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Comparison of water quality, zooplankton density, and cover in razorback sucker (Xyrauchen texanus [Abbott]) spawning areas of Lake Mead and Lake Mohave

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EXECUTIVE SUMMARY

Las Vegas Bay and Echo Bay in Lake Mead have small, self-sustaining populations of razorback sucker (*Xyrauchen texanus* [Abbot]). Increased productivity and cover have been hypothesized as reasons for successful recruitment of razorback sucker in Lake Mead. Conversely, reproduction has been documented on Lake Mohave, another lower Colorado River reservoir, but no recruitment has been observed. In 2000, BIO-WEST, Inc. was contracted by the Southern Nevada Water Authority to design and implement a study to examine nutrient levels, zooplankton density, and cover in areas with and without razorback sucker recruitment success. We sampled Echo Bay, Las Vegas Bay, and Trail Rapids Bay on Lake Mead, along with the Arizona Bay and Tequila Cove areas on Lake Mohave. The Lake Mohave locations were chosen because they are known to have razorback sucker reproduction, but no recruitment. During the first year of the study, we found that Las Vegas Bay had higher nutrient levels than all other locations. However, the amount of cover seemed to be the only factor distinguishing Las Vegas Bay and Echo Bay from the other three locations. We hypothesized that increased cover may provide larval and juvenile sucker with protection from predation by nonnative fishes. We suggested that the long-term lake level fluctuations in Lake Mead may be responsible for the increased cover and suggested continued studies to find links between environmental conditions and razorback sucker recruitment.

In 2001 we collected information on water quality and nutrients, zooplankton density, and cover at Las Vegas Bay, Echo Bay, and Trail Rapids Bay in Lake Mead and the Arizona Bay and Tequila Cove areas of Lake Mohave. As in 2000, Las Vegas Bay had higher nutrient levels than all other locations. Overall, most sites had higher ammonium and phosphate levels in 2001. The 2000 results showed no real trends in zooplankton density, but in 2001 we found that Las Vegas Bay and Tequila Cove had a higher zooplankton density than the other locations. Zooplankton density was substantially higher at Las Vegas Bay, Tequila Cove, and Arizona Bay in 2001 versus 2000. Cover was substantially reduced at Echo Bay and Las Vegas Bay in 2001. In May 2001 no significant differences were seen in percent cover at any of the locations. Lake level lowered over 24 feet from March 2000 to May 2001, and left much of the submerged vegetation that provided cover in 2000 dry on shore. However, turbidity, which also provides cover, was significantly higher at Las Vegas Bay and Echo Bay than the other study locations.

We recommend continuing and potentially expanding the study in future years. Cataloguing the conditions present in different years, under different lake elevations, and correlating them with the presence of a strong razorback sucker year class should identify what suite of factors is important in allowing razorback sucker recruitment in Lake Mead. Information on factors necessary for recruitment would assist in managing for the recovery of the species in the Lower Colorado River system.

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INTRODUCTION

Lake Mead and Lake Mohave are both home to remnant populations of the endangered razorback sucker (*Xyrauchen texanus* [Abbott]). While the Lake Mohave population is much larger than the Lake Mead population (Minckley 1983, Holden et al. 1999), the Lake Mohave population is persisting through continuous rearing and stocking efforts by the U.S. Department of the Interior, Bureau of Reclamation. Conversely, the Lake Mead population, which was once thought to have been extirpated, is surviving through limited recruitment in at least two areas of the lake: Las Vegas Bay (LVB) and Echo Bay (EB) (Holden et al. 1999, Holden et al. 2000a, Holden et al. 2000b, Holden et al. 2001). Predation by nonnative species is generally accepted to be the major reason why razorback sucker fail to recruit in Lake Mohave (Marsh and Langhorst 1988, Minckley et al. 1991). However, predator abundance in Lake Mead is thought to be at least as high as in Lake Mohave (J. Heinrich and M. Burrell, Nevada Division of Wildlife, personal communication). Therefore, other factors, such as productivity and cover (Holden et al. in press) may help determine the success of razorback sucker recruitment in the LVB and EB areas of Lake Mead.

In spring 2000 the Southern Nevada Water Authority (SNWA) initiated a study designed to identify the factors that might allow razorback sucker recruitment in Lake Mead. BIO-WEST, Inc. (BIO-WEST) was contracted by the SNWA to develop a study design to compare nutrient levels, zooplankton density, and available cover at sites in both Lake Mead and Lake Mohave. We implemented the study in spring 2000. The 2000 report reviewed available literature on nutrient levels, zooplankton abundance, and razorback sucker recruitment and summarized the methods and results of the first year of the study, March 2000-May 2000 (Golden and Holden 2001).

The review of past studies showed that the LVB area of Lake Mead is more productive than most other areas of Lake Mead and Lake Mohave. However, outside of the LVB area, nutrient and primary productivity values in Lake Mead are similar to and sometimes even lower than those found in Lake Mohave. Therefore, data indicated that areas outside of LVB in Lake Mead and areas in Lake Mohave probably do not differ in their food availability for larval razorback sucker (Paulson et al. 1980, Paulson and Baker 1984). However, Marsh and Langhorst (1988) found that certain spawning areas in Lake Mohave had extremely low zooplankton densities. Most of these historical data were collected from limnetic areas of the reservoirs. We felt that limitations for larval razorback sucker would occur in littoral areas, where they congregate, and designed our study to look at nutrients and zooplankton found in the littoral zone.

Therefore, during spring 2000 we measured nutrient levels, collected zooplankton, and mapped cover in LVB, EB, and Trail Rapids Bay (TRB) in Lake Mead and Tequila Cove (TQC) and Arizona Bay (AZB) in Lake Mohave. As expected, we found that LVB had higher nutrient levels than all the other locations. However, we saw no major differences in zooplankton densities to indicate higher levels of productivity at any one location. Zooplankton densities at all locations were relatively low, especially for zooplankton in the size ranges preferred by larval razorback sucker. The amount of cover seemed to be the only variable differentiating LVB and EB from the other three locations, supporting the idea that predation by nonnative fishes is probably a major factor impacting recruitment of razorback sucker in Lake Mohave and other areas of the lower Colorado River.

We hypothesized that the increased cover at these two Lake Mead sites is the result of the longer-term water level fluctuations driven by climactic factors versus the annual regime of water fluctuation resulting form water demand on Lake Mohave. BIO-WEST recommended continuing cover and productivity studies, in conjunction with the larval and adult studies already ongoing on Lake Mead, to help identify the exact years and sets of conditions that allow recruitment to take place. The following report presents findings from the second year of this study designed to determine if differences in cover, nutrients, and/or food can account for razorback sucker recruitment in certain areas of Lake Mead.

Methods

We sampled the same general study locations as in 2000: LVB, EB, and TRB in Lake Mead (Figure 1), and AZB and TQC in Lake Mohave (Figure 2). However, some of the study sites within the Lake Mead locations had to be changed in 2001 because of lower lake elevations that left some of our 2000 sites dry. We tried to make each site a 200 meter (m) x 20 m rectangle that encompassed a portion of shoreline. In LVB, the five sites for 2001 were distributed from the new Las Vegas Wash inflow to the south shore of LVB around Pitch Fork Cove (Figure 3) . The new entrance area of Las Vegas Wash was approximately 400 m out into the bay, compared with last year. Additionally, dropping water levels made parts of site 1 and site 4 unsampleable in May. In EB the 2001 sites were located from the spawning wall area on the south shore at the back of EB to the Pumphouse Bay area (Figure 4). At EB parts of site 1 and site 5 were unsampleable in May because of dropping water levels. In TRB sites were located from the back of the bay against the wash to just outside the mouth on the south side (Figure 5). The sites in AZB were located from the southeast corner of AZB to the first cove north of Yuma Cove (Figure 6). The sites in the TQC area originated on the south shore of Sandy Point Cove and extended north to the second cove north of TQC (Figure 7).

Sampling occurred during March and May 2001, which are months when larval razorback sucker are typically available in both Lake Mead and Lake Mohave. Within each 200 m X 20 m site, water quality measurements and zooplankton samples were taken at three locations. We measured temperature, dissolved oxygen, nitrate, ammonium, and total dissolved solids with a HydroLab Datasonde 4a and Surveyor 4. After completing the 2000 study, it was brought to our attention that several researchers felt EB and LVB had higher turbidity than the remainder of Lake Mead and also Lake Mohave. Therefore, we used the HydroLab Datasonde 4a and Surveyor 4 to measure turbidity and took some secchi disk depths during this second year of sampling. We took one grab sample at each site, preserved it with hydrochloric acid, and stored it on ice until it could be returned to NEL Laboratories in Las Vegas for analysis of total phosphorus. We pulled plankton tows using a 30 x 90 centimeter (cm) plankton net with 80 micrometer (μm) mesh at each of the three locations. Tows were pulled horizontally for approximately 6 m at 0-0.5 m from the surface. Therefore, the volume of water sampled was about 430.5 liters (l). We used 10% formalin to preserve the samples that were returned to the laboratory for analysis. Finally, we mapped aquatic cover (primarily dead or live vegetation) within each 200 m by 20 m site. Most areas could be mapped through visual observation from the boat, but we used an underwater video camera and snorkeling to assess vegetation in deeper areas.

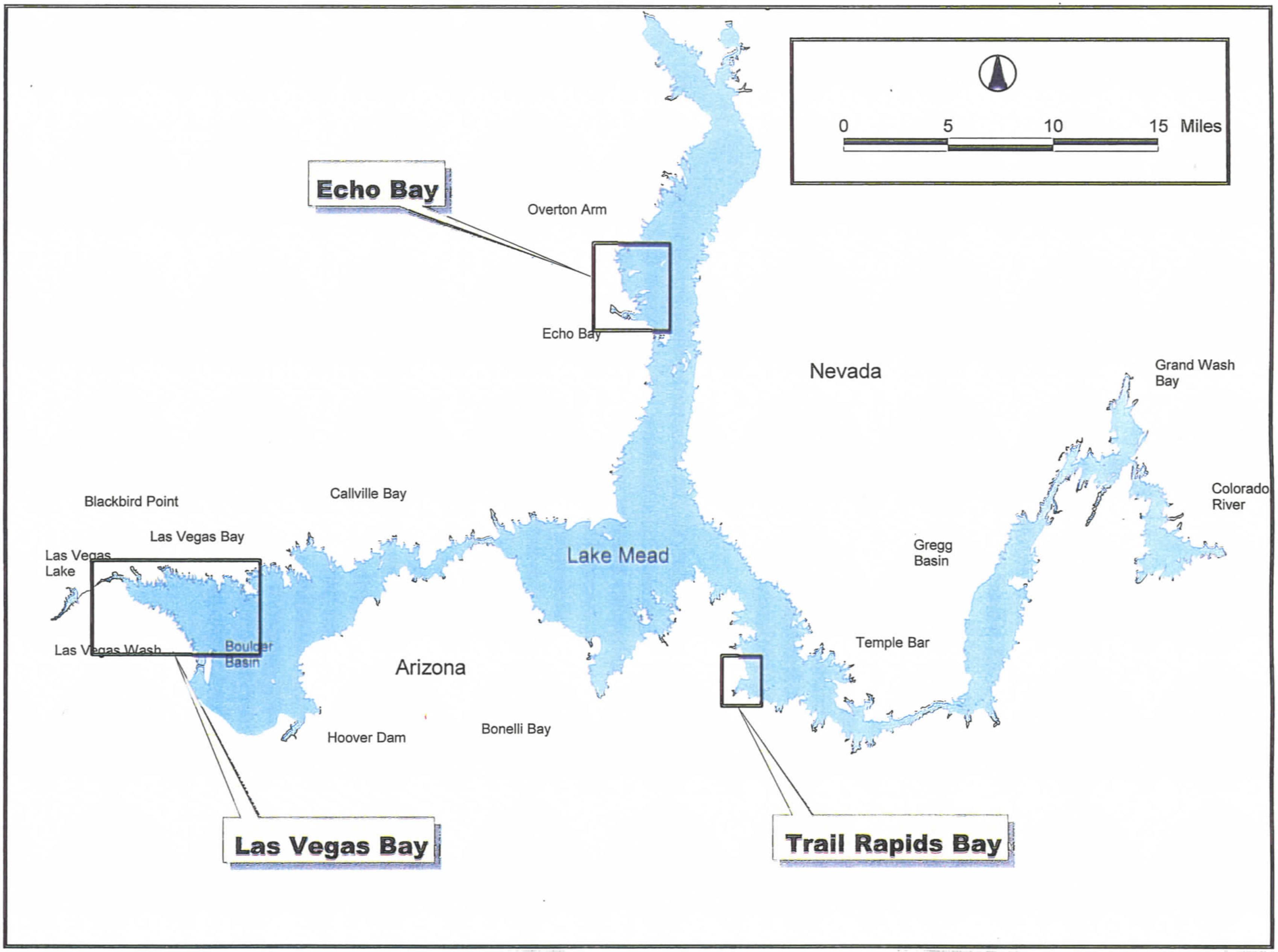


Figure 1. General sampling areas on Lake Mead.

Figure 2. General sampling areas on Lake Mohave.

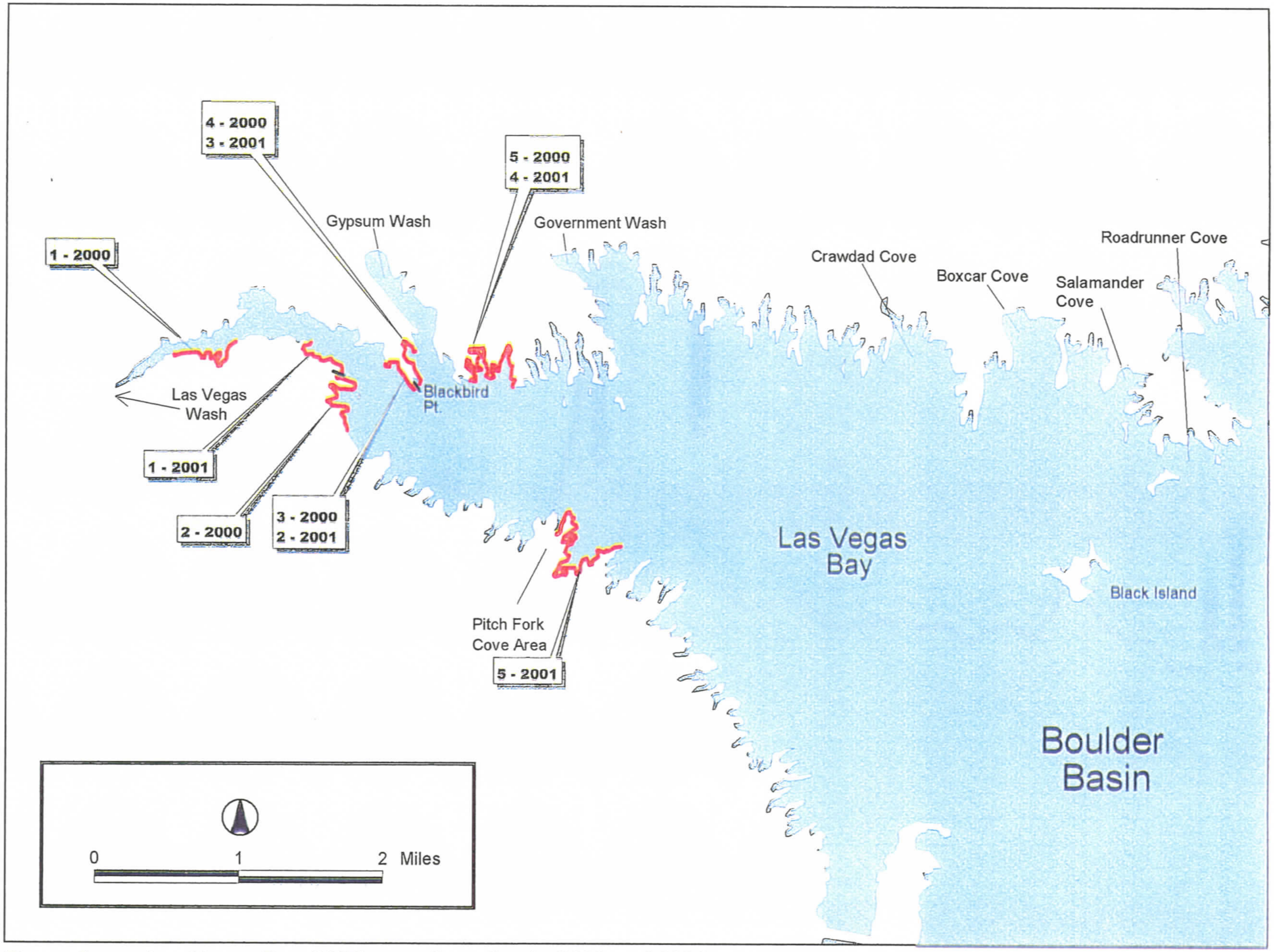


Figure 3. **Las Vegas Bay (LVB) sampling sites in 2000 and 2001.**

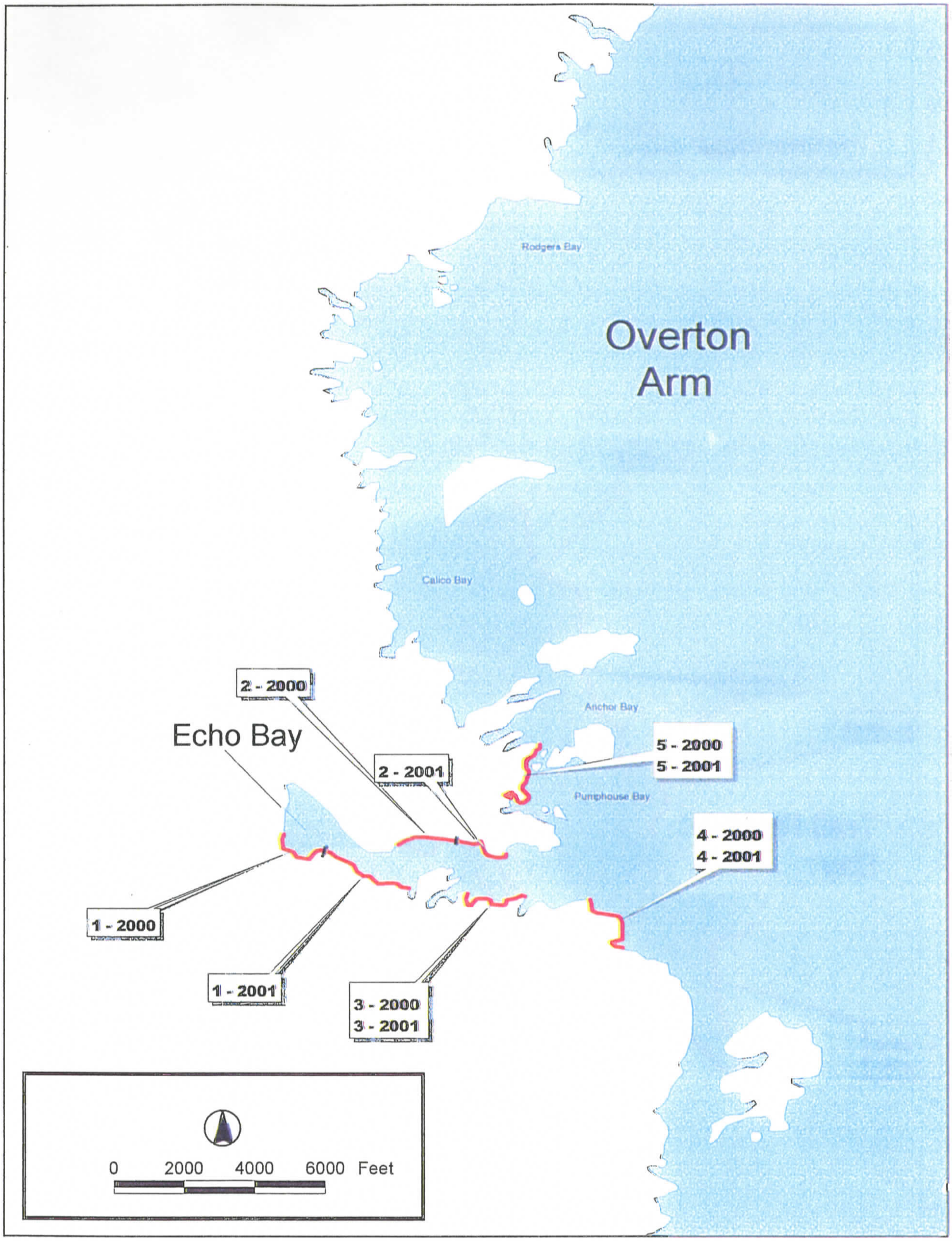


Figure 4. **Echo Bay (EB) sampling sites in 2000 and 2001.**

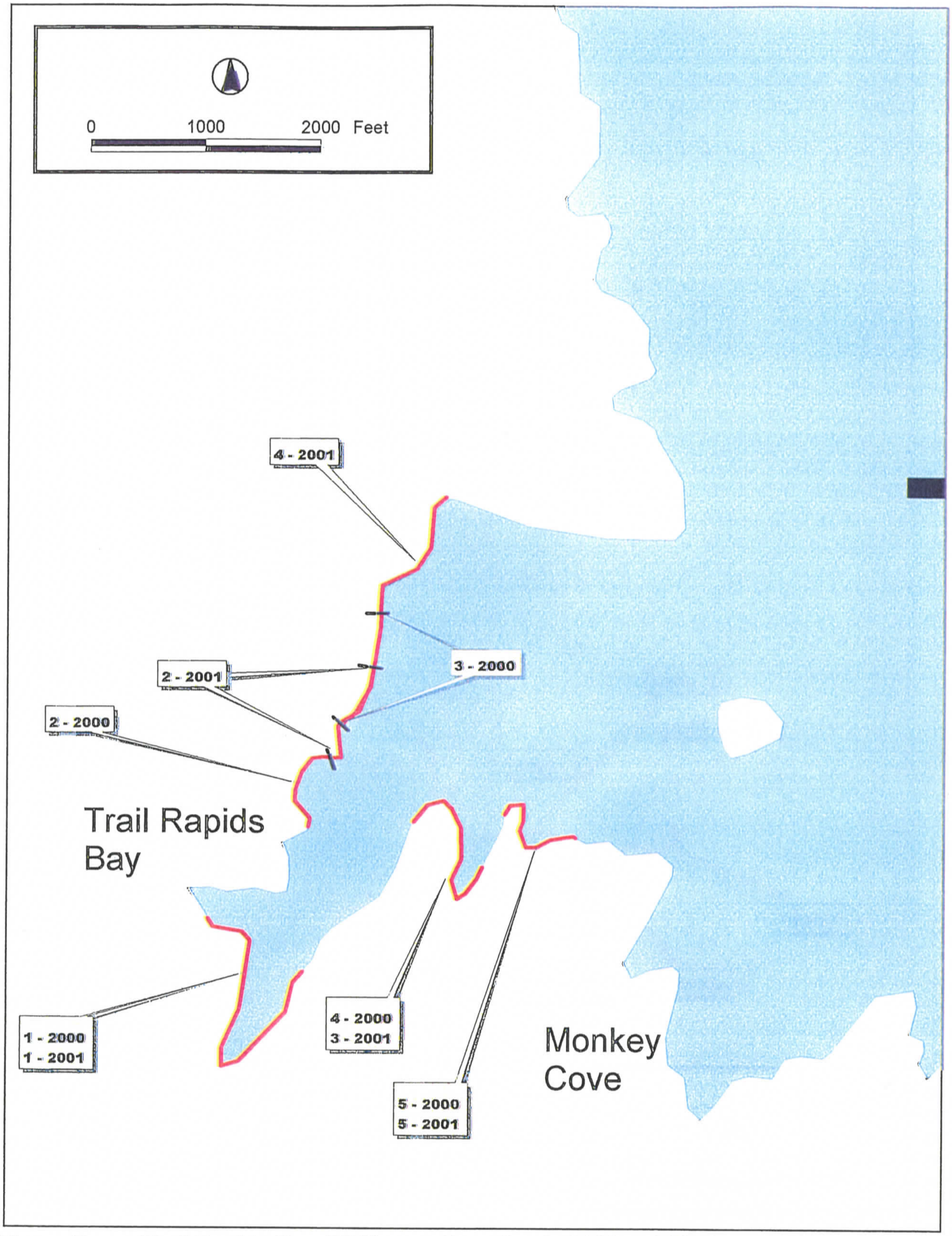


Figure 5. **Trail Rapids Bay (TRB) sampling sites in 2000 and 2001.**

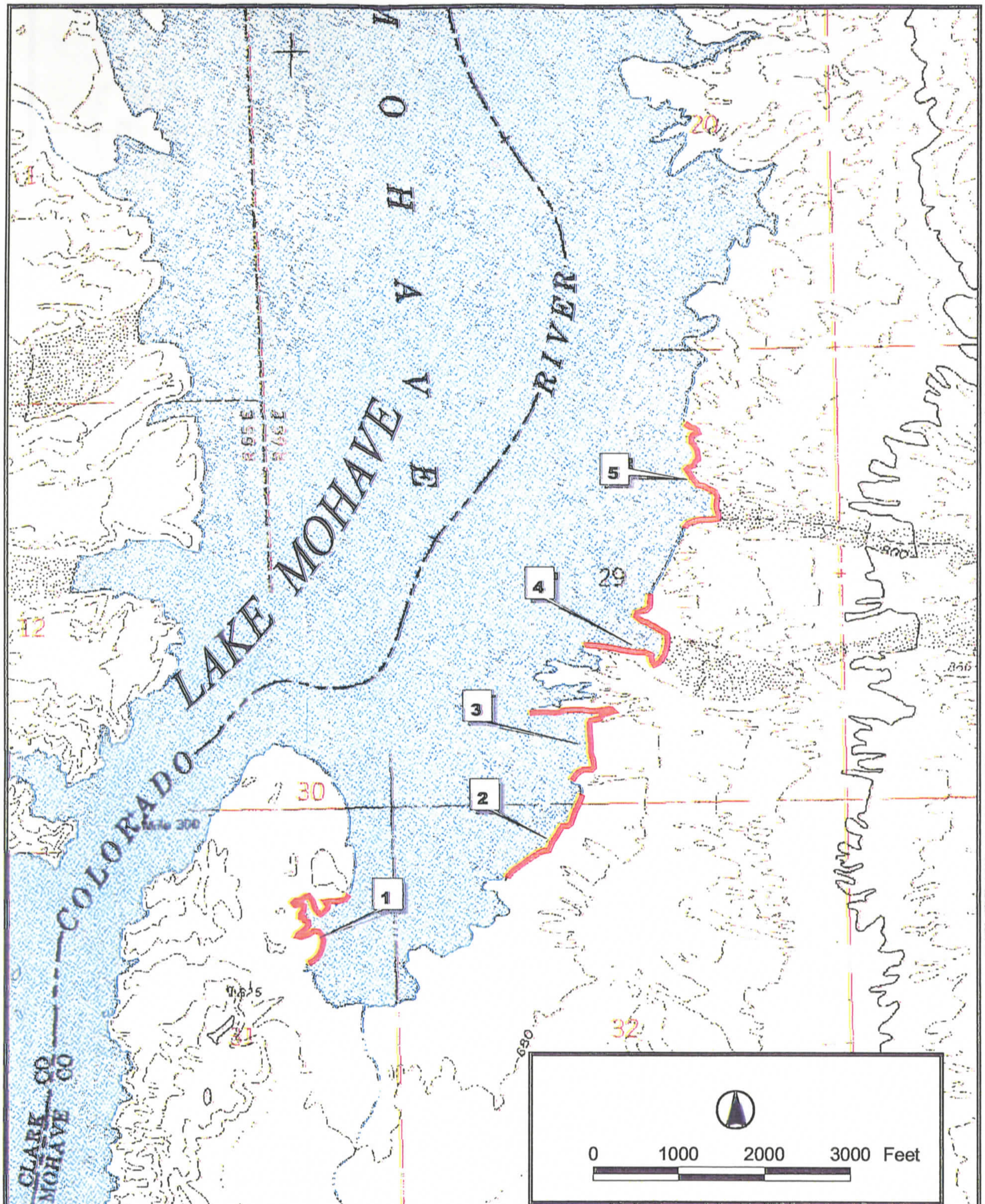


Figure 6. **Arizona Bay (AZB) sampling sites in 2000 and 2001.**

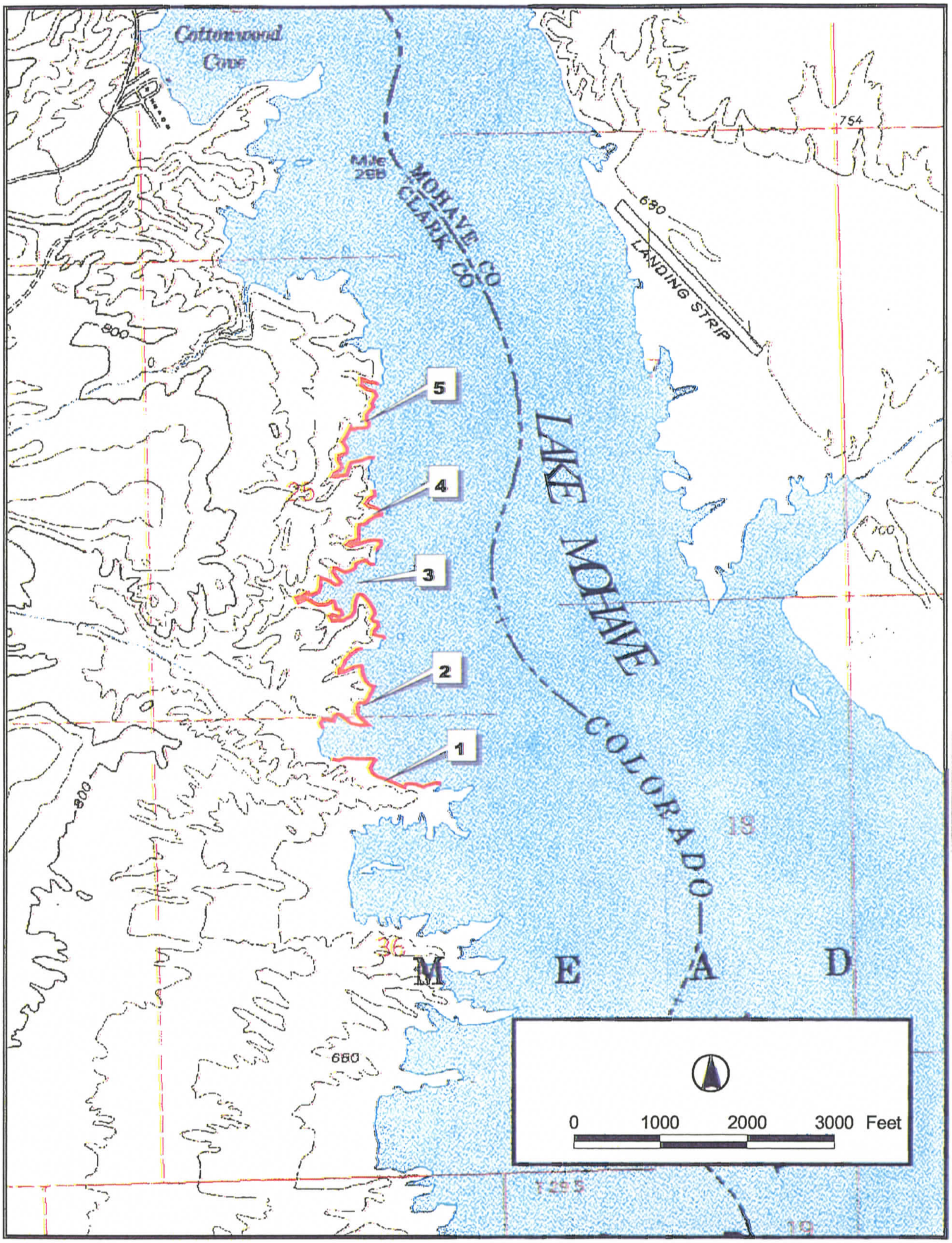


Figure 7. Tequila Cove (TQC) sampling sites in 2000 and 2001.

Zooplankton samples were examined and enumerated under 10x to 45x magnification using a Ward Counting wheel. Specimens were identified to the order, and in some cases family (Cladocera) level. Samples with large numbers of zooplankton were subsampled with a Henson Stemple pipette. We subsampled by suspending the entire sample from a site in 50 milliliter (ml) of water and extracting a 2 ml subsample with the pipette. We took two subsamples from over 50% of the samples. The two subsamples were compared to determine the efficiency and accuracy of the subsampling method. After determining that very little variation existed between subsamples, both 2 ml subsamples from each sample were combined for analysis. We tried to measure a subsample of 30 individuals from each taxonomic group in each sample. Zooplankton density was calculated as number of organisms/l.

We used analysis of variance with location and site as the main effects to determine differences in the water quality parameters and zooplankton density between sites within March and May 2001. In addition to the total number of zooplankton/l, we also looked at the number of zooplankton/l that were likely to be able to be food items for larval razorback sucker. Therefore, we also compared the density of zooplankton measuring < 0.3 mm (Papoulias and Minckley 1992) at each site within each location as well. We calculated the amount of cover by both the total area of cover square meters (m^2) within each location and the percent of the total wetted area that had cover at each site. We used analysis of variance with location as the main effect to compare percent cover at all locations during March and May 2001. We used Tukey's Honestly Significant Difference multiple comparison test (Dowdy and Wearden 1991) to examine all possible differences between means for all analysis of variance tests. We used paired t-tests, modified for unequal variances, using Bonferroni-adjusted probabilities to compare differences between years at each site for all variables of interest.

RESULTS

Water Quality

Similar to the results from 2000, LVB differed significantly from all other locations in virtually every water quality parameter. In March and May all the sites at LVB had significantly higher mean nitrogen as nitrate (NO^3-N) concentrations than all other sites sampled (Figure 8, $p<0.001$). In March the mean amount of NO^3-N within LVB was highest at LVB1 and declined significantly out to LVB4 ($p<0.001$), while in May the amount of NO^3-N at sites in the LVB area were in the following order 2>1>4>3>5 ($p\leq0.001$). During the March and May sampling, no significant differences in the mean amount of NO^3-N were detected between any other sites. The mean amount of NO^3-N did not differ between years at any of the locations.

Similar trends were seen for ammonium (NH^4-N) as for nitrogen (Figure 9). In March LVB sites 1-3 had significantly higher mean NH^4-N concentrations than all other sites ($p<0.02$). The LVB sites 4 and 5 had significantly higher mean NH^4-N concentrations than all sites except LVB 1-3, EB 5 and AZB 5 ($p<0.02$). The AZB 5 and EB 5 sites had higher mean NH^4-N concentrations than all other AZB, TQC, and TRB sites ($p<0.02$). Mean concentrations of NH^4-N were significantly higher in March 2001 than in March 2000 at all locations ($p<0.001$). In May LVB sites had higher mean NH^4-N concentrations than all other sites, and the concentrations were also significantly different between sites at LVB, following the same order as NO^3-N: 2>1>4>3>5 ($p<0.001$). Additionally, EB1 had significantly higher mean NH^4-N concentrations than several AZB, TRB, and TQC sites ($p<0.05$). May NH^4-N concentrations were also significantly higher at all locations in 2001 (Figure 10, $p<0.001$).

Since only one measurement of total phosphorus was taken at each site, no conclusions can be drawn regarding the statistical significance of the findings (Figure 11). In March all sites at both LVB and EB showed total phosphorus levels above detection limits (0.01milligrams per liter [mg /l]). Water samples from two sites at AZB and TQC also showed total phosphorus (P) levels above detection limits. The LVB sites showed much higher levels of total P than any of the other sites. In May LVB 1-3 and 5 had total phosphorus concentrations above detection limits along with EB 1, AZB 1 and 4, and TRB 2. The LVB 1 site had the highest levels of total P followed closely by AZB 1 and TRB 2. Combining the five total P samples taken at each location during each sampling trip, we were able to statistically compare the total P levels at the different locations between years (Figure 12). Mean total P levels were significantly higher in March 2001 than March 2000 at LVB ($p<0.001$). No other differences were seen between years.

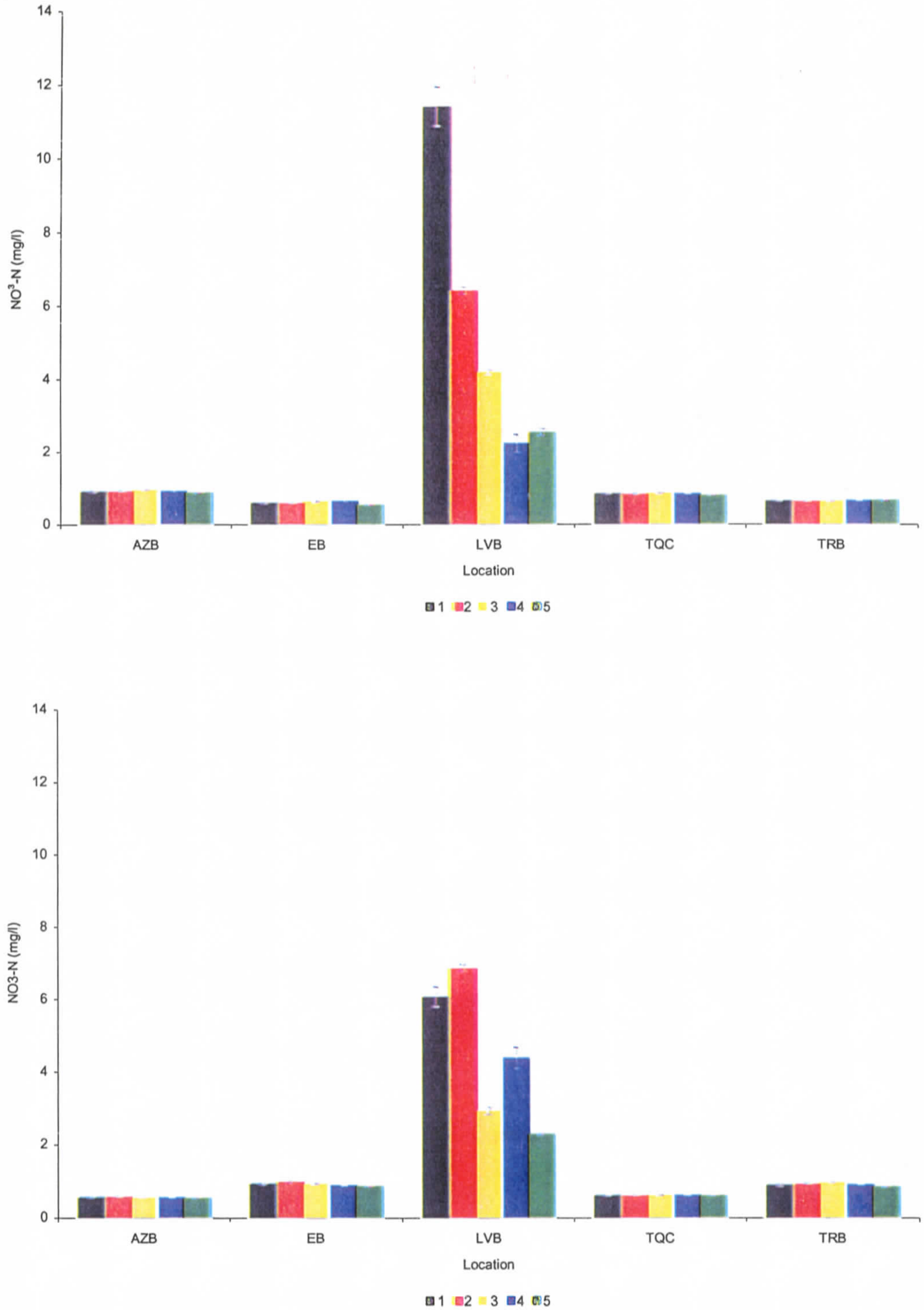
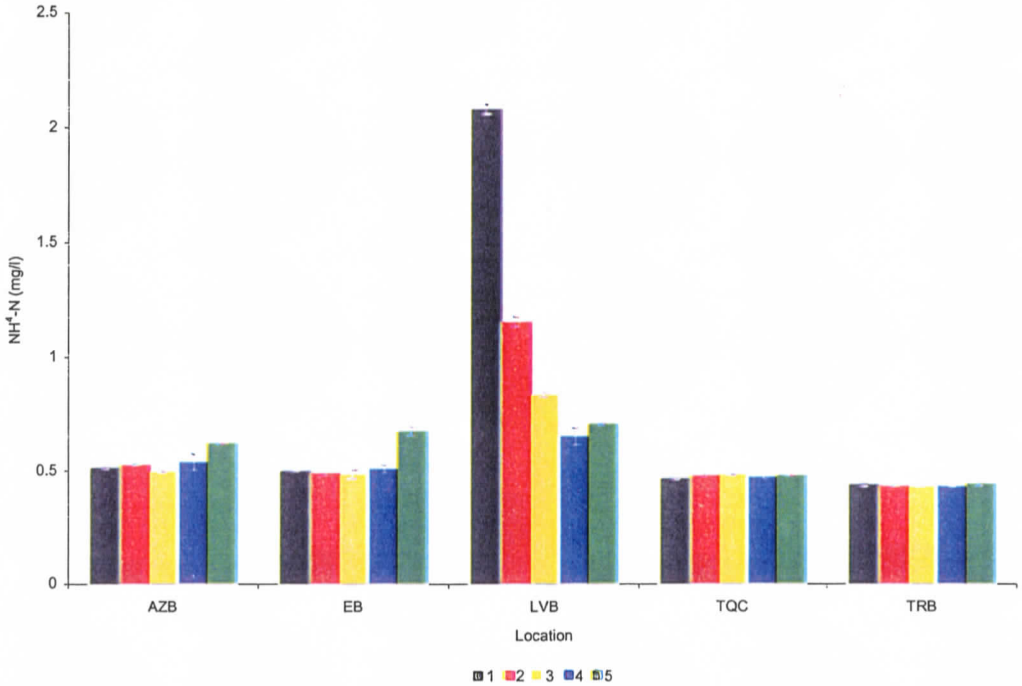


Figure 8. **Mean amount of nitrogen as nitrate (NO^3-N) at all sites in (a) March 2001 and (b) May 2001.**



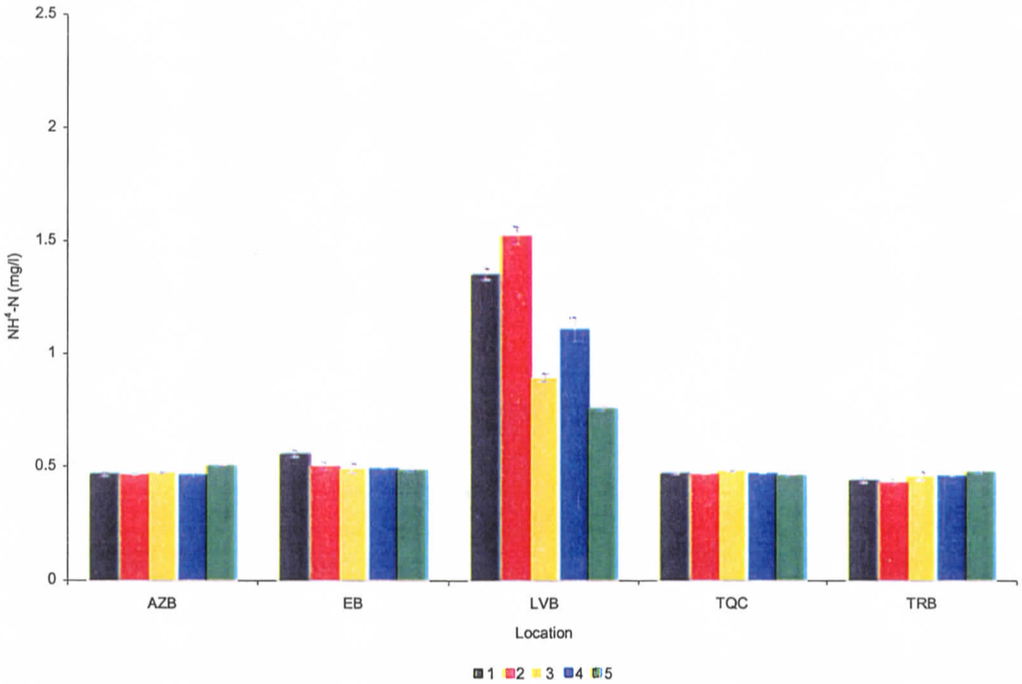


Figure 9. **Mean amount of nitrogen as ammonium (NH^4-N) at all sites in (a) March 2001 and (b) May 2001.**

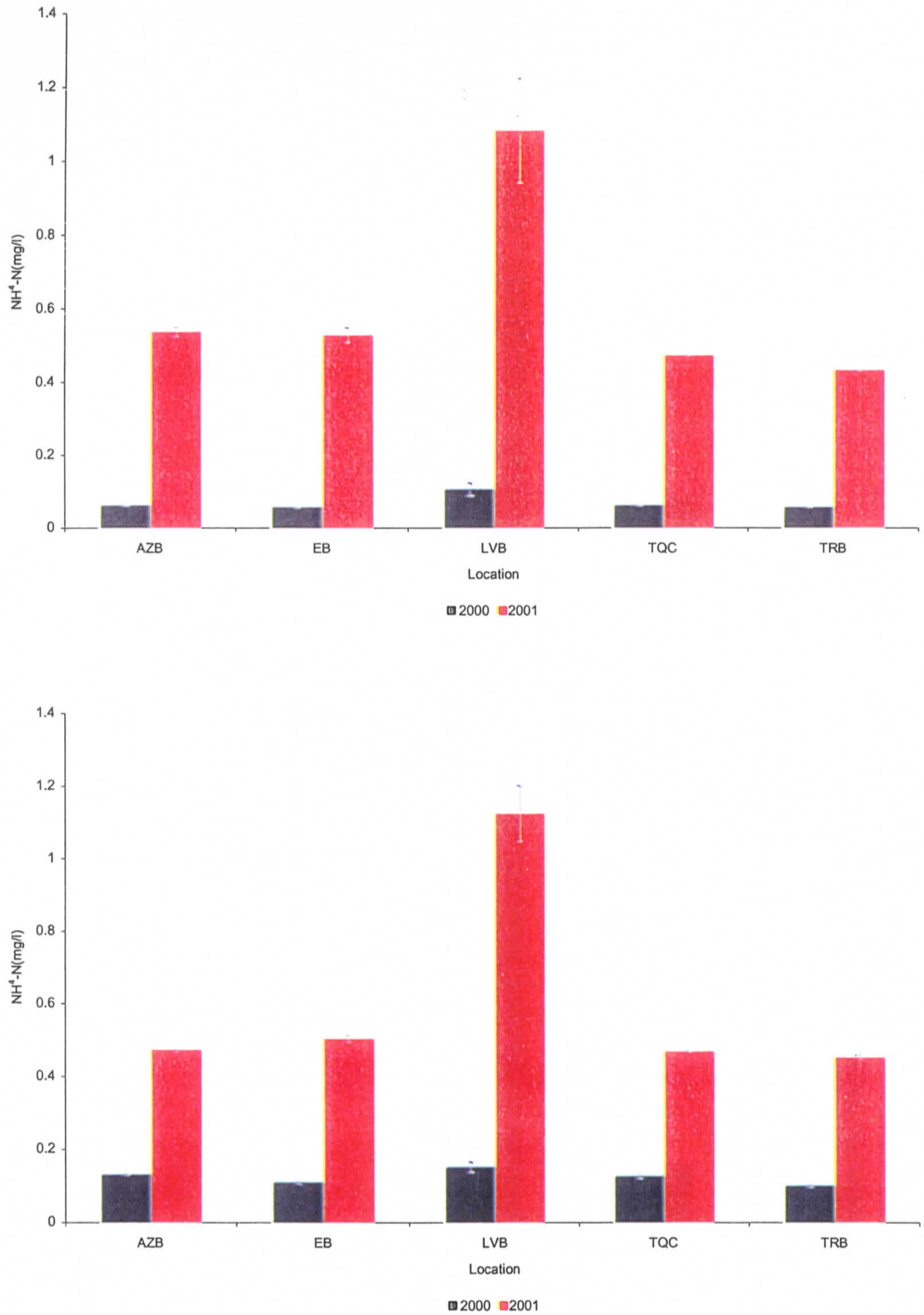


Figure 10. **Mean amount of nitrogen as ammonium (NH^4-N) between years at each location in (a) March and (b) May.**

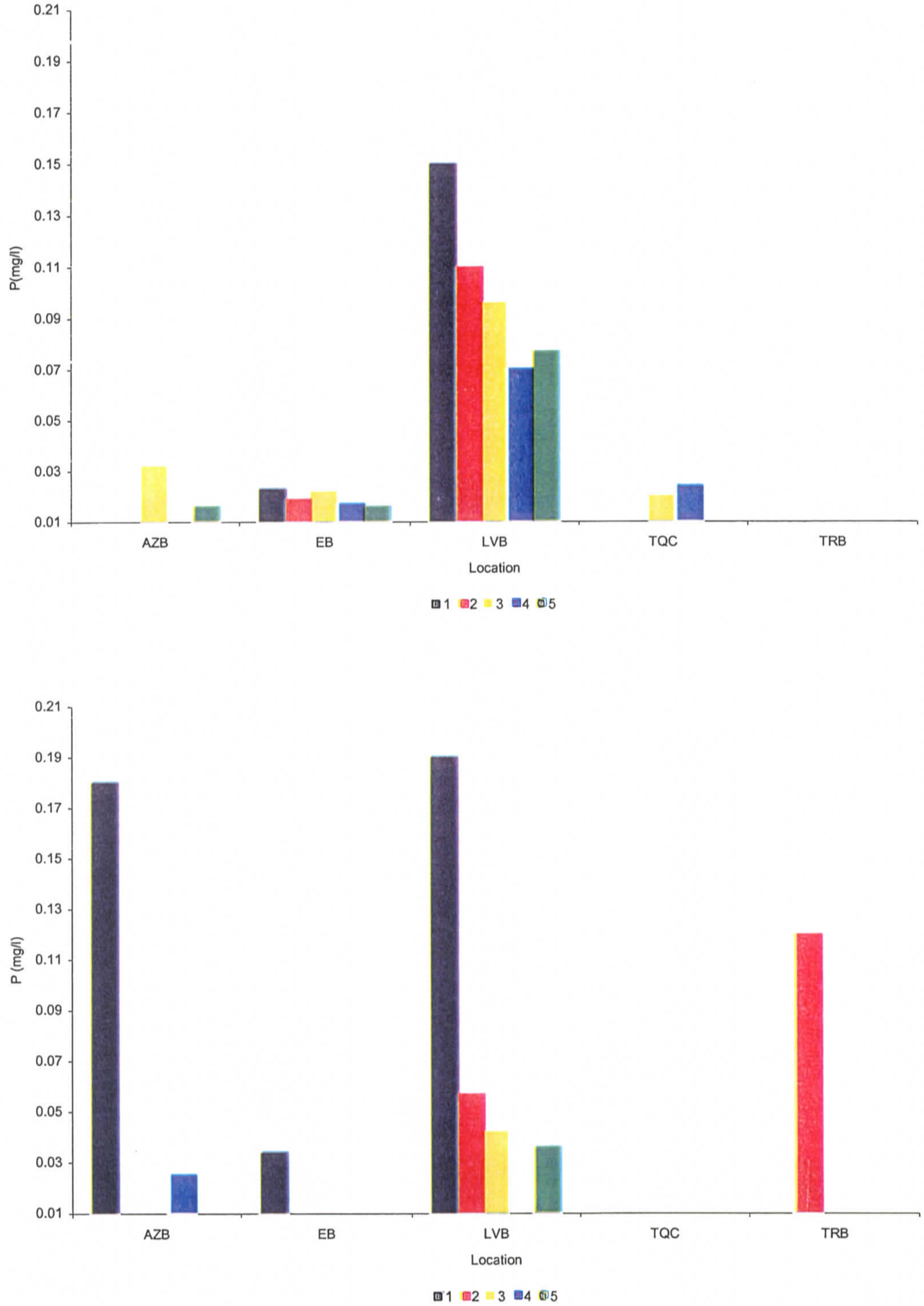


Figure 11. Total phosphorus (P) measured at all sites in (a) March 2001 and (b) May 2001.

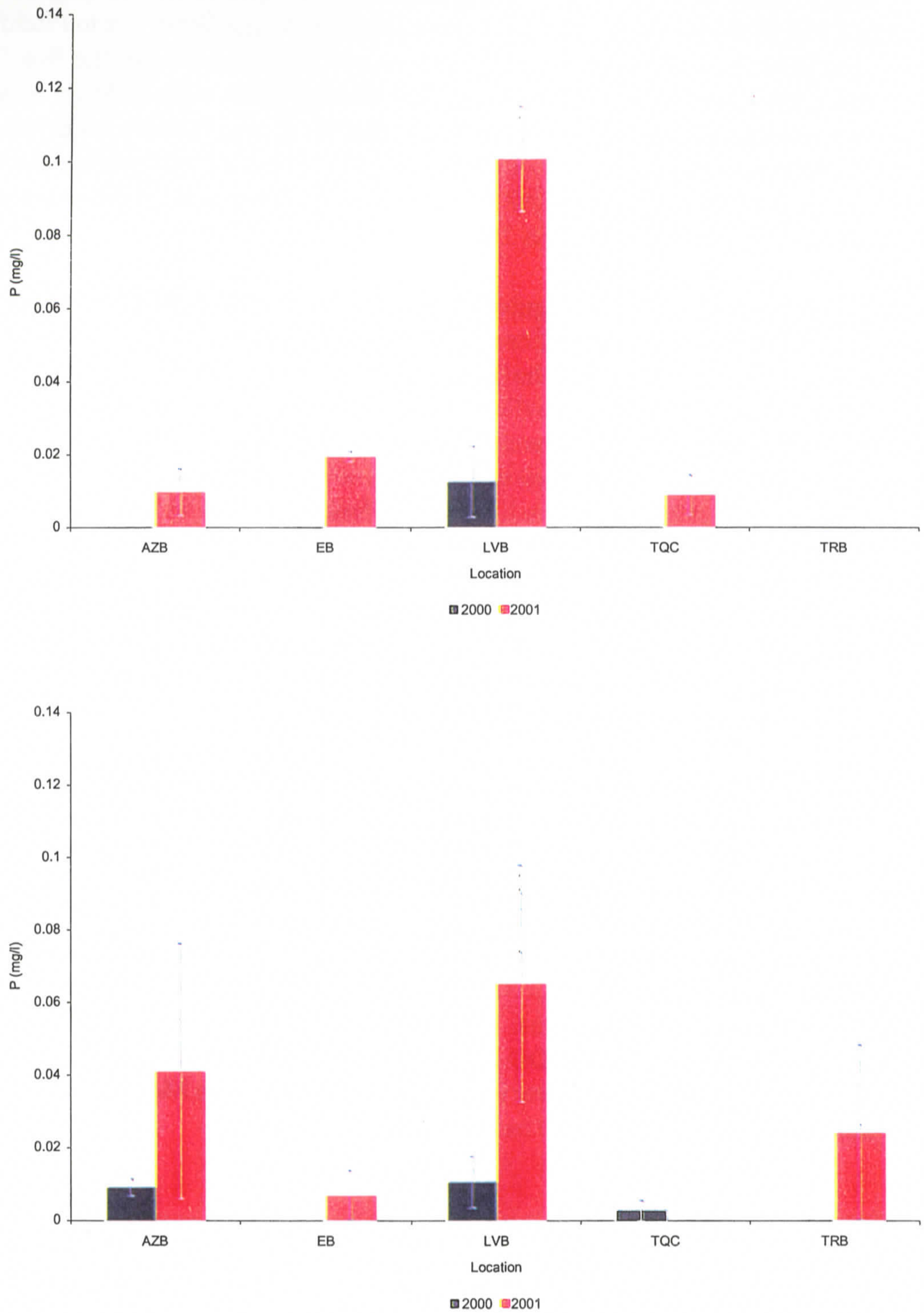
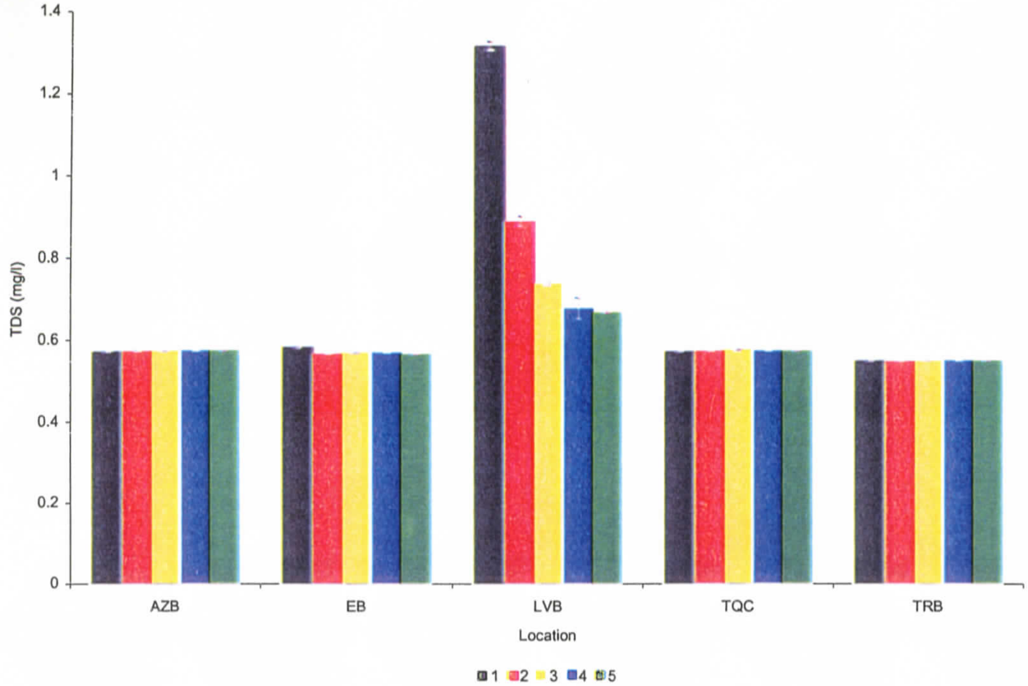


Figure 12. **Mean amount of total phosphorus (P) between years at each location in (a) March and (b) May.**

Total dissolved solids (TDS) were significantly higher at all LVB sites in March (Figure 13) ($p<0.001$). Within LVB, TDS showed a decreasing trend from Las Vegas Wash out to Pitchfork Cove ($p<0.001$). The EB 1 site had significantly higher levels of TDS than three of the five TRB sites ($p<0.02$). The LVB sites had higher levels of TDS than all other sites in May, as well ($p<0.001$). However, the decreasing trend from the Las Vegas Wash area out into LVB was not as defined, with sites following this order: 2>1>4>3>5 ($p<0.001$). The EB 1 site had significantly higher levels of TDS than all TRB, TQC, and AZB sites in May ($p\leq0.022$). No differences were seen in the levels of TDS between 2000 versus 2001.

Turbidity followed a trend similar to TDS (Figure 14). In March turbidity was highest at LVB 1, 2, 3, and 5, and EB 1. All these sites had significantly higher turbidity than other sites at EB, TRB, AZB, and TQC ($p<0.05$). In May LVB 1 had the highest turbidity, being significantly higher than all other sites, except for EB 1 ($p\leq0.008$). The EB 1 site had significantly higher turbidity than all sites except LVB 1 and 5 ($p\leq0.001$). In March Secchi disk depths at the two Lake Mohave locations varied from 8.0 m to 11.2 m, and they were slightly lower in May ranging from 6.5-7.2 m. Visibility was best at TRB in March, where Secchi disk depths were greater than 17 m. Both EB and LVB showed decreased visibility at sites near the back of the bays that increased toward the outermost sites. In March Secchi disk depths at EB ranged from 1.6 - 11.8 m, and Secchi depths at LVB ranged from 0.6-3.4 m. In May LVB again had the lowest visibility ranging from 0.5-1.9 m. The EB Secchi depths ranged from 0.9-4.5 m, while TRB Secchi depths ranged from 4.7-7.7 m. Part of the reason for the extremely low Secchi depths in LVB in both March and May was the extensive algae bloom occurring throughout spring 2001.

Dissolved oxygen (DO) concentrations varied widely throughout the five locations in March, but they were relatively the same at all locations in May (Figure 15). Once again, LVB had the extreme values. In March LVB sites 2-5 had significantly higher mean DO concentrations than all other sites except EB 5, which was not significantly different from LVB 4 ($p<0.05$). All TRB sites had significantly higher mean DO concentrations than all AZB sites ($P<0.05$). A few EB sites also had higher mean DO concentrations than some AZB sites ($P<0.05$). In May differences seemed to be between individual sites and not between overall locations, although LVB still had a slightly higher mean DO levels than the other locations. Overall DO concentrations were higher in 2001. The LVB sites had significantly higher mean DO concentration in March and May 2001 ($p\leq0.024$), while EB and TQC sites had significantly lower mean DO concentrations in May 2001 ($p<0.001$). No differences were seen in the levels of DO between 2000 and 2001.



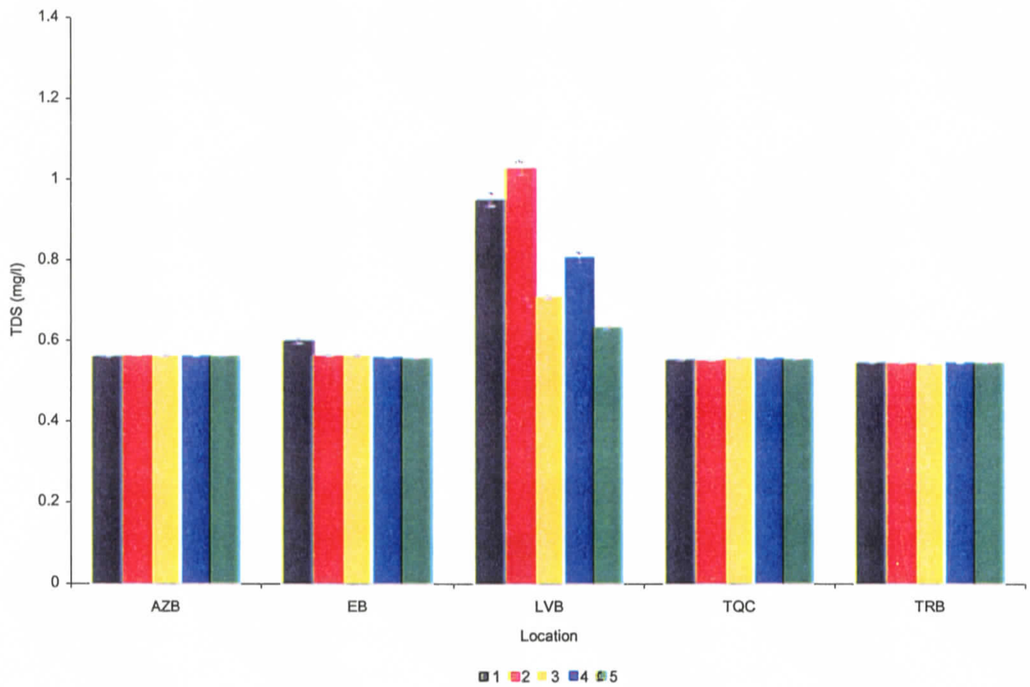
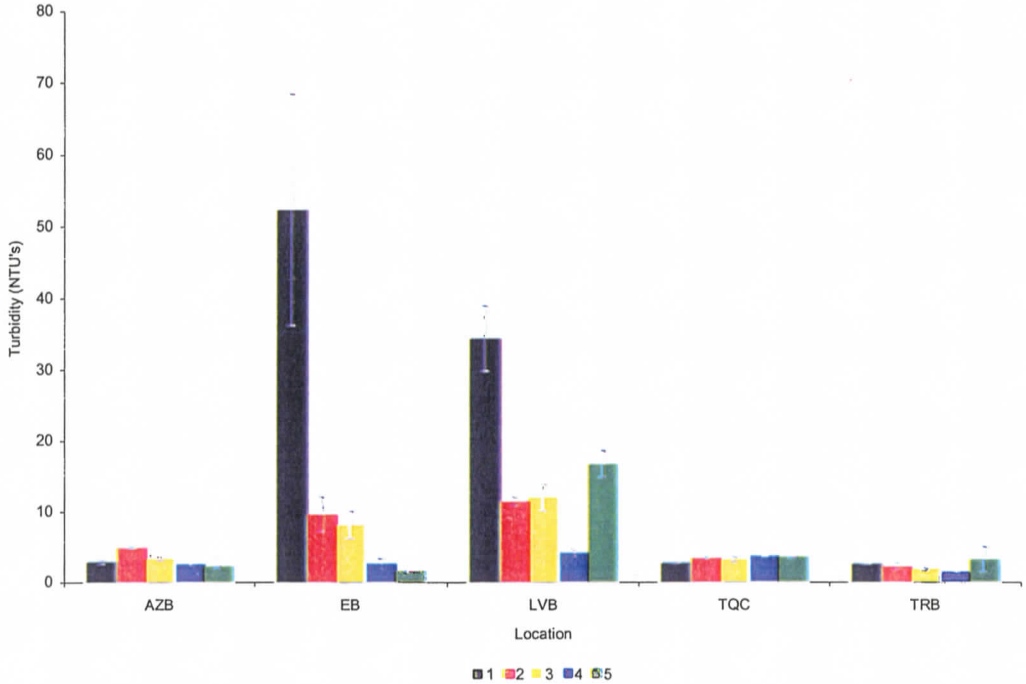


Figure 13. **Mean amount of total dissolved solids (TDS) at all sites in (a) March 2001 and (b) May 2001.**



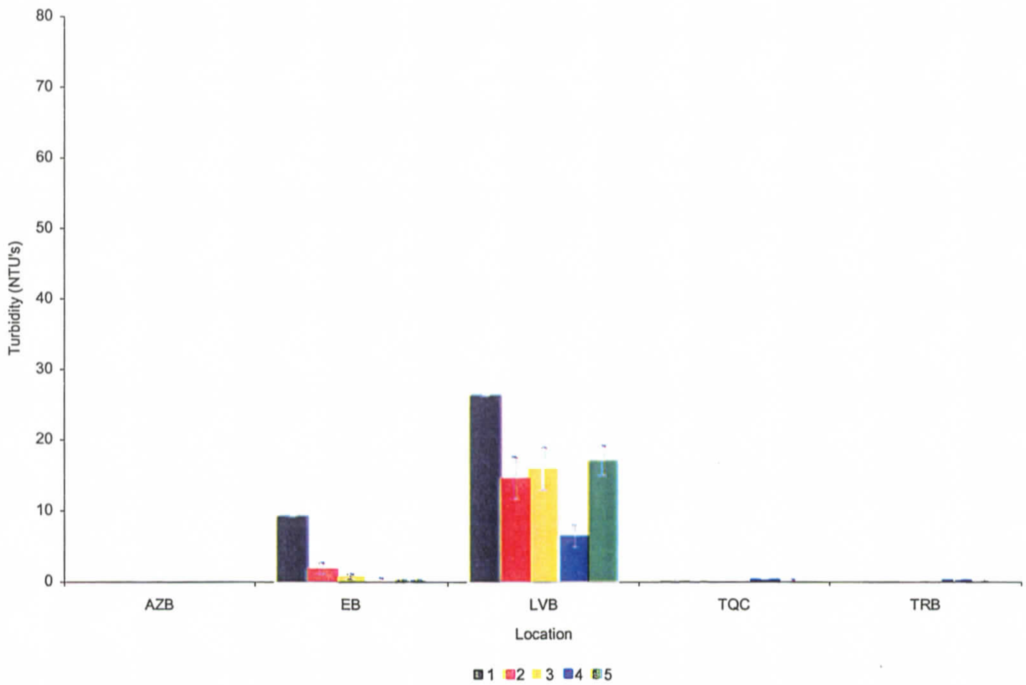
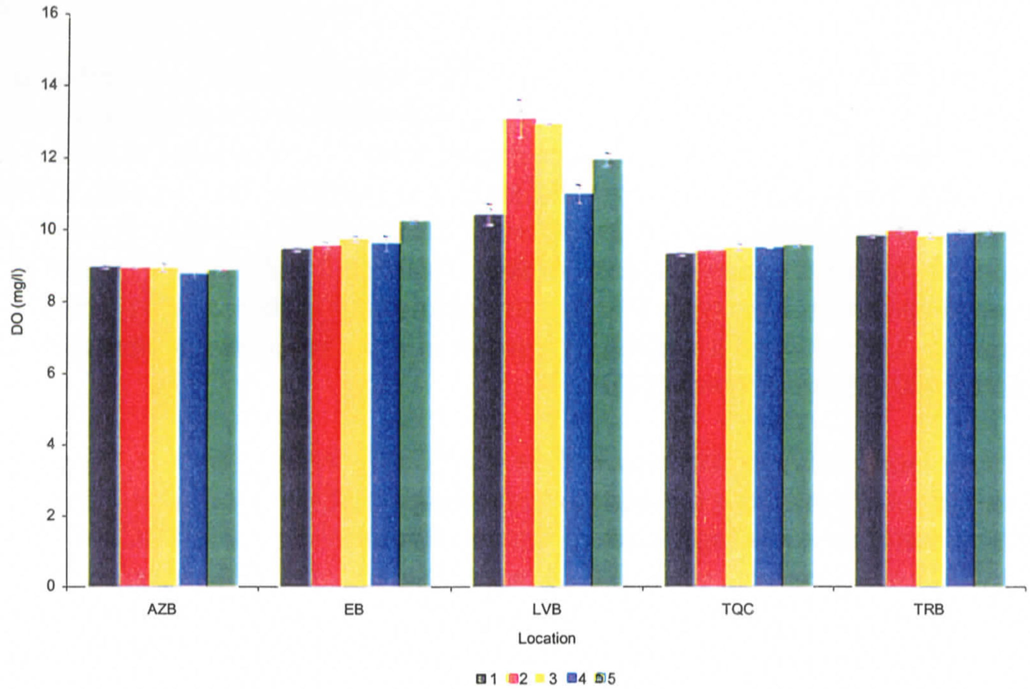


Figure 14. **Mean amount of turbidity at all sites in (a) March 2001 and (b) May 2001.**



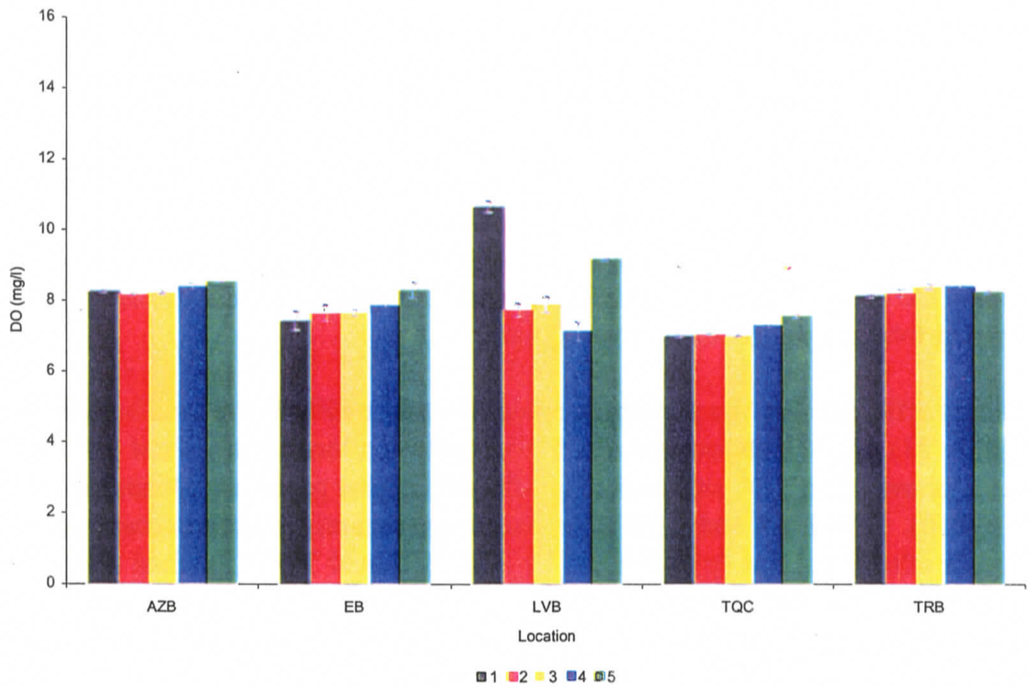


Figure 15. Mean amount of dissolved oxygen (DO) at all sites in (a) March 2001 and (b) May 2001.

Zooplankton

In March 2001 mean density of zooplankton at LVB and TQC was significantly higher than at TRB and EB (Figure 16, $p<0.001$). However, the variability at sites within locations was very high. For example, mean zooplankton density at LVB sites ranged from 27 organisms/l at LVB 5 to 99 organisms/l at LVB 4. When the data were analyzed looking at individual stations, only LVB 4 had significantly higher zooplankton density than stations at TRB and EB ($p<0.05$). The LVB 4 site also had significantly higher mean zooplankton density than AZB 2 and 3 ($p\leq0.01$). For all sites combined, mean zooplankton density in March was significantly higher in 2001 ($p<0.05$), but within locations only LVB showed a significant increase in mean zooplankton density in March 2001 over March 2000 (Figure 17, $p<0.001$).

In May 2001 mean zooplankton density was highest at LVB (Figure 18, $p<0.001$). Additionally, overall mean density of zooplankton was significantly higher at TQC than at AZB, EB, and TRB ($p\leq0.021$). Again variability was high between sites within locations. The TQC 3 site had an average density of 10.8 organisms/l, while LVB 4 had an average of 44.4 organisms/l. Site TQC 4 had the highest density of zooplankton, which was significantly higher than all other sites except LVB 2, 3, and 5 ($p\leq0.007$). For all sites combined, mean zooplankton density in May was significantly higher in 2001 ($p<0.001$), and the AZB, LVB, and TQC locations had a significantly higher mean zooplankton density in May 2001 over May 2000 (Figure 19, $p\leq0.016$).

Trends in small zooplankton density($\leq$ 0.3 mm) were similar to those seen for total zooplankton density (Figure 20). In March 2001, total small zooplankton density was significantly higher at LVB and TQC than at EB and TRB ($p\leq0.003$). However, variability between individual sites was so high no significance was seen in the location*site interaction term of the ANOVA model. Small zooplankton density in May 2001 was lower than in March at all sites. In May, LVB and TQC had higher total small zooplankton density than AZB, EB, and TRB ($p<0.001$). Some significant differences were seen between sites, but they all involved individual LVB and TQC sites being higher than sites at the other three locations. The number of small zooplankton/l also showed the same differences as total zooplankton/l between years.

We saw significant differences in the percent composition of the different taxa in both March and May 2001 (Figure 21). In March we saw differences between locations but not between Lake Mead and Lake Mohave. The TQC sites had a significantly higher percent of Bosminidae than all other sites ($p\leq0.016$). The LVB and TRB sites had a significantly higher percentage of adult Copepoda than all other locations ($p\leq0.006$). The AZB, EB, and TQC sites had a significantly higher percent composition of Copepod nauplii than all other sites ($p\leq0.037$). The EB sites also had a significantly higher percentage of combined Cladoceran and Copepod eggs than LVB, TQC, and TRB ($p\leq0.02$).

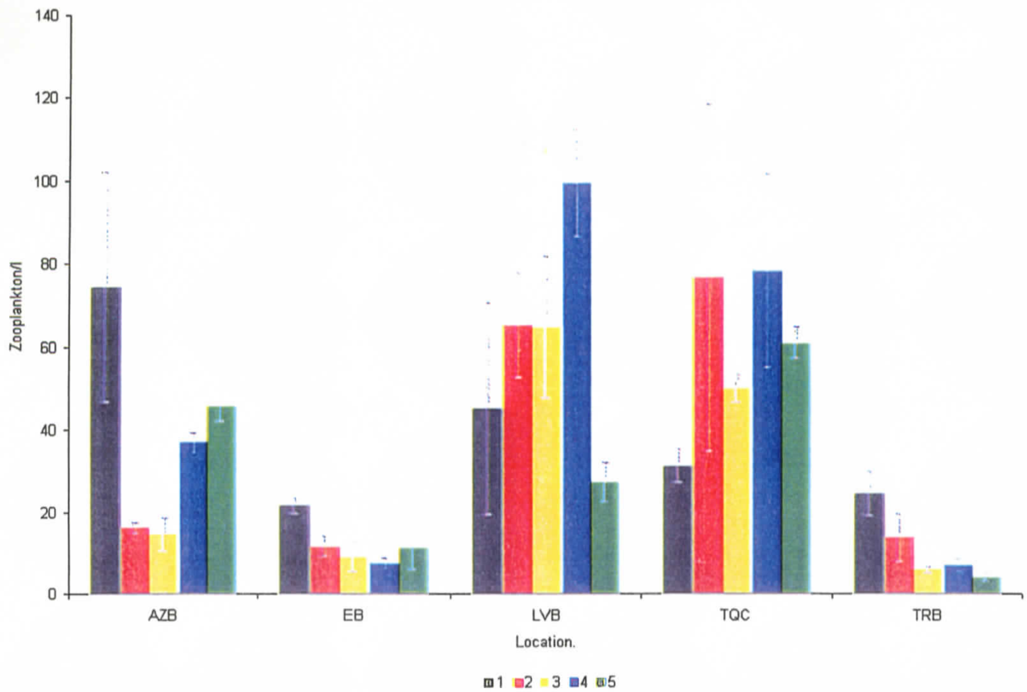


Figure 16. **Mean number of zooplankton per liter at each site in March 2001.**

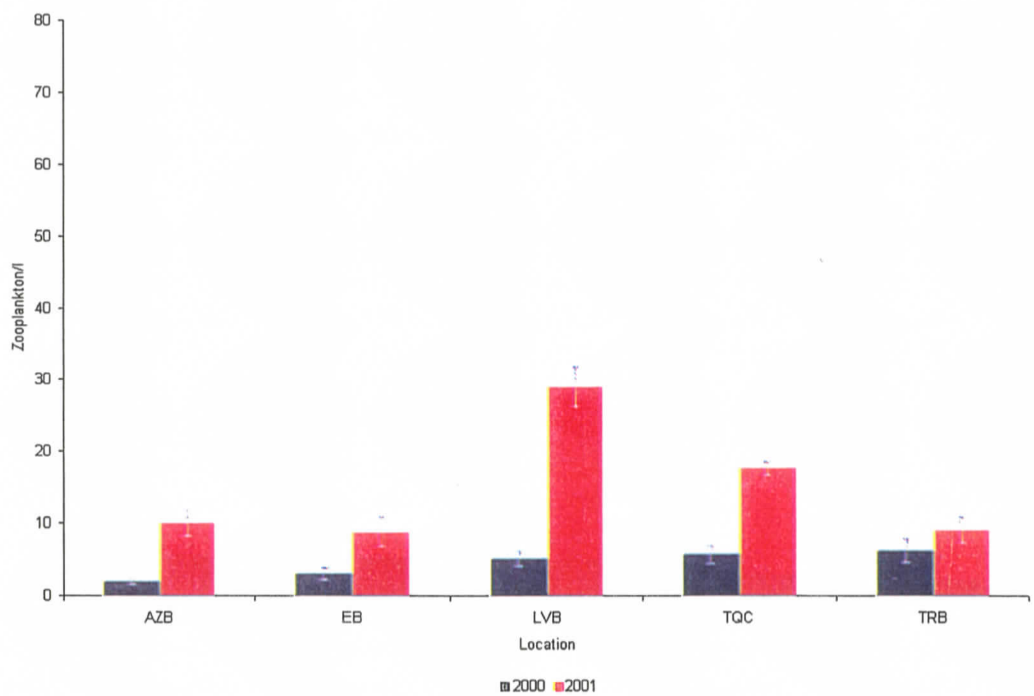


Figure 17. **Comparison of the mean number of zooplankton per liter between years at each location in March.**

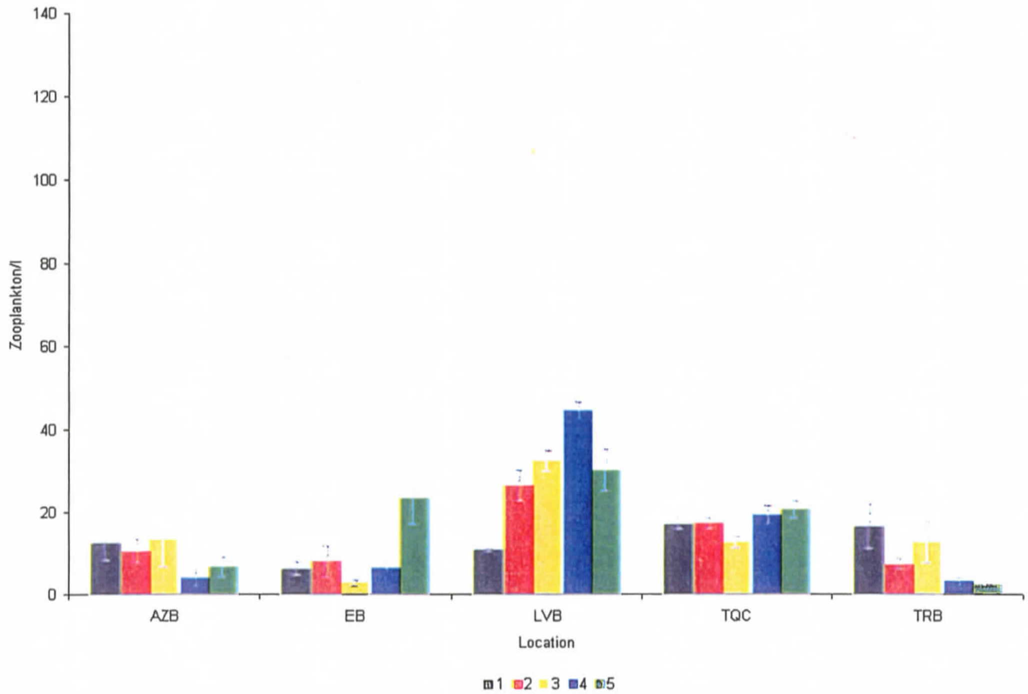


Figure 18. Mean number of zooplankton per liter at each site in May 2001.

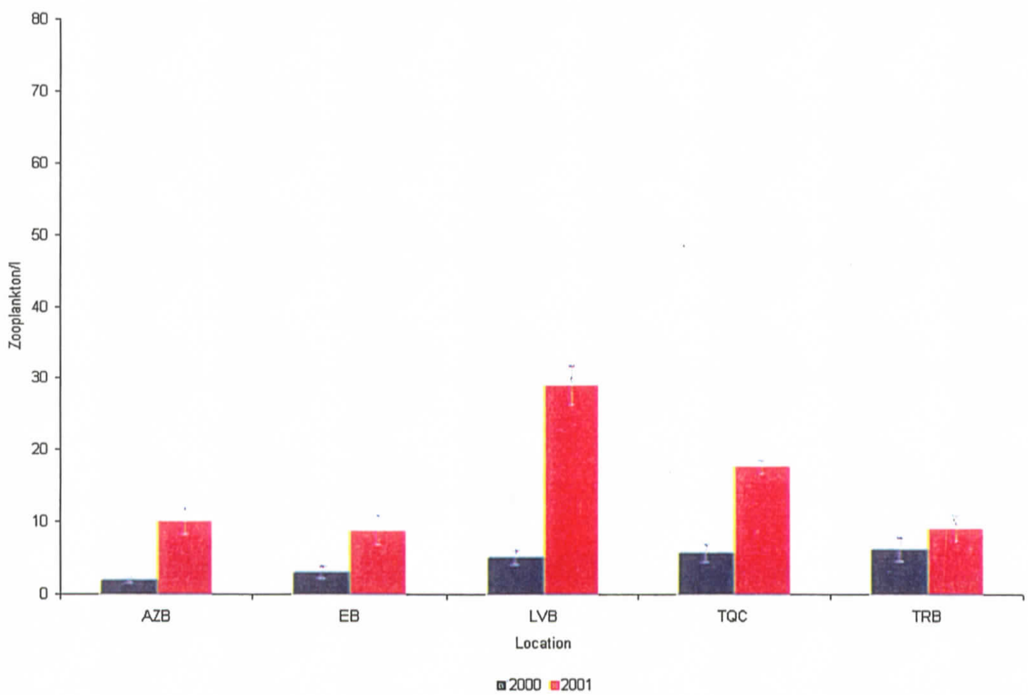


Figure 19. Comparison of the mean number of zooplankton per liter between years at each location in May.

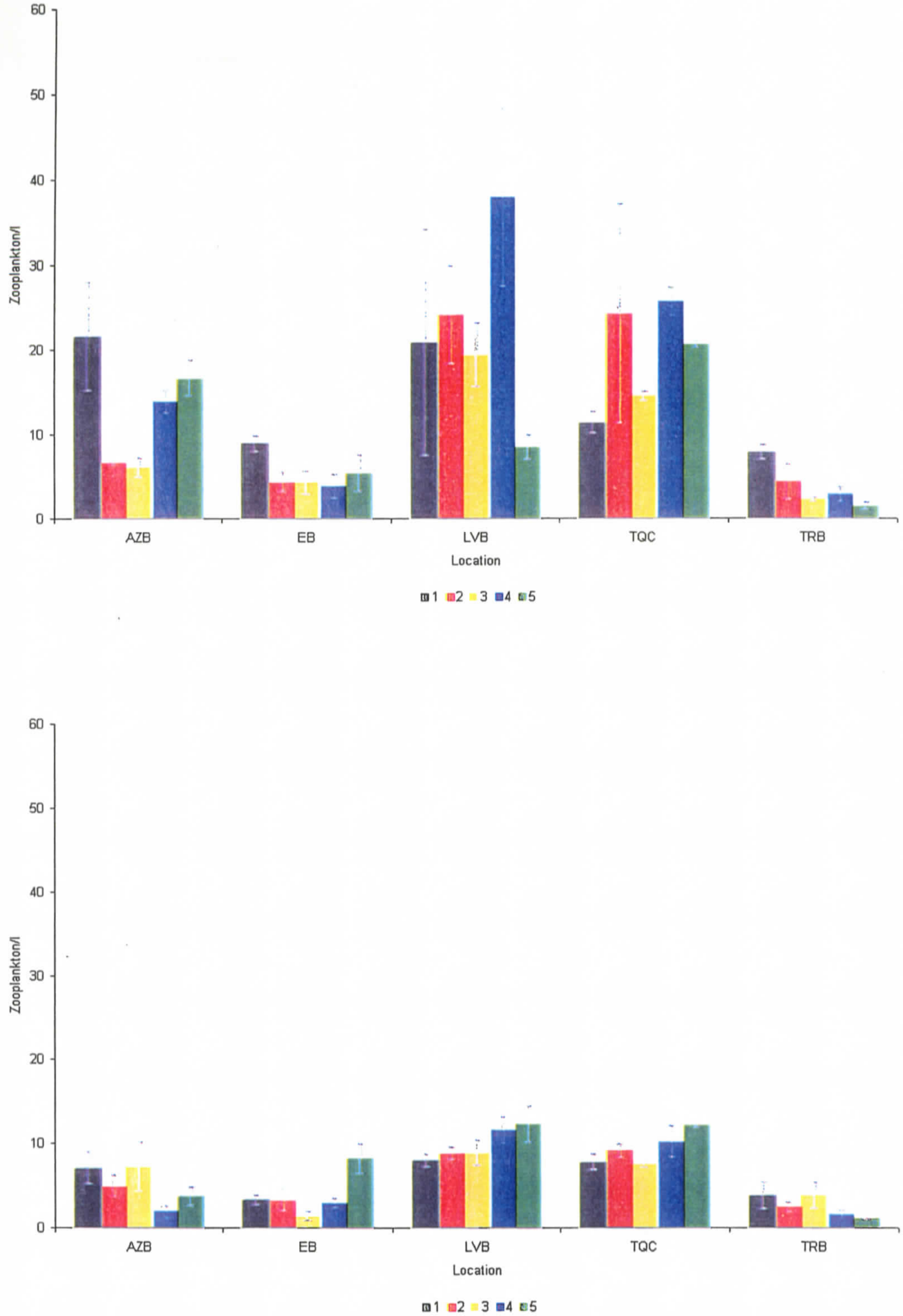


Figure 20. **Mean number of small zooplankton per liter at each site in (a) March 2001 and (b) May 2001.**

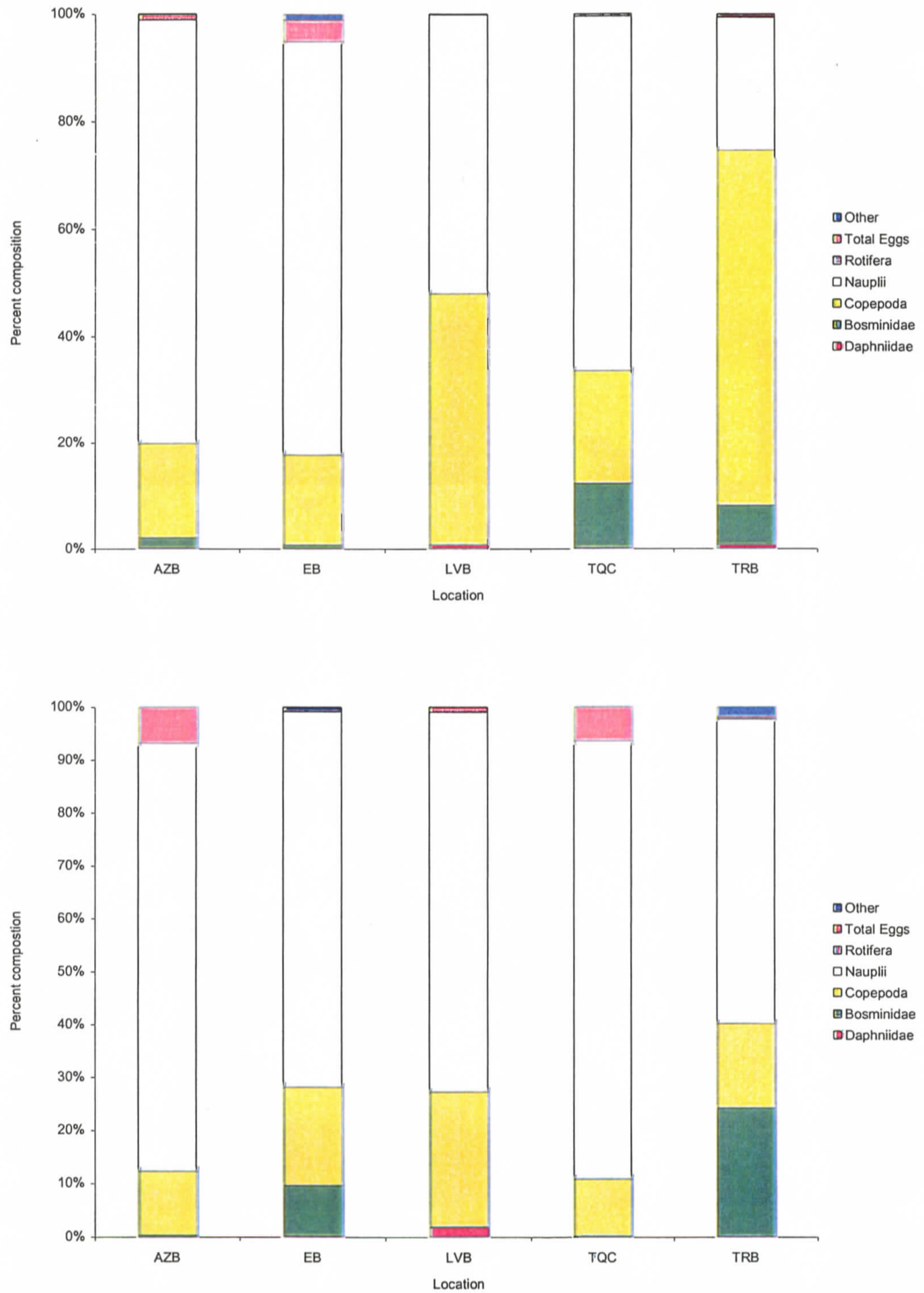


Figure 21. Percent composition of each taxa at each location in (a) March 2001 and (b) May 2001.

In May Lake Mead sites seemed to have a larger percentage of Copepoda than Lake Mohave sites, but the difference was only significant for LVB and EB ($p \leq 0.04$). The LVB sites also had a significantly higher percentage of Daphniidae than all other sites ($p<0.001$). The TRB sites had a significantly higher percentage of Bosminidae than all other sites ($p<0.001$) but a significantly lower percentage of Copepod nauplii ($p \leq 0.034$). The Lake Mohave sites had a higher percentage of combined Cladoceran and Copepoda eggs, but the difference was only significant at AZB ($p<0.001$).

Adult Copepoda and Copepod nauplii dominated the zooplankton at all locations in March and May 2001. Conversely, in 2000, Cladocerans in the family Bosminidae and Daphniidae made up a large proportion of the taxa at some locations. Paired t-tests, modified for unequal variances and using Bonferroni adjusted probabilities, showed that the percentage of Copepod nauplii was significantly higher at all locations in March and May 2001 versus March and May 2000. The percentage of Daphniidae was significantly higher in 2000 at LVB in March and May than in 2001 ($p \leq 0.005$). At the Lake Mohave sites, the percentage of Bosminidae was significantly higher in March and May 2000 than 2001 ($p \leq 0.003$).

Cover

Table 1 shows the results of the estimates of cover at all sites within all locations. The dropping lake levels between March and May 2001 changed the amount of area sampled in May versus March at all the Lake Mead locations. The EB 1 site provides the most drastic example of this phenomenon, losing over 42% of the area sampled between March and May. Average lake elevation declined by over 7 feet, from 1,194.68 in March 2001 to 1,187.32 in May 2001 (Figure 22).

The percent cover at LVB was not significantly higher than any of the other sites in March or May of 2001 (Figure 23). In March EB had significantly higher percent cover than TQC ($p = 0.004$), but in May none of the sites differed in mean percent cover. The possibility exists that LVB cover may have been underestimated because of poor visibility caused by an algae bloom. However, we feel that cover was still lower at LVB in 2001 than in 2000. While paired t-tests revealed no significant differences in percent cover between years at each location, LVB and EB both saw large reductions in cover between March 2000 and May 2001(Figure 24). Lake elevation lowered by about 24 feet over this time period (Figure 22).

Table 1. **Area, area with cover, and percent cover estimates for all sites within each location in March and May 2001.**

Year	Location	Site	March Area	May Area	March Cover	May Cover	March % Cover	May % Cover
2001	AZB[a]	1	3,900	3,900	28.5	28.5	0.73	0.73
2001	AZB	2	4,000	4,000	533.4	771.8	13.3	19.29
2001	AZB	3	4,000	4,000	981.25	1195	24.53	29.88
2001	AZB	4	4,000	4,000	0	0	0	0
2001	AZB	5	4,000	4,000	47.7	118.95	1.19	2.97
2001	EB[b]	1	4,137	2,377	439	36.4	10.6	1.5
2001	EB	2	3,445	3,052.5	453.65	306.2	13.17	10.03
2001	EB	3	3,440	2,535	836.1	424.45	24.3	16.74
2001	EB	4	3,287.5	2,821.5	558.73	436.83	17	15.48
2001	EB	5	3,410	2,962.5	630	323	18.48	10.9
2001	LVB[c]	1	2,950	2,660	131.3	38.4	4.5	1.4
2001	LVB	2	3,325	2,875	273.9	171.05	8.2	5.9
2001	LVB	3	3,230	2,410	163.75	35	5.1	1.5
2001	LVB	4	3,200	1,965	489	223.78	15.28	11.39
2001	LVB	5	3,775	3,498	236.03	161.15	6.25	4.61
2001	TQC[d]	1	3,800	3,800	73	201.25	1.92	5.3
2001	TQC	2	4,000	4,000	108	138.88	2.7	3.5
2001	TQC	3	3,500	3,500	4	52.92	0.11	1.5
2001	TQC	4	2,700	2,700	7.2	44.25	0.27	1.6
2001	TQC	5	3,400	3,400	7.2	7.2	0.21	0.21
2001	TRB[e]	1	3,400	2,480	315.95	126.8	9.29	5.1
2001	TRB	2	3,300	2,868	76.23	40.5	2.3	1.4
2001	TRB	3	3,137.5	2,512.5	119	71.2	3.79	2.83
2001	TRB	4	2,607.5	1,932.5	154.18	92.5	5.91	4.8
2001	TRB	5	3,125	2,385	312.38	95.63	10	4.01

[a] Arizona Bay.
[b] Echo Bay.
[c] Las Vegas Bay.
[d] Tequila Cove.
[e] Trail Rapids Bay.

Figure 22. Mean monthly elevations of Lake Mead (1975-2001).

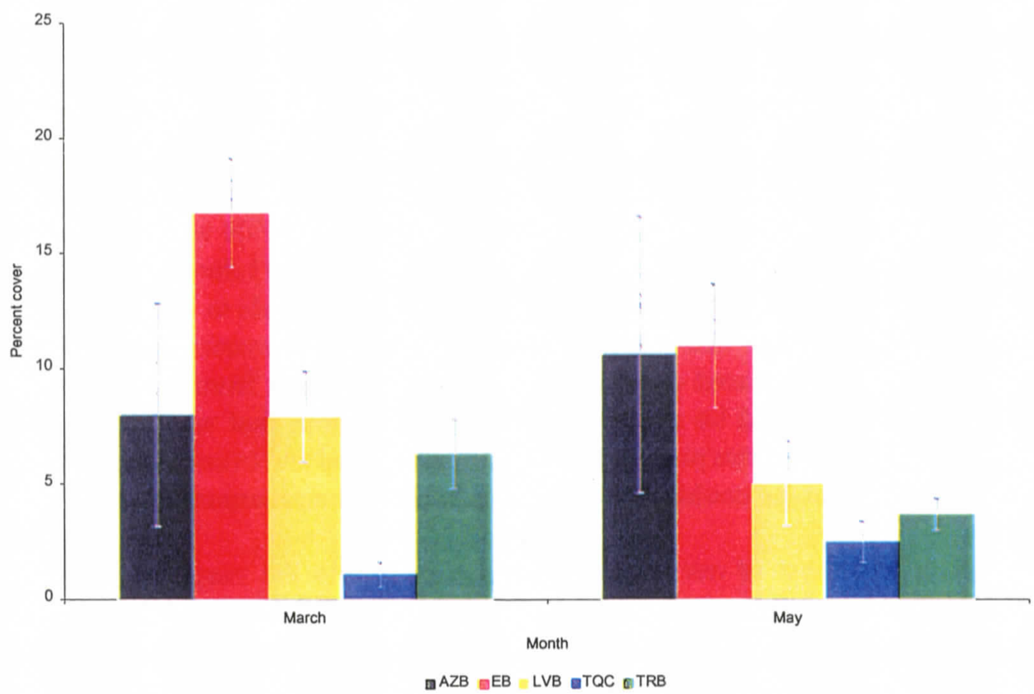


Figure 23. Mean percent cover at each location in March and May 2001.

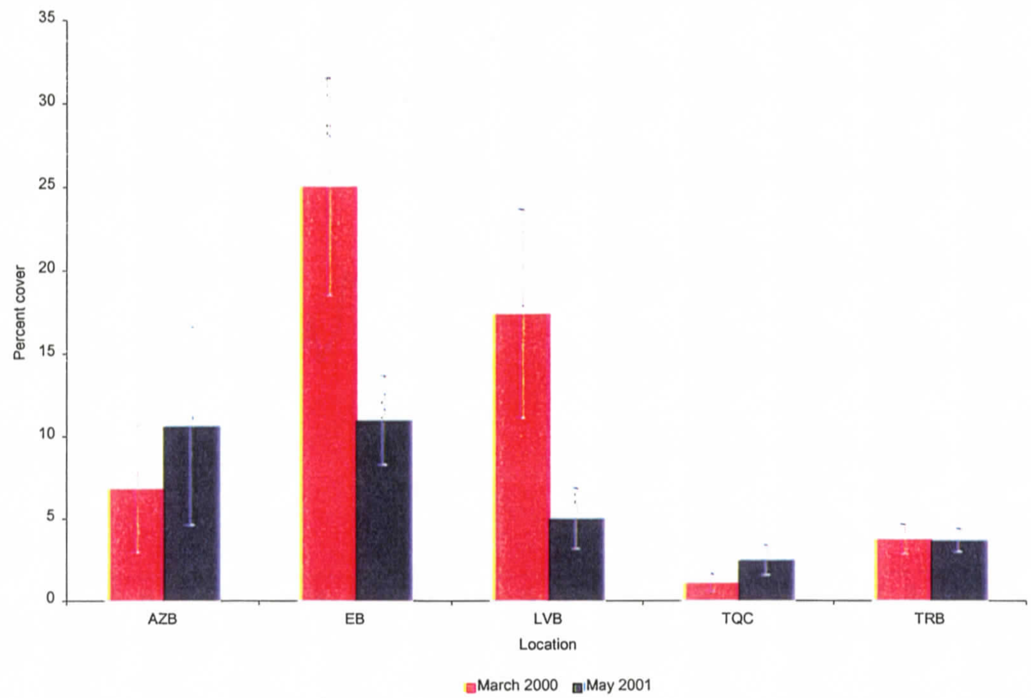


Figure 24. Mean percent cover at each location in March 2000 versus May 2001.

Discussion

Similar to last year, we found that sites in LVB had significantly higher amounts of nutrients than all the other locations. We also saw that the amounts of total P and NH^4-N were higher in 2001 versus measurements made in 2000, especially at LVB. The SNWA(2001) also saw higher surface levels of total P in spring 2001 at LVB. They attributed these higher levels to increased sediment transport from construction around Las Vegas Wash and spring storm events, lower lake levels concentrating nutrients, and increased overflow and shallow interflow from Las Vegas Wash. Increased ammonium levels could be explained by the algae bloom that was concentrated in Boulder Basin, evidence of which was present throughout Lake Mead and even into Lake Mohave. Decomposition of the dying algae could have resulted in increased ammonium levels.

As was the case in 2000, most of our measurements were within the range of nitrogen and phosphorus values found by other researchers (LaBounty et al. 1998; Holdren et al. 1998; Southern Nevada Water Authority 2001, 2002). While LVB had consistently higher values for all nutrients, for the most part EB had similar nutrient levels to the other three locations. However, total P levels in March 2001 seemed to be slightly higher at EB than at either of the Lake Mohave locations and TRB. Overall, the results from the 2001 study still indicate that LVB is the only Lake Mead location that might have higher nutrient levels than Lake Mohave. Historical data collected on the two reservoirs supports this assertion (e.g., Paulson et al. 1980, Paulson and Baker 1984).

Since LVB had significantly higher nutrient levels than the rest of the locations, we might expect to find higher numbers of zooplankton at this location. While this expectation was not borne out in the data from 2000, the data from March and May 2001 showed that overall mean density of zooplankton was significantly higher at LVB. Food availability was cited as a factor impacting razorback sucker recruitment in Lake Mohave, so an increase in zooplankton density could improve the odds for recruitment at LVB (Marsh and Langhorst 1988, Papoulias and Minckley 1990). However, EB had lower zooplankton densities than most of the other locations, indicating that the total number of zooplankton per liter is not the predominant reason for razorback sucker recruitment, at least at EB.

The densities we saw at LVB in 2001 were within the range of those seen by the SNWA (2001). However, mean zooplankton density was higher at all locations in March and May 2001 than in March and May 2000. The large algal bloom that occurred throughout the system from February to June 2001 may have provided an increased food supply for zooplankters. Additionally, the concentration of nutrients and food caused by the lowering lake levels could also have increased zooplankton production in Lake Mead. However, in 2000 we sampled with a 153 μm mesh net, while in 2001 we switched to an a 80 μm mesh net to be more consistent with other researchers (Paulson et al. 1980, Sollberger and Paulson 1992, Baker et al. 1997). The confounding factor of switching to a smaller mesh size makes it difficult to infer anything about the increased numbers of zooplankton in 2001.

Adult Copepoda and copepod nauplii dominated the zooplankton samples at all locations in each month in 2001. Again, this differs from the 2000 results, when the March samples from the Lake Mohave locations were dominated by Cladocerans of the family Bosminidae, as were the May samples at TRB. Marsh and Langhorst (1988) showed selectivity for certain taxa and sizes of zooplankters by razorback sucker larvae in Lake Mohave and backwater areas off of Lake Mohave. They found that larvae selected for the Cladoceran *Bosmina* spp. in both areas. Therefore, the differences we saw in communities between locations and years could potentially influence the razorback sucker growth and survival. The SNWA (2001) noted that the zooplankton community of the LVB and Boulder Basin areas of Lake Mead is dominated by Copepoda, with a summer bloom of Rotifera. Switching to a smaller mesh size could have resulted in the increased numbers of the smaller Copepod nauplii we observed in 2001. Unfortunately, the smaller mesh size also confounds interpretation of this result.

Papoulias and Minckley (1992) found that razorback sucker larvae selected for certain food items, mainly on the basis of size. While we found no consistent differences in the amount of small zooplankton between our five locations in 2000, the mean number of small zooplankton/l followed the same trend as the total number of zooplankton per liter in 2001, with LVB and TQC having higher numbers of small zooplankton. The high numbers of Copepod nauplii represented a large proportion of the small zooplankton. Papoulias and Minckley (1990) identified an average density of small zooplankton between 10 to 20 items/l, as critical for the recruitment success of larval razorback sucker. Average density of small zooplankton was higher than 10 items/l in March at LVB, TQC, and AZB, and close to that level at LVB and TQC in May. However, at EB and TRB average density of small zooplankton was well below 10 items /l in March and May 2001. Therefore, as we saw in 2000, food quantity and quality could have some influence on razorback sucker recruitment at these locations, but at EB, where we know recruitment occurs, we found densities equal to or lower than all the other locations sampled.

As in 2000 our sampling had the limitation of not providing a comprehensive picture of the range of zooplankton found at these sites. The study produced two small "snapshots" of zooplankton densities throughout the spawning season on which to base our conclusions. However, other data from LVB indicate that we were well within the range of zooplankton density and the species composition found at this location throughout the spring (SNWA 2001). Therefore, we feel that while the limited sampling does not provide extensive data about the range of density and species present throughout the spawning period, at least it can act as an index of the zooplankton composition and abundance for that particular year.

Data from 2001 generally reinforced our conclusions from 2000. Once again, zooplankton density at LVB, while being on the upper end, was not substantially higher than at some of the other locations. Our sampling data from 2000 and 2001, along with historical data, showed that zooplankton density at EB was fairly low compared with most of the other locations. We can infer from this that differences in food availability between the five locations probably do not account for the recruitment of razorback sucker at LVB and EB. However, in 2001 we did see that higher productivity at LVB was evident in higher zooplankton densities during the spawning season in both our data and data collected by the SNWA (2001). Therefore, the influx of nutrients from Las Vegas Wash may play a role in larval razorback sucker survival at LVB during certain years.

Las Vegas Wash provides the largest nutrient input to Lake Mead (Baker et al. 1977, Sartoris and Roline 1993). The nutrient input from Las Vegas Wash is often carried in a density current out into Boulder Basin (Tew et al. 1976, Fischer and Smith 1983, LaBounty and Horn 1997). Water in Boulder Basin can easily continue downstream through Hoover Dam into Lake Mohave. Therefore, AZB and TQC may see the results of large nutrient inputs from Las Vegas Wash. Conversely, EB and TRB are in areas relatively unaffected by Las Vegas Wash. Echo Bay would be most influenced by inputs from the Muddy River and Virgin River inflows, and TRB would be most influenced by the Colorado River inflow. All three of these inflows are far less nutrient laden than Las Vegas Wash (Baker et al. 1977). The location of these areas in relation to nutrient sources helps explain the differences seen in water quality and productivity.

Results from the 2000 sampling indicated that increased amounts of cover in the form of submerged vegetation, was the main variable distinguishing EB and LVB from the remaining locations sampled for this project. We concluded that the long-term lake level fluctuations in Lake Mead may result in larger amounts of cover. Since predation on razorback sucker eggs and larvae by nonnative fishes has been established as one of the main factors impacting razorback sucker recruitment (Loudermilk 1985, Langhorst 1987, Marsh and Langhorst 1988, Hawkins and Nesler 1991, Lentsch et al. 1996, Holden et al. 1999), then the increased protection afforded by cover for larval and juvenile sucker could increase their probability of recruitment. In 2001 we found that the amounts of cover were substantially reduced from those seen in 2000 at EB and LVB. By May 2001 neither EB or LVB had significantly higher amounts of cover than any of the other locations.

The decline in the amount of cover available at EB and LVB is directly related to the long-term lake level fluctuations of Lake Mead. Lake level declined by over 24 feet between March of 2000 and May 2001. We expected that during periods of low water on Lake Mead less cover would be available. Conversely, while lake elevation is low, vegetation (e.g., *Tamarix* sp. [salt cedar], *Scirpus* sp. [bullrush], and *Typha* sp. [cattails]) is growing in along the shoreline. When Lake Mead water levels begin to rise, this vegetation will be inundated and become a source of cover for larval razorback sucker. Therefore, while EB and LVB had lower amounts of cover in 2001, the cycle of prolonged lake level elevation changes will provide increased cover for larval and juvenile razorback sucker in the future.

We also found that EB and LVB had higher levels turbidity than all of the other locations we sampled. Turbidity at LVB is probably the result of the increased TDS and sediment load carried by the Las Vegas Wash inflow. No clear cut explanation is available for EB. Wind action, combined with the configuration of EB and the predominantly silt bottom, may be the reason that EB shows higher turbidity at certain times. The SNWA (2001) measured secchi disk depths as low as 1.5 m in LVB. We saw secchi disk visibility as low as 0.5 m in May 2001. We also saw secchi disk visibilities as low as 0.9 m at EB. Conversely, the lowest secchi disk visibility we saw at the Lake Mohave locations was 6.5 m. Higher turbidity at LVB and EB may act as another form of protection from predation on larval and juvenile razorback sucker. The large algal bloom in LVB and Boulder Basin added to the decreased visibility in this area. The algal bloom could have provided increased cover and food for young razorback sucker this year.

The first 2 years of this study provided some conflicting results, but the results make sense in the context of our larger hypotheses. As expected, LVB has higher nutrient levels than all other locations. However, it does not appear as though LVB has substantially higher zooplankton densities than those found at the Lake Mohave sampling locations. When we view this along with the fact that EB has had a lower density of zooplankton than the Lake Mohave locations in both the years sampled, it appears that the food quality and quantity are not the major factors allowing razorback sucker to recruit in Lake Mead. Cover, whether in the form of vegetation or turbidity, seems to be the key parameter differentiating EB and LVB from the other locations sampled. Additionally, we believe that the decrease in cover at EB and LVB in 2001 supports our hypothesis that the long-term lake level fluctuations of Lake Mead play an important role in the ability of razorback sucker to recruit and persist in the reservoir.

Recommendations for Future Study

Data from the first 2 years of this study support the assertion that fluctuating lake levels have a major influence on the environmental conditions experienced by razorback sucker at LVB and EB. If razorback sucker are only recruiting in certain years, as evidenced by the aging data from Holden et al. (2000b, 2001), then certain conditions advantageous to recruitment must prevail during those years. Therefore, we recommend continuing the current investigation to examine the differences in cover and productivity at EB and LVB, along with our other three locations. Additionally, we recommend sampling at the Colorado River inflow area if further research can confirm the existence of a spawning population of razorback sucker in that area.

We believe that continuing to collect data over multiple years will provide a more-complete view of the conditions that occur at these locations at different lake levels. Nutrients and zooplankton appear to become more concentrated at low water levels, thereby offering higher food availability, but this might be offset by concentrating nonnative predators in a smaller area and reducing cover. Hopefully, we can begin to correlate the information on productivity and cover with recruitment of razorback sucker, through the continued collection and aging of juvenile razorback sucker in the larger Lake Mead study. Additionally, we can start to compare historical information on water quality, zooplankton density, and lake level with the peaks in recruitment we are beginning to see from adult population aging (Holden et al. 2000b, 2001). Cataloguing the conditions present in different years under different lake elevations and correlating them with the presence of a strong razorback sucker year class should identify what suite of factors is important in allowing razorback sucker recruitment in Lake Mead. Information on factors necessary for recruitment would assist in managing for the recovery of the species in the Lower Colorado River system.

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