year1	small	targeted	Largemouth Bass	350	0.94	L1	NA	16	350 mm Standard Size
2	Calaveras Reservoir	Year1	medium	random	Largemouth Bass	350	0.86	L1	NA	11	350 mm Standard Size
2	Calaveras Reservoir	Year1	medium	random	Largemouth Bass	350	0.31	L2	NA	11	350 mm Standard Size
2	Lower Crystal Springs Reservoir	Year1	small	random	Largemouth Bass	350	0.85	L1	NA	11	350 mm Standard Size
2	Coyote Lake	Year2	small	targeted	Largemouth Bass	350	0.76	L1	NA	11	350 mm Standard Size
2	Coyote Lake	Year2	small	targeted	Common Carp	636.6	0.47	L1	1	5	Location Composite
2	Coyote Lake	Year2	small	targeted	Common Carp	633.4	0.35	L1	2	5	Location Composite
2	Stevens Creek Reservoir	Year1	small	targeted	Largemouth Bass	350	0.70	L1	NA	11	350 mm Standard Size
2	Stevens Creek Reservoir	Year1	small	targeted	Common Carp	601.4	0.32	L1	2	5	Location Composite
2	Stevens Creek Reservoir	Year1	small	targeted	Common Carp	606.4	0.29	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	random	Largemouth Bass	350	0.57	L1	NA	11	350 mm Standard Size
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	520.8	0.54	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	520.6	0.29	L1	2	5	Location Composite
2	Lake del Valle	Year2	small	targeted	Largemouth Bass	350	0.56	L1	NA	11	350 mm Standard Size
2	Lake del Valle	Year2	small	targeted	Channel Catfish	506.8	0.32	L1	2	5	Location Composite
2	Lake del Valle	Year2	small	targeted	Channel Catfish	506.6	0.13	L1	1	5	Location Composite
2	San Pablo Reservoir	Year1	small	targeted	Largemouth Bass	350	0.48	L1	NA	11	350 mm Standard Size
2	San Pablo Reservoir	Year1	small	targeted	Common Carp	500	0.17	L1	2	4	Location Composite
2	San Pablo Reservoir	Year1	small	targeted	Common Carp	506.4	0.09	L1	1	5	Location Composite



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Oiger Quarry Ponds	Year1	small	random	Largemouth Bass	350	0.45	L1	NA	11	350 mm Standard Size
2	Oiger Quarry Ponds	Year1	small	targeted	Sacramento Sucker	438.4	0.31	L1	1	5	Location Composite
2	Oiger Quarry Ponds	Year1	small	targeted	Sacramento Sucker	436.4	0.26	L1	2	5	Location Composite
3	Chesbro Reservoir	Year1	small	targeted	Largemouth Bass	350	1.04	L1	NA	11	350 mm Standard Size
3	Chesbro Reservoir	Year1	small	targeted	Common Carp	524	0.55	L1	1	5	Location Composite
3	Chesbro Reservoir	Year1	small	targeted	Common Carp	522.6	0.51	L1	2	5	Location Composite
3	Uvas Reservoir	Year1	small	targeted	Largemouth Bass	350	0.91	L1	NA	11	350 mm Standard Size
3	Hernandez Reservoir	Year2	small	targeted	Largemouth Bass	350	0.83	L1	NA	16	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.61	L1	NA	6	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.48	L2	NA	11	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.40	L3	NA	11	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Common Carp	535.8	0.20	L3	1	5	Location Composite
3	Lake Cachuma	Year2	large	targeted	Common Carp	528.6	0.18	L1	1	5	Location Composite
3	Lake Cachuma	Year2	large	targeted	Common Carp	536.6	0.16	L2	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	502.6	0.56	L2	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	510	0.50	L3	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	421.2	0.37	L1	1	5	Location Composite
4	Crystal Lake	Year1	small	targeted	Largemouth Bass	350	0.95	L1	NA	5	350 mm Standard Size
4	Crystal Lake	Year1	small	targeted	Pumpkinseed	135	0.19	L1	1	5	Location Composite
4	Santa Fe Reservoir	Year1	small	targeted	Largemouth Bass	350	0.59	L1	NA	16	350 mm Standard Size
4	Santa Fe Reservoir	Year1	small	targeted	Common Carp	531.8	0.16	L1	1	5	Location Composite
4	Santa Fe Reservoir	Year1	small	targeted	Common Carp	531.4	0.12	L1	2	5	Location Composite



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
4	Lake Sherwood	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	16	350 mm Standard Size
4	Hansen Lake	Year1	small	targeted	Largemouth Bass	350	0.49	L1	NA	16	350 mm Standard Size
4	Hansen Lake	Year1	small	targeted	Common Carp	547.4	0.12	L1	2	5	Location Composite
4	Hansen Lake	Year1	small	targeted	Common Carp	547.8	0.08	L1	1	5	Location Composite
4	Lake Piru	Year1	small	targeted	Largemouth Bass	350	0.46	L1	NA	16	350 mm Standard Size
4	Lake Piru	Year1	small	targeted	Brown Bullhead	295.6	0.10	L1	2	5	Location Composite
4	Lake Piru	Year1	small	targeted	Brown Bullhead	296.6	0.06	L1	1	5	Location Composite
5	New Melones Lake	Year2	medium	targeted	Largemouth Bass	350	1.22	L1	NA	11	350 mm Standard Size
5	New Melones Lake	Year2	medium	targeted	Largemouth Bass	350	1.03	L2	NA	11	350 mm Standard Size
5	New Melones Lake	Year2	medium	targeted	Common Carp	587.4	0.26	L1	1	5	Location Composite
5	New Melones Lake	Year2	medium	targeted	Common Carp	544	0.20	L2	1	5	Location Composite
5	Cosumnes River	Year1	small	random	Largemouth Bass	350	1.15	L1	NA	16	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.51	L3	NA	11	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.41	L1	NA	11	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.37	L2	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Largemouth Bass	350	1.05	L2	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Largemouth Bass	350	1.03	L1	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Common Carp	671.4	0.33	L1	1	5	Location Composite
5	Eastman Lake	Year2	medium	targeted	Common Carp	652.8	0.27	L2	1	5	Location Composite
5	Zayak/Swan Lake	Year1	small	random	Largemouth Bass	350	0.98	L1	NA	16	350 mm Standard Size



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Hetch Hetchy Reservoir	Year1	medium	targeted	Brown Trout	462.3	0.96	L2	1	3	Location Composite
5	Hetch Hetchy Reservoir	Year1	medium	targeted	Brown Trout	444	0.54	L1	1	5	Location Composite
5	Hensley Lake	Year1	medium	targeted	Largemouth Bass	350	0.80	L2	NA	12	350 mm Standard Size
5	Hensley Lake	Year1	medium	targeted	Largemouth Bass	350	0.72	L1	NA	10	350 mm Standard Size
5	Hensley Lake	Year1	medium	targeted	Common Carp	469.4	0.16	L1	1	5	Location Composite
5	Hensley Lake	Year1	medium	targeted	Common Carp	480.4	0.13	L2	1	5	Location Composite
5	Shasta Lake	Year1	ex-large	targeted	Channel Catfish	592.6	0.80	L2	1	5	Location Composite
5	Shasta Lake	Year1	ex-large	targeted	Channel Catfish	681.5	0.36	L1	1	4	Location Composite
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.79	L2	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.77	L3	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.75	L1	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Common Carp	444.8	0.17	L2	1	5	Location Composite
5	Lake McClure	Year1	large	targeted	Common Carp	425	0.13	L3	1	5	Location Composite
5	Lake McClure	Year1	large	targeted	Common Carp	413.6	0.12	L1	1	5	Location Composite
5	Lake Combie	Year1	small	random	Largemouth Bass	350	0.78	L1	NA	11	350 mm Standard Size
5	Lake Combie	Year1	small	targeted	Sacramento Sucker	443.6	0.60	L1	1	5	Location Composite
5	Lake Combie	Year1	small	targeted	Sacramento Sucker	443.2	0.46	L1	2	5	Location Composite
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.77	L1	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.60	L4	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.53	L3	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.51	L2	NA	11	350 mm Standard Size



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Rollins Reservoir	Year2	small	targeted	Sacramento Sucker	448.6	0.68	L1	1	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Sacramento Sucker	481.4	0.66	L1	1	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Sacramento Sucker	479.8	0.59	L1	2	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Rainbow Trout	305.8	0.08	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.62	L4	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.57	L2	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.57	L3	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.51	L1	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	767.75	0.35	L2	1	4	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	728.2	0.25	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	801.4	0.19	L3	1	5	Location Composite
5	Lake Amador	Year2	small	targeted	Largemouth Bass	350	0.60	L1	NA	16	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.59	L1	NA	11	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.48	L2	NA	11	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.34	L3	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.58	L3	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.53	L2	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	targeted	Common Carp	585	0.09	L1	1	5	Location Composite
5	Pine Flat Lake	Year1	large	targeted	Common Carp	590	0.07	L2	1	5	Location Composite
5	Los Banos Reservoir	Year1	small	targeted	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Lake Natomas	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	11	350 mm Standard Size
5	Lake Natomas	Year1	small	targeted	Common Carp	579	0.26	L1	1	5	Location Composite
5	Lake Natomas	Year1	small	targeted	Common Carp	568.4	0.25	L1	2	5	Location Composite
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.54	L3	NA	11	350 mm Standard Size
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.38	L2	NA	11	350 mm Standard Size
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.27	L1	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Largemouth Bass	350	0.54	L2	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Largemouth Bass	350	0.46	L1	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Common Carp	653.4	0.25	L1	1	5	Location Composite
5	Lake Kaweah	Year2	medium	targeted	Common Carp	684.8	0.17	L2	1	5	Location Composite
5	Lake McSwain	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	9	350 mm Standard Size
5	Lake McSwain	Year1	small	targeted	Sacramento Sucker	406.8	0.15	L1	2	5	Location Composite
5	Lake McSwain	Year1	small	targeted	Sacramento Sucker	410.6	0.08	L1	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	495.4	0.52	L2	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	527.4	0.42	L3	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	489	0.28	L1	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.24	L1	NA	11	350 mm Standard Size
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.23	L2	NA	11	350 mm Standard Size
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.21	L3	NA	10	350 mm Standard Size
5	East Park Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.52	L2	NA	11	350 mm Standard Size
5	East Park Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.39	L1	NA	11	350 mm Standard Size



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	East Park Reservoir	Year1	medium	targeted	Common Carp	451	0.25	L2	1	5	Location Composite
5	East Park Reservoir	Year1	medium	targeted	Common Carp	452.8	0.18	L1	1	5	Location Composite
5	Loon Lake	Year1	small	targeted	Brown Trout	430.4	0.50	L1	1	5	Location Composite
5	Loon Lake	Year1	small	targeted	Brown Trout	429	0.30	L1	2	5	Location Composite
5	Meadows Slough	Year1	small	targeted	Sacramento Sucker	519	0.47	L1	2	5	Location Composite
5	Meadows Slough	Year1	small	random	Largemouth Bass	350	0.45	L1	NA	11	350 mm Standard Size
5	Meadows Slough	Year1	small	targeted	Sacramento Sucker	519	0.38	L1	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.46	L3	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.46	L1	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.40	L2	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	563	0.20	L2	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	516.2	0.16	L3	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	555.8	0.15	L1	1	5	Location Composite
5	Stony Gorge Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.45	L2	NA	11	350 mm Standard Size
5	Stony Gorge Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.34	L1	NA	11	350 mm Standard Size
5	Stony Gorge Reservoir	Year1	medium	targeted	Sacramento Sucker	322.4	0.14	L2	1	5	Location Composite
5	Stony Gorge Reservoir	Year1	medium	targeted	Sacramento Sucker	313.4	0.11	L1	1	5	Location Composite
5	Camp Far West Reservoir	Year1	medium	targeted	Channel Catfish	418	0.44	L2	1	5	Location Composite
5	Camp Far West Reservoir	Year1	medium	targeted	Channel Catfish	458.6	0.32	L1	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Common Carp	497.6	0.44	L2	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Common Carp	494.6	0.41	L1	1	5	Location Composite



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Isabella Lake	Year2	large	targeted	Common Carp	529.4	0.35	L3	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.21	L2	NA	11	350 mm Standard Size
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.19	L1	NA	11	350 mm Standard Size
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.16	L3	NA	11	350 mm Standard Size
6	Little Rock Reservoir	Year2	small	targeted	Largemouth Bass	350	0.92	L1	NA	11	350 mm Standard Size
6	Little Rock Reservoir	Year2	small	targeted	Common Carp	497.4	0.43	L1	1	5	Location Composite
6	Little Rock Reservoir	Year2	small	targeted	Common Carp	497	0.37	L1	2	5	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	350	0.49	L1	NA	16	350 mm Standard Size
8	Irvine Lake	Year1	small	targeted	Largemouth Bass	350	0.48	L1	NA	11	350 mm Standard Size
8	Irvine Lake	Year1	small	targeted	Common Carp	596	0.11	L1	2	5	Location Composite
8	Irvine Lake	Year1	small	targeted	Common Carp	597	0.09	L1	1	5	Location Composite
9	Loveland Reservoir	Year1	small	random	Largemouth Bass	350	0.63	L1	NA	11	350 mm Standard Size
9	Loveland Reservoir	Year1	small	targeted	Common Carp	456.4	0.11	L1	2	5	Location Composite
9	Loveland Reservoir	Year1	small	targeted	Common Carp	455.6	0.09	L1	1	5	Location Composite

Although methylmercury concentrations were generally not as high in southern California, the methylmercury problem is not confined to northern California and its well-known mining regions. Most of the 83 lakes in southern California were between 0.07 and 0.44 ppm (57%), but 16% had a maximum species average above 0.44 ppm (Table 6). Average concentrations above 0.90 ppm were observed in two lakes in close proximity to each other: Crystal Lake (0.95 ppm in largemouth) and Little Rock Reservoir (0.92 ppm in largemouth). The remaining lakes (27%) in this region had a species average below 0.07 ppm (Table 6, Figure 2). Largemouth bass were collected at only seven of the 22 lakes that were below 0.07 ppm in southern California.

Implications Regarding Sources

Although identifying sources of contamination was not a primary goal of the study, this is one of the broader goals of the SWAMP. With an extensive statewide dataset, an attempt was made to determine whether the results from this study could shed some light on the relative importance of sources contributing to bioaccumulation of methylmercury uptake such as historic mining activity and atmospheric deposition. Understanding the relative importance of these and other sources has significant implications for management of the methylmercury problem in California.

Two approaches were taken to attempt to discern the importance of different sources. The first approach was quantitative – the development of a statistical model to evaluate the relative importance of many potentially important factors influencing methylmercury bioaccumulation (Negrey et al. 2010). This assessment examined watershed attributes relating to contaminant sources (mercury and gold mining, soil mercury, point sources) and other factors (e.g., watershed area, forested area, wetland area), as well as detailed information on lake attributes, making use of information generated in companion study to develop bioaccumulation factors for lakes. This quantitative assessment focused on the 17 lakes where detailed information was available.

The second approach, presented in Davis et al. (2010), was a qualitative evaluation of the fish methylmercury data in comparison to broad scale datasets on mining and geology. This qualitative effort focused on assessing the potential influence of atmospheric deposition of mercury. Considerable uncertainty surrounds this topic.

It seems certain that atmospheric deposition contributes to food web uptake to some degree. Global atmospheric transport brings a significant quantity of mercury across the Pacific Ocean. Local terrestrial sources of atmospheric mercury then add to this global background. Mercury deposited to surface waters from the atmosphere is considered to have relatively high bioavailability (Hintelmann et al. 2002).

However, the extent of the atmospheric deposition contribution to food web mercury in California's lakes and reservoirs is unclear. At one end of the spectrum is the hypothesis that atmospheric deposition alone could be sufficient to cause the degree of methylmercury bioaccumulation that is observed across California. One major body of evidence in support of this hypothesis is extensive data from other regions in North America where atmospheric deposition is clearly the driver of bioaccumulation (Wiener et al. 2006, Harris et al. 2007). In spite of the extensive mining legacy in California, the degree of food web contamination in this state does not differ greatly from that seen across the rest of the continent (discussed further below). An alternative hypothesis is that atmospheric deposition constitutes a lower level background that contributes to, but does not dominate, food web contamination, and that mining legacy or geologic mercury is the primary source of methylmercury in the food web in California's lakes and reservoirs.



The approach taken by Davis et al. (2010) to evaluate these hypotheses was to compare patterns in some of the key watershed attributes identified by Negrey et al. (2010) to fish methylmercury at a selected subset of the 272 lake dataset. The subset of lakes selected for this analysis all had largemouth bass, and included the 14 lakes with the highest bass methylmercury concentrations, the 14 lakes with the lowest concentrations, and the 17 lakes included in the quantitative analysis. It was hoped that any obvious patterns would readily emerge from a comparison of lakes with low and high methylmercury concentrations in fish.

Overall, this analysis suggested that in the active and complex geology of California it is not possible to conclusively determine whether specific watersheds are free from the possible influence of historic mining activity or mercury-enriched geology based solely on available GIS layers. In order to resolve the question of the influence of atmospheric deposition it would be necessary to perform more detailed, site-specific field work to assess the contributions of mining sediment or geology. The simplest approach would be to measure the amount of total mercury in lake sediments and see how this correlates with mercury in the food web. This approach appears promising based on Negrey et al. (2010). To reduce potential variability related to food web structure, a more definitive study would ideally examine accumulation in young-of-the-year fish (Wiener et al. 2007). Another possible approach would be to assess mercury sources through the use of mercury isotopes, which have shown some promise in identifying sources of food web mercury in San Francisco Bay (unpublished data).

Available data appear to support a general conceptual model that includes a combination of atmospheric deposition, legacy contamination from mining, and geological sources as the drivers of methylmercury bioaccumulation in California lakes and reservoirs. Methylmercury concentrations in largemouth bass of approximately 0.2 ppm in two coastal lakes situated relatively far from geologic sources of mercury but very close to the coast may be a reasonable indication of the degree of contamination attributable to long-range atmospheric transport and deposition from sources across the Pacific Ocean. Atmospheric deposition can probably lead to significantly higher or lower concentrations in aquatic food webs depending on site-specific biogeochemistry or limnology (e.g., lake productivity). Emissions from urban areas, historic mining districts, and geological sources lead to increased atmospheric deposition in inland areas adding to the background oceanic input. Mining-contaminated sediments, mercury-rich soils, and other terrestrial sources are transported into aquatic ecosystems and can also contribute to severe food web contamination, with the Guadalupe Reservoir (Tetra Tech 2005; also described in the next section) being the most extreme example. Lake biogeochemistry can also greatly dampen or increase the impact of the combined mix of sources. The end result of the interplay of these and other factors is the spatially heterogeneous patchwork of aquatic food web contamination observed in this survey.

Comparison to the National Lakes Survey

USEPA recently published results from a national probabilistic survey of contaminants in fish based on sampling conducted in 2000-2003 (Stahl et al. 2009). The results from this survey provide a national frame of



reference for the present study. Unfortunately, the data from the two surveys are not directly comparable for two major reasons. First, the USEPA survey used a similar approach with a predator and a bottom-dweller targeted at each lake. However, USEPA analyzed fillets in the predator, but whole bodies in the bottom-dweller. USEPA consequently presented results for predators and bottom-dwellers separately. Second, USEPA did not make as great an effort to control for the size of fish analyzed. The sizes of fish collected were more variable and they did not estimate concentrations at a standard size.

The national survey found that fillets of predators in 49% of the sampled population of lakes had methylmercury concentrations that exceeded the USEPA 0.3 ppm fish tissue criterion for mercury. The median methylmercury concentration in predator fillets in the national survey was 0.28 ppm (Table 9). In comparison, the median for predator fillets in this survey was much lower: 0.16 ppm. However, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%). The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median methylmercury concentration in largemouth bass in this study was 0.34 ppm, slightly higher than the national median (0.28 ppm). Overall, although it is difficult to make a direct comparison, both the California data for predators and for largemouth bass indicate that methylmercury concentrations in California sport fish are at or below the national median.

The USEPA survey sampled 18 California lakes. Nine out of 18 (50%) of these lakes had a sample above the USEPA threshold of 0.3 ppm, similar to the national dataset as a whole. In general these data fell within the range of results from the present survey. One exception was Guadalupe Reservoir, which was sampled by USEPA but was not in the California survey. The largemouth bass composite sample from Guadalupe Reservoir had a methylmercury concentration of 6.60 ppm, the highest concentration measured in the entire country. The carp composite from Guadalupe Reservoir measured 0.52 ppm, close to the national maximum for bottom dwellers of 0.60 ppm. Exceptionally high methylmercury contamination in Guadalupe Reservoir, downstream of the historic New Almaden mercury mining district, has previously been documented (e.g., Tetra Tech 2005).

Priorities for Further Assessment

Lakes with average methylmercury concentrations of one or more species above 0.44 ppm should clearly be considered high priorities for further assessment to determine the need for consumption guidelines and management actions. Many lakes had concentrations well above the 0.44 ppm threshold (Table 8). Almaden Lake in Santa Clara County (also downstream of New Almaden) had the highest species average methylmercury concentration in this survey: 2.15 ppm in largemouth bass. Other lakes with a species average concentrations above 1 ppm included (all are in 350 mm largemouth bass unless otherwise noted): Lake Pillsbury in Region 1 (1.31 ppm); Upper San Leandro Reservoir (1.01 ppm) and Calero Reservoir (1.05 ppm) in Region 2; Cosumnes River (1.15 ppm), Lower Mokelumne River 7 (1.21 ppm in Sacramento pikeminnow), New Melones Lake (1.12 ppm), and Eastman Lake (1.04 ppm) in Region 5; and Chesbro Reservoir (1.04 ppm) and Lake Nacimiento (1.00 ppm in smallmouth bass [not size-adjusted]) in Region



3. All of these lakes above 1 ppm were in the mercury and gold mining regions in the northern part of the state. Table 8 shows the data for samples at the 61 lakes that had a species average above 0.44 ppm based on either individual or composite samples. Consumption guidelines have already been issued for 20 (33%) of these lakes, but 41 (67%) do not have guidelines.

Other priorities for further assessment to understand the sources and patterns of methylmercury contamination in California lakes are discussed in the last section of this report: Recommendations for Future Monitoring.

Table 9
Comparison of data from this study to data from the national study of contaminants in fish from lakes (Stahl et al. 2009). Data from this study for largemouth bass and predators (including all bass and trout species, as well as Sacramento pikeminnow) are compared to predator data from the national survey. All data are for muscle fillets.

		Mercury (ppm wet)	DDTs (ppb wet)	PCBs (ppb wet)
This study: largemouth bass	# of samples	199	101	101
	MEDIAN	0.34	1.9	1.1
This study: predators (181 trout, 44%)	# of samples	414	191	191
	MEDIAN	0.16	1.96	0.46
USEPA: predators (59 trout, 12%)	# of samples	486	486	486
	MEDIAN	0.28	1.5	2.2

PCBS

Comparison to Thresholds

PCBs (measured as the sum of 55 congeners) were second to methylmercury in reaching fish tissue concentrations posing potential health risks to consumers of fish caught from California lakes. However, far fewer lakes had PCB concentrations exceeding OEHHA's higher risk thresholds (Tables 4 and 10, Figure 7). Overall, only three of the 272 lakes assessed (1.1%) had a species with an average concentration high enough that OEHHA would consider recommending no consumption of the contaminated species (120 ppb). The vast majority of lakes in the survey (92%) were below the three serving ATL for PCBs (21 ppb).

The lowest threshold for PCBs was the FCG (3.6 ppb). For PCBs, 33% of the 272 lakes were above this threshold: 20% of the random lakes and 35% of the targeted lakes (Figures 8a,b). Southern California had a higher percentage of lakes with at least one sample above 3.6 ppb (60%) than lower elevation lakes in northern California (40%) and northern California trout lakes (8%) (Table 10).

The frequency distributions were different for random and targeted lakes (Figures 8a,b). This was due to the relatively extensive sampling of Region 4, the Region with the highest PCB concentrations. For the random lakes, the percentages expressed on an areal basis were very similar to those expressed on a per lake basis.

Spatial Patterns

PCB concentrations across the state varied at a regional scale (Table 10, Figure 7). Similar to the regional pattern seen for methylmercury, in northern California low concentrations were commonly observed in high elevation lakes in the Sierra Nevada and Trinity Alps. The vast majority of species averages observed in these lakes were below the FCG (3.6 ppb). For the 87 northern California lakes where trout were collected, 92% had a maximum species average below 3.6 ppb, 7% were between 3.6 and 21 ppb (the 3 serving ATL), one lake (1%) was between 21 and 42 ppb (the 2 serving ATL), and none were above 42 ppb. The highest species average measured in this region was 28 ppb in a brown trout sample from Silver Lake in Region 6.

PCB concentrations in low elevation (below 2000 ft) lakes in northern California were greater than those in the trout lakes (Table 10, Figure 7). Of the 82 low elevation lakes sampled in northern California, 60% had a maximum species average below 3.6 ppb, 29% were between 3.6 and 21 ppb, 2% were between 21 and 42 ppb, 7% were between 42 and 120 ppb, and one was above 120 ppb. The one lake with a species average above 120 ppb was Lake Vasona in Region 2, where two common carp composites had an average of 147 ppb (Table 11). The two composites measured 204 and 89 ppb. Average concentrations at two other low elevation lakes from northern California were among the highest concentrations measured in the state (Table 11): Lake Chabot in San Leandro in Region 2 (98 ppb) and San Luis Reservoir in Region 5 (85 ppb).

Table 10
Percentages of lakes in PCB concentration categories by region.
 Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each PCB Concentration Category				
		<3.6	3.6-21	21-42	42-120	>120
California	272	67	25	3	4	1
Northern California Trout Lakes	87	92	7	1	0	0
Northern California Lower Elevation (<2000 ft)	82	60	29	2	7	1
Southern California	83	40	46	5	7	2



Southern California was the region with the highest PCB concentrations. Of the 83 lakes in southern California sampled, 40% had a maximum species average below 3.6 ppb, 46% were between 3.6 and 21 ppb, 5% were between 21 and 42 ppb, 7% were between 42 and 120 ppb, and two lakes (2%) were above 120 ppb (Table 10). Average concentrations at four lakes from southern California were among the highest concentrations measured in the state (Table 11): Pyramid Lake (238 ppb in brown bullhead), Elderberry Forebay (131 ppb in channel catfish), and Echo Lake (101 ppb in common carp) in Region 4; and Silverwood Lake (93 ppb in largemouth bass) in Region 6. Pyramid Lake and Elderberry Forebay were the two lakes in southern California exceeding the 120 ppb no consumption ATL. The PCB concentrations observed in largemouth bass in Silverwood Lake are exceptionally high for this species, and much higher than those measured in largemouth bass from Pyramid Lake where the higher lipid, bottom-feeding species (brown bullhead) reached the maximum concentrations observed in the entire dataset.

Implications Regarding Sources

The geographic distribution of PCBs measured in California sport fish provides an indication of the location and nature of the principal sources of these chemicals. A review of historic bioaccumulation monitoring of PCBs in California (Davis et al. 2007) found that high concentrations of PCBs tended to occur in areas of historic use or maintenance of electrical equipment. These areas tend to be concentrated in urban centers with high amounts of industrial activity, but also occur in scattered areas across the landscape where electrical equipment or other PCB-containing equipment was used. The many hydroelectric facilities in the state are potential sites of past or present PCB contamination.

Similar to methylmercury, significant variation exists among species in their tendency to accumulate PCBs, with high-lipid bottom-feeders like common carp, channel catfish, and brown bullhead usually accumulating the highest concentrations. Trophic position is also an important influence on biomagnification of organic contaminants, though factors leading to high concentrations in bottom-feeding species in California freshwater systems seem to predominate. Because of this interspecific variation, a map of concentrations in common carp and channel catfish provides a clearer picture of spatial variation (Figure 9).

The patchy distribution of PCBs across the state, with lakes with low concentrations observed in most areas and scattered lakes with much higher concentrations, is consistent with contamination by local sources. The Los Angeles and San Francisco Bay regions appear to be exceptions to this general pattern, with a very high prevalence of lakes above the FCG (Figure 9) that may suggest an elevated signal of regional atmospheric deposition. Other urban sources, such as urban runoff and landfill leachates may also contribute to this regional pattern.

Comparison to the National Lakes Survey

USEPA's national lakes survey did not analyze bottom-feeder fillets. Whole body and fillet samples typically exhibit very different concentrations of organics, so it is not possible to directly compare the bottom-feeder



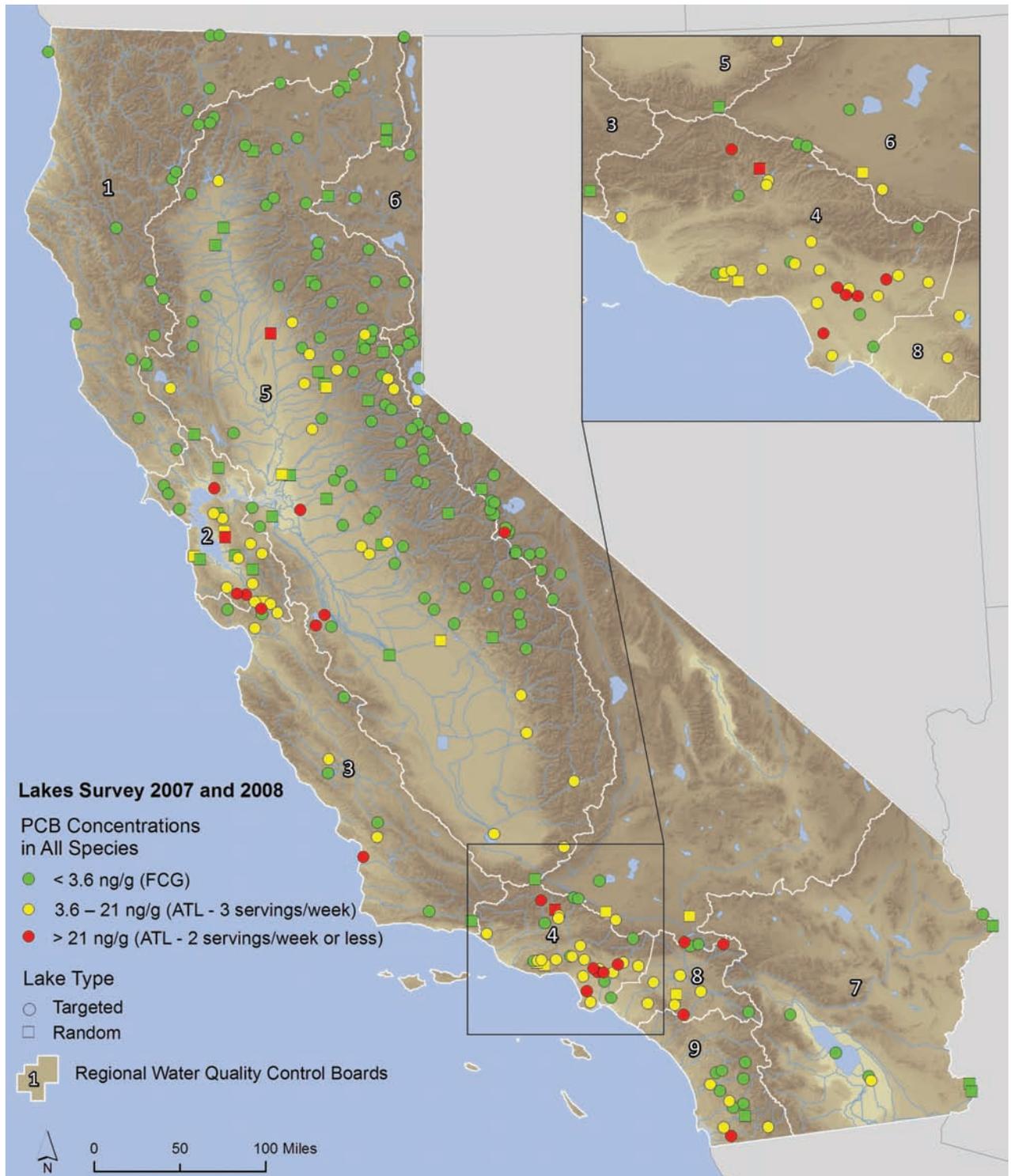


Figure 7. Spatial patterns in PCB concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note different scale from the methylmercury maps, with the two serving ATL as the highest threshold.

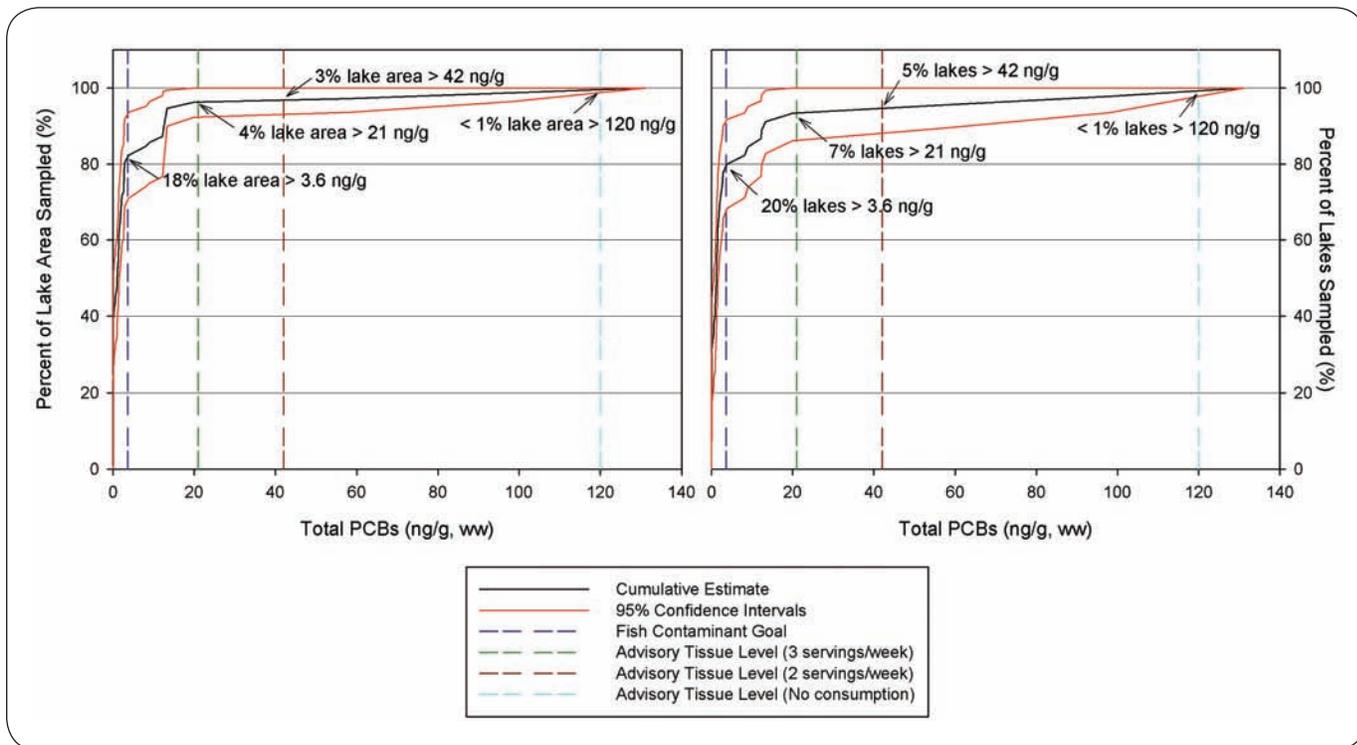


Figure 8a. Cumulative distribution function (CDF) plot for PCBs at random lakes, shown as percent of lake area (left) and percent of lakes (right). Concentrations (ng/g wet weight) are the highest species average for each lake, based on lake-wide composites at randomly sampled lakes in the Lakes Survey. Vertical lines are threshold values. Text on figure describes the percent of lake area or lakes that exceed each threshold value.

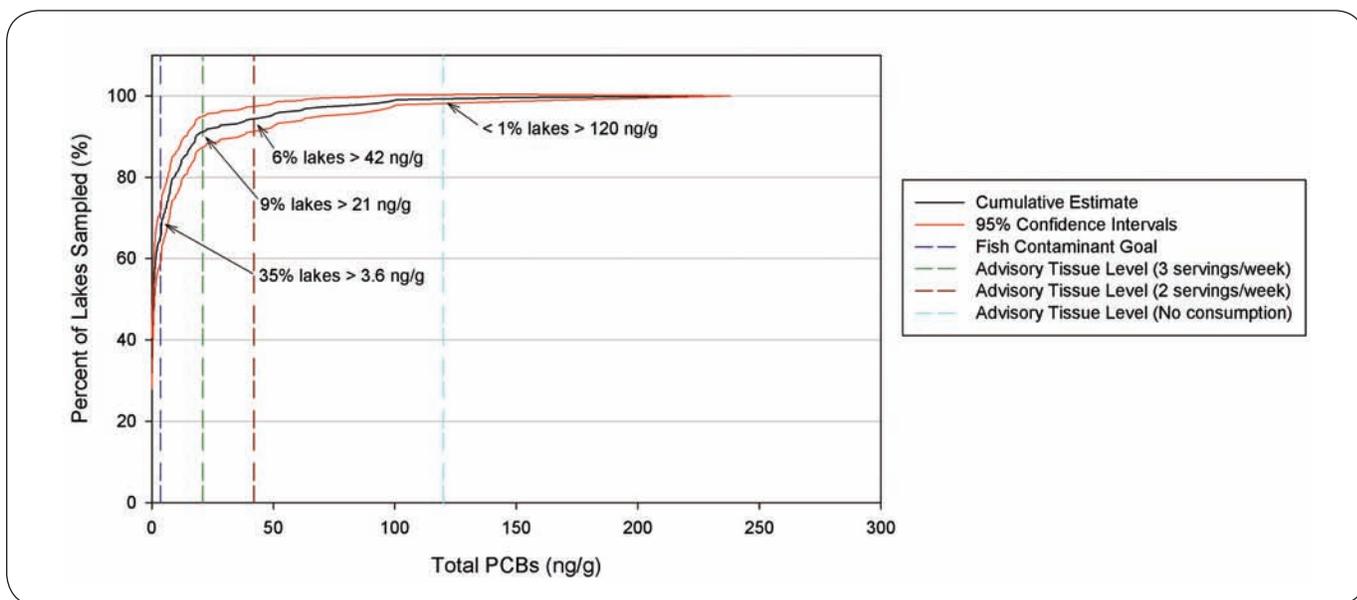


Figure 8b. Cumulative Distribution Function (CDF) plot for PCBs at targeted lakes, shown as percent of lakes sampled. Concentrations (ng/g wet weight) are the highest species average for each lake, based on lake-wide composites at targeted lakes in the Lakes Survey. Vertical lines are threshold values.

Table 11
Lakes with the highest PCB concentrations (ppb).
 Data for samples of individual fish are not included in this table.

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppb)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Lake Vasona	Year2	small	targeted	Common Carp	591	204	L1	1	5	Location Composite
2	Lake Vasona	Year2	small	targeted	Common Carp	590	89	L1	2	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	521	148	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	521	48	L1	2	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	319	416	L1	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	353	195	L1; L2	NA	10	Lake-wide Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	359	66	L1; L2	NA	10	Lake-wide Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	361	66	L1	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	387	60	L2	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	357	35	L2	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Channel Catfish	587	146	L1	2	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Channel Catfish	594	116	L1	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Largemouth Bass	350	32	L1	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Largemouth Bass	347	20	L1	2	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Common Carp	501	119	L1	1	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Common Carp	498	83	L1	2	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Largemouth Bass	380	65	L1	1	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Largemouth Bass	380	31	L1	2	5	Location Composite



Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppb)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	801	133	L3	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	766	100	L1; L2; L3	NA	14	Lake-wide Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	728	81	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	768	42	L2	1	4	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	368	131	L1	1	5	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	367	55	L1	2	5	Location Composite

data in the national and California datasets. Although organics concentrations were generally lower in predator tissues, the predator fillets provide the best basis for comparing the two datasets. USEPA found that predator fillets in 16.8% of the sampled population of lakes had total PCB tissue concentrations that exceeded a 12 ppb human health risk-based threshold (Stahl et al. 2009). The median PCB concentration in predator fillets in the national survey was 2.2 ppb (Table 9). In comparison, the median for predator fillets in this survey was much lower: 0.46 ppb. However, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%), and trout tend to accumulate lower concentrations of PCBs than bottom-feeding warmwater species such as carp and catfish. The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median PCB concentration for largemouth bass in this study was 1.1 ppb, also well below the national median of 2.2 ppb (Table 9). Both the California data for predators and for largemouth bass indicate that PCB concentrations in California sport fish are below the national median. Overall, the degree of PCB contamination of California lakes documented in this survey is relatively low compared to the rest of the country.

The USEPA survey sampled bottom dwellers in 11 California lakes. Seven out of 11 (64%) of these lakes had a sample above 12 ppb. In general these samples had higher PCB concentrations than observed in the present study. Particularly high concentrations were measured in Lake Oroville (252 ppb in common carp), Guadalupe Reservoir (103 ppb in common carp), and San Luis Reservoir (102 ppb in Sacramento sucker). This result for San Luis Reservoir was similar to results from the present study (average of 85 ppb in common carp fillets - Table 11).

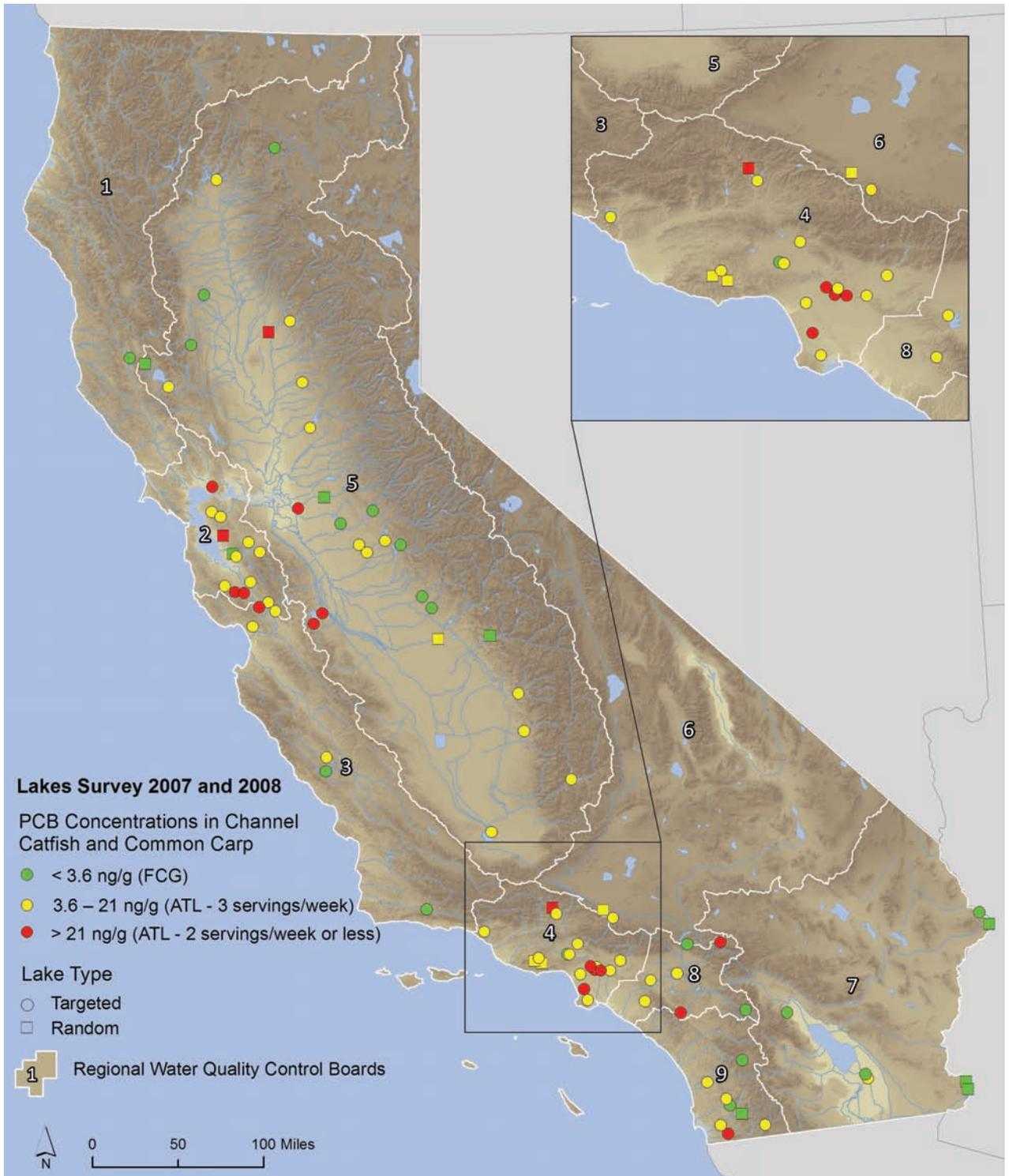


Figure 9. Spatial patterns in PCB concentrations (ng/g wet weight) in common carp and channel catfish at lakes sampled in the Lakes Survey, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

Priorities for Further Assessment

Using the same criterion that was employed for methylmercury (i.e., exceedance of the no consumption ATL - 120 ppb for PCBs) only three lakes (in contrast to 61 for methylmercury) stand out as high priorities for further assessment to determine the need for consumption guidelines and management actions. Pyramid Lake in Region 4 had the highest species average by far for PCBs in the state (224 ppb in brown bullhead), and the highest concentration in a sample (416 ppb in a composite sample) (Table 11). Elderberry Forebay, a lake just 10 miles away from Pyramid Lake, was another lake with an average concentration exceeding 120 ppb (131 ppb in channel catfish) (Table 11). The third lake with an average above 120 ppb was Lake Vasona in Region 2 (146 ppb in common carp) (Table 11).

Other lakes with relatively high PCB concentrations included Echo Lake (average of 101 ppb in common carp), Lake Chabot (San Leandro) (average of 98 ppb in common carp), Silverwood Lake (average of 93 ppb in largemouth bass), and San Luis Reservoir (average of 85 ppb in common carp). The high concentrations in largemouth bass at Silverwood Lake suggest that this water body may warrant further investigation. Consumption guidelines have been issued for only one of these lakes: Lake Chabot (San Leandro), which has guidelines resulting from PCB contamination.

OTHER POLLUTANTS WITH THRESHOLDS

OEHHA (Klasing and Brodberg 2008) developed thresholds for four other pollutants that were analyzed in this survey: dieldrin, DDT, chlordane, and selenium. Concentrations of these pollutants infrequently exceeded any threshold, and only one highly unusual lake exceeded any no consumption ATLs (Tables 12-15). Results for these pollutants are briefly summarized below.

Table 12
Percentages of lakes in dieldrin concentration categories by region. Concentrations in ppb.
 Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Dieldrin Concentration Category				
		< .46	.46-15	15-23	23-46	>46
California	272	80	20	0	0	0
Northern California Trout Lakes	87	89	11	0	0	0
Northern California Lower Elevation (<2000 ft)	82	72	28	0	0	0
Southern California	83	73	25	0	0	1



Table 13
Percentages of lakes in DDT concentration categories by region. Concentrations in ppb.
 Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each DDT Concentration Category				
		<21	21-520	520-1000	1000-2100	>2100
California	272	87	13	0	0	0
Northern California Trout Lakes	87	99	1	0	0	0
Northern California Lower Elevation (<2000 ft)	82	76	24	0	0	0
Southern California	83	82	17	0	0	1

Table 14
Percentages of lakes in chlordane concentration categories by region. Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Chlordane Concentration Category				
		<5.6	5.6-190	190-280	280-560	>560
California	272	91	9	0	0	0
Northern California Trout Lakes	87	99	1	0	0	0
Northern California Lower Elevation (<2000 ft)	82	87	13	0	0	0
Southern California	83	86	14	0	0	0

Table 15
Percentages of lakes in selenium concentration categories by region. Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Selenium Concentration Category				
		<2500	2500-4900	4900-7400	7400-15000	15000
California	189	98	2	0	0	0
Northern California Trout Lakes	8	100	0	0	0	0
Northern California Lower Elevation (<2000 ft)	81	99	1	0	0	0
Southern California	80	96	4	0	0	0



Dieldrin

The maximum species averages for dieldrin were below the lowest threshold (the 0.46 ppb FCG) in 80% of all the lakes sampled, including 89% of the northern California trout lakes, 72% of the northern California low elevation lakes, and 73% of the southern California lakes (Table 12, Figure 10). Only one lake out of the 272 lakes sampled exceeded an ATL threshold – Little Oso Flaco Lake, which had an exceptionally high average concentration of 276 ppb based on two goldfish composites. The next highest species average measured was 6.6 ppb in common carp from San Luis Reservoir. Only Little Oso Flaco Lake appears to be a high priority for further assessment or action based on dieldrin concentrations.

Little Oso Flaco Lake is a small lake in the midst of agricultural fields and dunes 1.5 miles from the coast in San Luis Obispo County. Probably due to its proximity to agricultural fields, this lake is noteworthy for its extremely high concentrations of dieldrin, DDTs, and chlordanes. Little Oso Flaco Lake had the highest concentrations in the state for dieldrin and DDT, and one of the highest concentrations of chlordanes.

DDTs

The maximum species averages for DDTs were below the lowest threshold (the 21 ppb FCG) in 87% of all the lakes sampled, including 99% of the northern California trout lakes, 76% of the northern California lower elevation lakes, and 82% of the southern California lakes (Table 13, Figure 11). As for dieldrin, Little Oso Flaco Lake stood out as the only one of 272 lakes exceeding the no consumption ATL of 2100 ppb. DDTs in the two goldfish composites from Little Oso Flaco averaged 7490 ppb. Only one other lake had a sample exceeding the 3 serving ATL threshold for DDTs (520 ppb): Pinto Lake in Region 3, which had a concentration of 557 ppb in a common carp composite (and 290 ppb in a second carp composite). Only Little Oso Flaco Lake appears to be a high priority for further assessment of human health risks due to DDT contamination.

USEPA's national lakes survey found that predator fillets in 1.7% of the sampled population of lakes had concentrations that exceeded the 69 ppb human health risk-based threshold for DDT (Stahl et al. 2009). The median DDT concentration in predator fillets in the national survey was 1.5 ppb (Table 9). In comparison, the median for predator fillets in this survey was much higher: 2.0 ppb. Another factor suggesting relatively high DDT concentrations in California is that, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%), and trout tend to accumulate lower concentrations of DDTs than bottom-feeding warmwater species such as carp and catfish. The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median DDT concentration for largemouth bass in this study was 1.9 ppb, also above the national median. Both the California data for predators and for largemouth bass indicate that DDT concentrations in California sport fish are slightly above the national median.



The maximum DDT concentration observed in the national survey was 1,761 ppb (whole body). The average concentration observed for Little Oso Flaco Lake in this study (7490 ppb in muscle) greatly exceeded all of the concentrations measured by USEPA. Overall, the degree of DDT contamination of California lakes documented in this survey is slightly elevated compared to the rest of the country.

The USEPA survey sampled bottom dwellers in 11 California lakes. Four out of 11 (36%) of these lakes had a DDT sample above 69 ppb. In general these whole body samples had higher DDT concentrations than observed in fillets in the present study. Particularly high DDT concentrations were measured in Clear Lake (154 ppb in goldfish and 106 ppb in largemouth bass), San Luis Reservoir (97 ppb in Sacramento sucker), and Guadalupe Reservoir (85 ppb in common carp). The result for San Luis Reservoir was lower than the result from the present study (average of 196 ppb in common carp), but the present study found high variance among three composites at this reservoir (324, 175, and 90 ppb). The USEPA bottom dweller result for Clear Lake was very similar to the concentration observed in common carp at Clear Lake in the present study (134 ppb).

Risks to wildlife from DDT contamination in some lakes are likely to be significant. Based on the degree of contamination observed in this survey, DDT would be expected to exceed thresholds for effects on raptor reproduction in some lakes. In addition to Little Oso Flaco Lake, Pinto Lake, San Luis Reservoir, and Clear Lake, other lakes with relatively high DDT concentrations included Sepulveda Lake (275 ppb in common carp), Perris Reservoir (193 ppb in largemouth bass), Lake del Valle (104 ppb in channel catfish), and Almaden Lake (99 ppb in common carp).

Chlordanes

The maximum species averages for chlordanes were below the lowest threshold (the 5.6 ppb FCG) in 91% of all the lakes sampled, including 99% of the northern California trout lakes, 87% of the northern California lower elevation lakes, and 86% of the southern California lakes (Table 14, Figure 12). None of the ATL thresholds were exceeded in any part of the state. The highest species average measured was 68 ppb in common carp from Almaden Lake in Region 2. The highest concentration measured in any sample was 78 ppb in a common carp composite from Lake Lindero (a second sample in Lake Lindero measured 43 ppb). Other lakes with relatively high concentrations were Lake Chabot (San Leandro) (42 ppb) and Little Oso Flaco Lake (36 ppb).

USEPA compared their predator results to a threshold of 67 ppb for chlordanes. Predator fillets in 0.3% of the national sampled population of lakes had concentrations that exceeded this threshold. Bottom-dweller concentrations (whole body) in the national survey had a median concentration of 1.65 ppb. Only one lake in the present study had a concentration (fillet) above 67 ppb (Almaden Lake). None of the lakes sampled appear to be a high priority for further assessment or action based on chlordane concentrations.



Selenium

The maximum species averages for selenium were below the lowest selenium threshold (the 3 serving ATL of 2,500 ppb) in 98% of all lakes sampled, including 100% of the northern California trout lakes, 99% of the northern California lower elevation lakes, and 96% of the southern California lakes (Table 15, Figure 13). Only Lake Cunningham (3,780 ppb) in Region 2, Ramer Lake (3,020 ppb) and Salton Sea (2,580 ppb) in Region 7, and Lake Lindero (2,790 ppb) in Region 4 exceeded the 2,500 ppb threshold. The highest concentration measured in any sample was 4,040 ppb in a common carp composite from Lake Cunningham. Only one sample (the carp composite from Lake Cunningham) exceeded a no effect threshold of 4 ppm (SFEI 2008) for effects on fish. None of the lakes sampled appear to be a high priority for further assessment or action based on selenium concentrations.



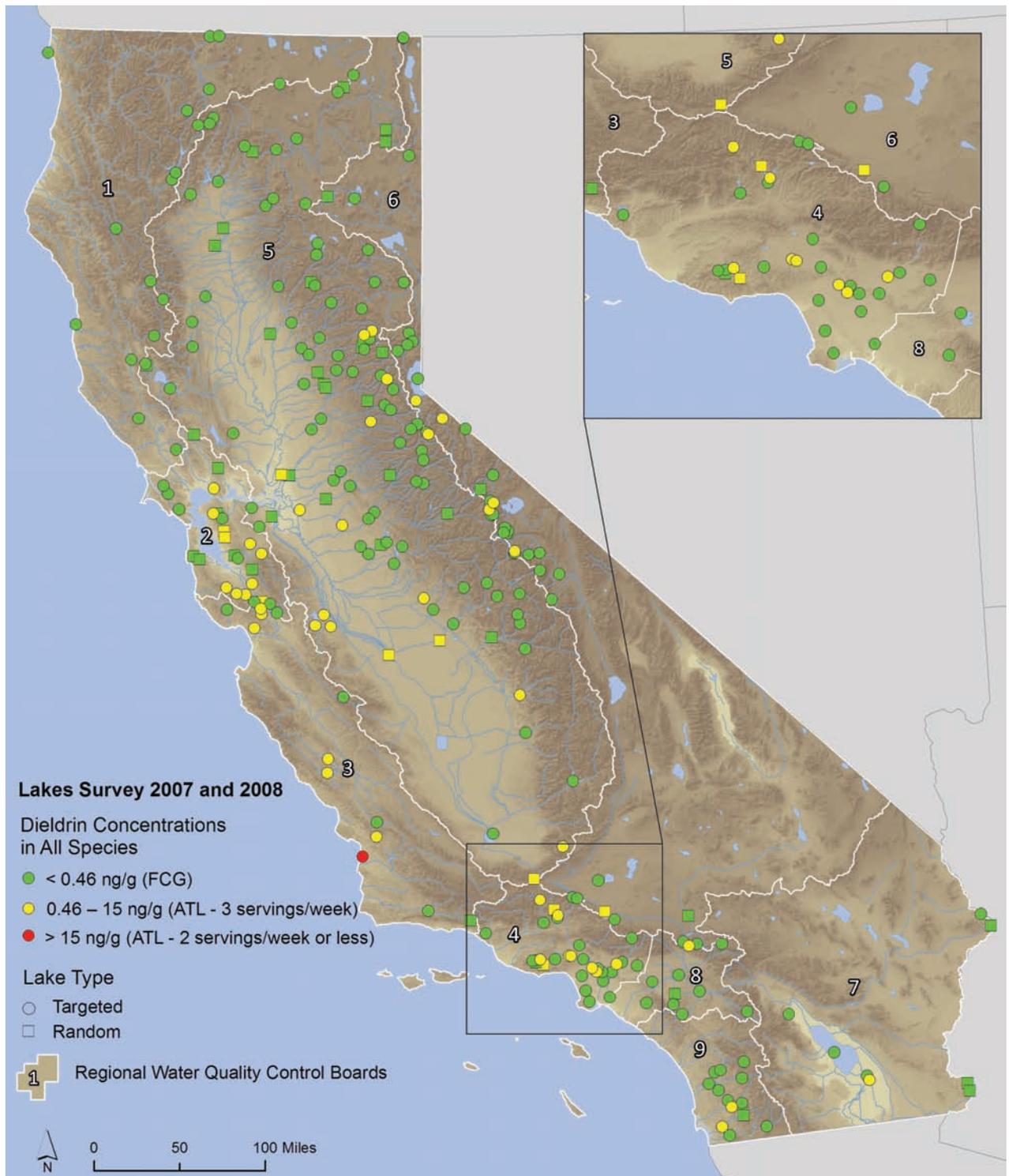


Figure 10. Spatial patterns in dieldrin concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Colors represent dieldrin concentration categories. Note that the two serving ATL is the highest threshold shown on this map.

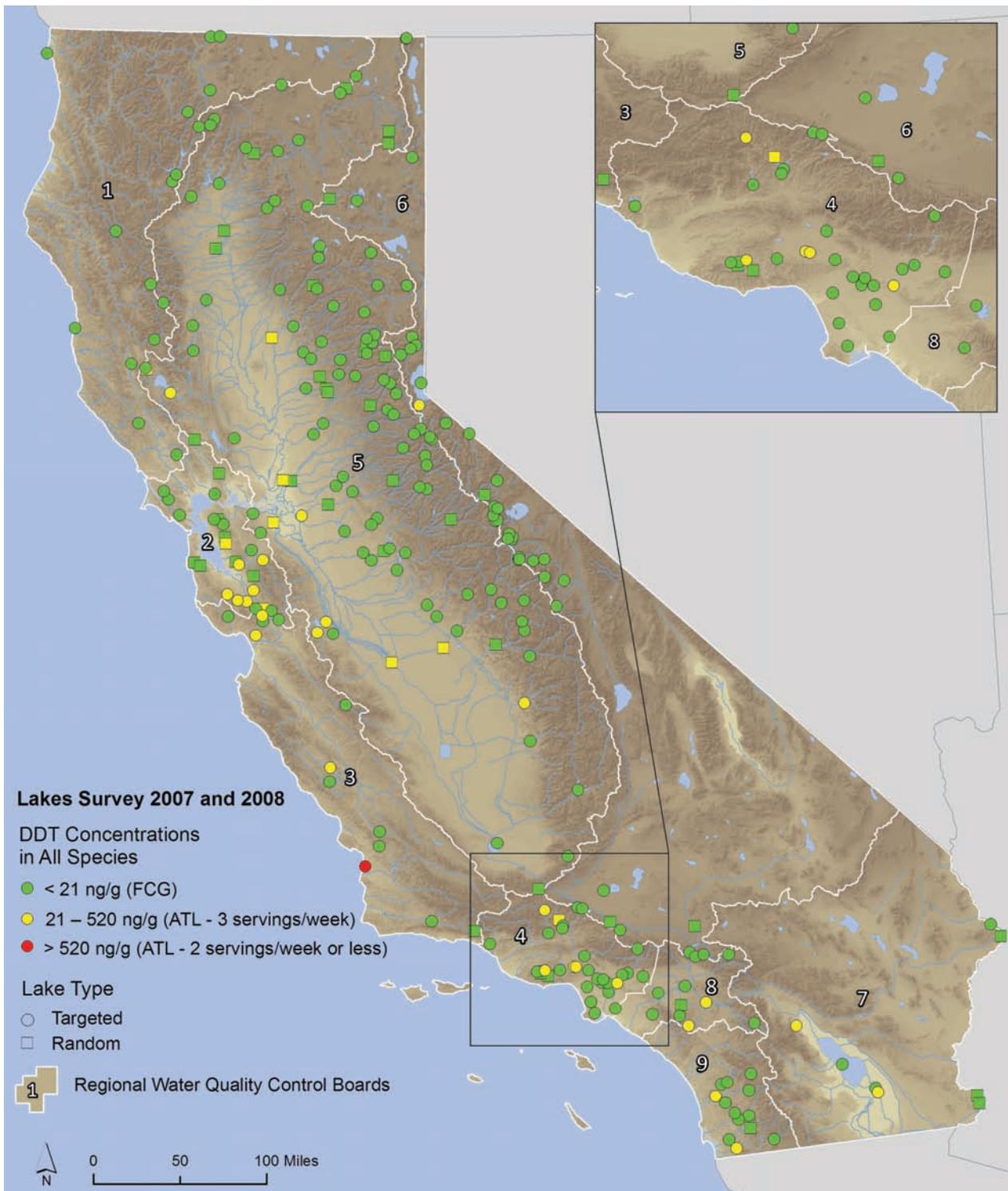


Figure 11. Spatial patterns in DDT concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

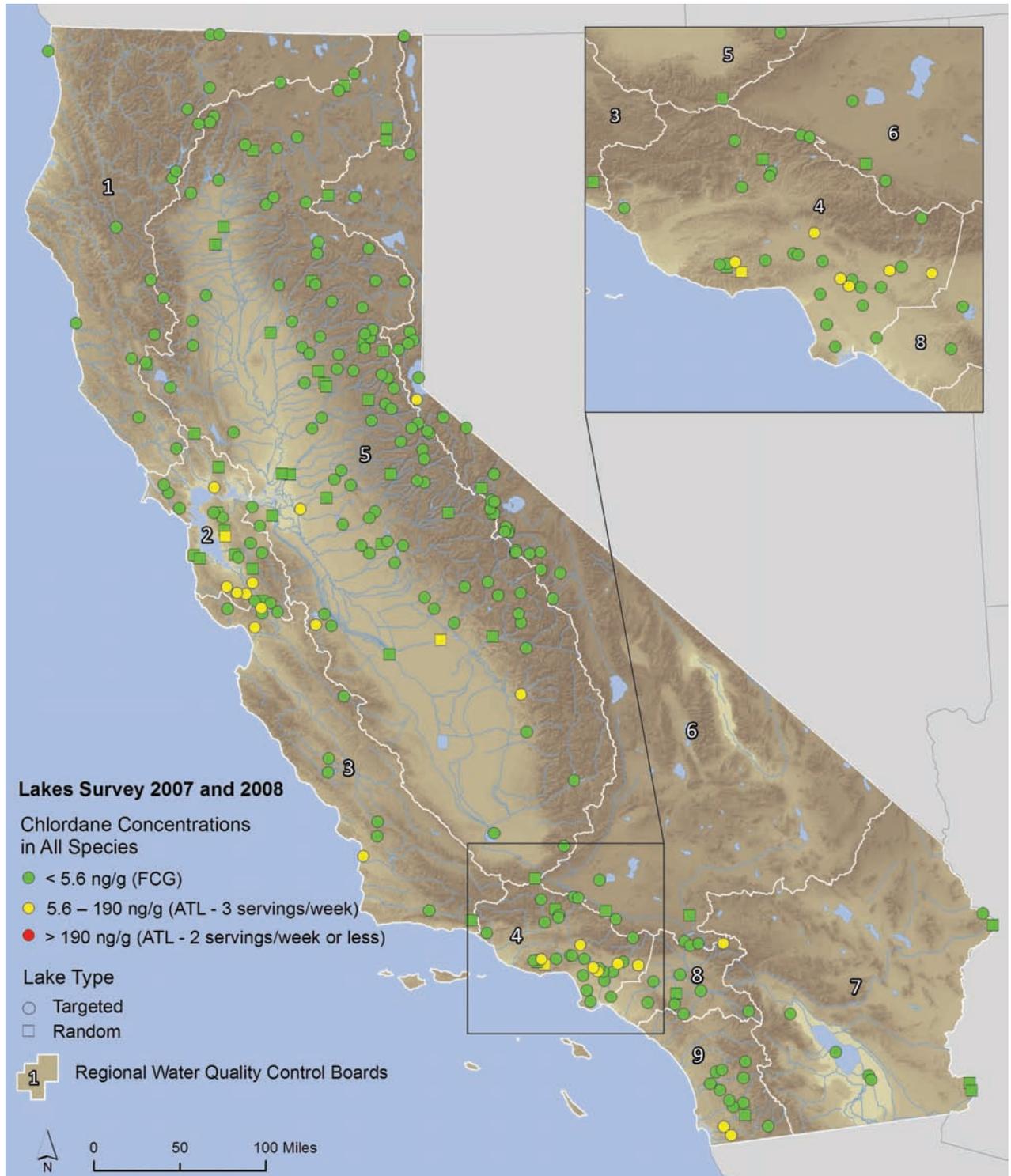


Figure 12. Spatial patterns in chlordane concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

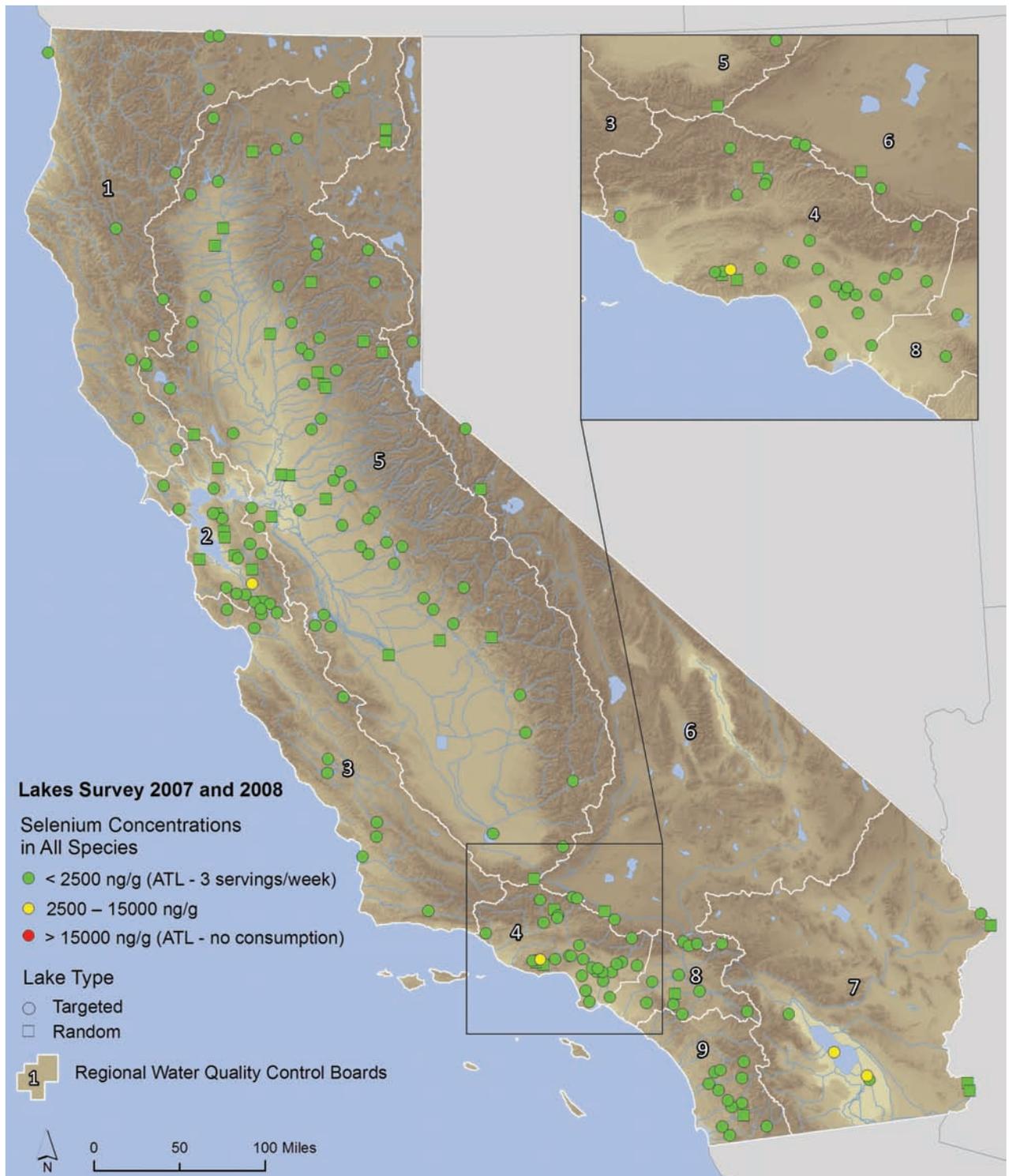


Figure 13. Spatial patterns in selenium concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

SECTION 4

RECOMMENDATIONS FOR FUTURE MONITORING

The work presented in this report represents a major step forward in understanding the extent of chemical contamination in sport fish in California lakes and reservoirs, and the impact of this contamination on the fishing beneficial use. The study has shown that mercury accumulation in fish is a significant problem throughout much of the state. However, comparison to USEPA's national survey indicate that the degree of mercury contamination in California is not unusual compared to the rest of the country, in spite of the intensive mercury and gold mining that has occurred here. For other contaminants, concentrations were much lower relative to thresholds for human health concern. It should also be noted that this survey focused on the species that accumulate the highest contaminant concentrations. Concentrations in some of the other species can be expected to be substantially lower than observed for the predators and bottom-feeders evaluated in this study.

This survey has also raised many questions, and left other questions unanswered. Several areas where further study would be of great value in addressing management issues are described below. The needed studies are described below in general terms, as details should be developed through a deliberate and thoughtful group process.

1) FOLLOW-UP SAMPLING TO DEVELOP CONSUMPTION GUIDELINES AT LAKES WITH HIGHLY CONTAMINATED FISH

High priority water bodies in this regard with elevated concentrations were discussed in the mercury and PCB sections. Development of consumption guidelines requires data from a broader spectrum of species, so anglers can be directed to cleaner species if they are present (as is often the case). Obtaining the needed data typically costs approximately \$20,000 per lake. Costs are greater for larger lakes. Some of this work is already underway in Regions 2 and 4, but significant additional resources would be needed to perform this follow-up work at the many lakes with concentrations above thresholds.

2) FOCUSED EVALUATIONS OF SELECTED LAKES TO IDENTIFY CONTAMINANT SOURCES

Distinguishing the relative importance of legacy contamination from mining, atmospheric deposition, and other sources is critical to effective management of methylmercury contamination. The efforts in this report and in Negrey et al. (2010) to identify sources and controlling factors for methylmercury have provided a



foundation for progress on this front, and information that can help in pursuing more refined approaches in the future. More detailed, site-specific field work could be performed to assess the contributions of different sources. Identifying and sampling lakes without mining influence could yield valuable insights. Studies that include assessment of key parameters in sediment, the food web (including lower trophic levels and trophic position), lake water, and the watersheds would have the best chance of answering source questions. Emerging tools such as mercury isotopes may be valuable in this context.

3) ASSESSMENT OF RISKS TO WILDLIFE FROM BIOACCUMULATIVE CONTAMINANTS

Although this study did not focus on risks to wildlife due to funding limitations, they are likely to be a significant concern. Exposures and risks to wildlife, including fish and fish-eating birds (Sandheinrich and Wiener 2009), are likely to be substantially higher than for humans in some instances. These risks could be assessed in a preliminary manner by estimating likely exposures based on extrapolation from the sport fish data to other species. The best approach would be to conduct monitoring targeted at addressing this question. A sampling design focusing on wildlife prey or directly on piscivorous species would be needed for an accurate assessment of exposure and risks in wildlife.

4) EMERGING CONTAMINANTS

Again due to funding limitations, this study did not evaluate emerging contaminants. Two of these contaminants, polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs), are known to accumulate in fish. Human health thresholds for these chemicals in fish are anticipated (PBDEs) or available (PFC screening values have been developed by the state of Minnesota). These and other emerging contaminants accumulate in fish and should be tracked to provide information that managers need in order to act before they become the legacy contaminants of tomorrow. In the short-term, samples archived from this study could be analyzed for these chemicals. In the longer-term, rising concerns such as these should be included in future surveys. A decreased emphasis on legacy contaminants that are on the decline in future surveys could free up funding to evaluate emerging contaminants.

5) TREND MONITORING

Lake and reservoir food webs are contaminated with mixtures of contaminants, some with declining concentrations, some rising, and some not changing appreciably. Tracking these trends is essential to effective management of water quality in these ecosystems. Large-scale processes such as climate change can influence trends. A recent study indicates that lakes in California are warming twice as fast as surface air temperatures (Schneider et al. 2009). The likely effect of this on mercury cycling is not known, but some effect on trends seems plausible. Contaminant trends in lakes are affected by a host of sources and processes operating at global (e.g., atmospheric deposition) and local scales. An effective program to monitor trends is



needed. This could include establishing long-term time series at selected locations. More thorough sampling of ancillary parameters (e.g., trophic position) would greatly enhance interpretation of these time series. It will also be valuable to repeat a broad lakes survey, but the optimal interval for this has not yet been determined.



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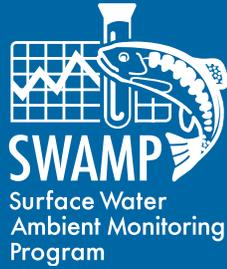
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