
**Determining Conditions That Promote Razorback Sucker Recruitment
in Lake Mead:
A Summary of the 2000-2002 Pilot Study**

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EXECUTIVE SUMMARY

Las Vegas Bay and Echo Bay in Lake Mead have small, recruiting 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, razorback sucker reproduction has been documented in 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 in 2000 and 2001. The Lake Mohave locations were chosen because they are known to have razorback sucker reproduction but no recruitment. During the first 2 years 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 in 2000. However, dropping lake levels in 2001 substantially reduced cover at Echo Bay and Las Vegas Bay. We also compared turbidity, another possible source of cover for young razorback sucker, between locations in 2001. Again Echo Bay and Las Vegas Bay had significantly higher levels of turbidity. We hypothesized that increased vegetative cover and/or turbidity may provide larval and juvenile razorback suckers with protection from predation by nonnative fishes. We felt that the long-term lake level fluctuations in Lake Mead are probably responsible for the increased cover and suggested continued studies to find links between environmental conditions and razorback sucker recruitment.

In 2002 we continued to collect 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. The 2002 information generally reinforced what we had already surmised from the first 2 years of study: data from this 3-year pilot study indicate that while higher nutrient levels and increased food availability may help to increase razorback sucker recruitment at Las Vegas Bay, they are certainly not responsible for the recruitment seen at Echo Bay. Instead, a reduction in depredation of larval and juvenile razorback sucker, resulting from increased cover, seems to be the more probable mechanism allowing recruitment in these two locations.

We recommend examining the water level records and any water quality measurements relating to turbidity for Lake Mead to attempt to determine what years were probably good cover years for razorback sucker larvae and juveniles. Comparing these data with our existing aging data, and continuing to collect and age adult razorback suckers from Las Vegas Bay and Echo Bay, should enable us to determine if larger numbers of razorback suckers have recruited in years where more cover was present. Compiling this evidence should solidify the link between cover and recruitment.

We also recommend comparing cover types, cover density, and turbidity at Echo Bay and Las Vegas Bay with other coves that do not support razorback suckers. Such comparisons may help elucidate what cover types are necessary to facilitate recruitment. Additionally, gathering

information on cover and turbidity in bays throughout the lake would provide helpful information for any future attempts to repatriate hatchery-reared razorback suckers or locate additional populations of razorback sucker throughout Lake Mead.

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INTRODUCTION

In the early 1990s a remnant population of razorback sucker was discovered in Lake Mead. Research over the last 10 years has shown that two small populations of razorback sucker are actively recruiting in the Echo Bay (EB) and Las Vegas Bay (LVB) areas of Lake Mead (Holden et al. 1999, Holden et al. 2000a, Holden et al. 2000b, Holden et al. 2001, Abate et al. 2002). Conversely, a much larger Lake Mohave adult population is persisting through continuous rearing and stocking efforts by the U.S. Department of the Interior, Bureau of Reclamation. Little if any recruitment has been documented for the Lake Mohave population. Depredation of larval and juvenile razorback sucker by nonnative species is generally accepted to be the 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 pilot study to compare some of the suspected factors, including nutrient levels, zooplankton density, and available cover, at locations in both Lake Mead and Lake Mohave. We implemented the pilot study in spring 2000 and continued to collect data in 2001.

In addition to collecting data, we also reviewed literature pertaining to water quality and zooplankton abundance in the two reservoirs. The review showed that outside of the LVB area, nutrient and primary productivity values in Lake Mead are similar to and even sometimes lower than those found in Lake Mohave (Golden and Holden 2001). Conversely, the LVB area of Lake Mead is more productive than most other areas of Lake Mead and Lake Mohave, mainly because of the influence of Las Vegas Wash. The 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.

During spring 2000 and 2001, 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.

In 2000 the amount of cover seemed to be the only variable differentiating LVB and EB from the other three locations. The fact that this was the major factor separating the areas on Lake Mead with razorback sucker recruitment from other areas on Lake Mead and Lake Mohave supported 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 (Marsh and Langhorst 1988, Minckley et al. 1991, Golden and Holden 2001). The discovery that both EB and LVB also had significantly higher turbidity in 2001 also seemed to support the hypothesis that cover may be reducing depredation in these areas.

However, by May 2001 the amount of cover at LVB and EB was not significantly different from the other areas. Reservoir levels in Lake Mead were dramatically lower in 2001 than in 2000, and much of the dead terrestrial vegetation that had been submerged at 2000 reservoir levels was left on dry land as the reservoir receded over 2000-2001. We had also hypothesized that the increased cover we saw in 2000 at these two Lake Mead locations was the result of the longer-term water level fluctuations driven by climactic factors versus the annual regime of water fluctuation resulting from water demand on Lake Mohave (Golden and Holden 2001). The loss of cover we saw as the reservoir receded and the new growth of terrestrial vegetation we observed along the shore in 2001 supported this hypothesis (Golden and Holden 2002).

BIO-WEST recommended continuing cover and productivity studies, in conjunction with the larval and adult studies already ongoing on Lake Mead, to help further identify the exact years and sets of conditions that allow recruitment to take place. The following report presents findings from the third 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. Additionally, this report summarizes the findings from all 3 study years and draws conclusions from data collected throughout the 3-year project.

METHODS

We sampled the same general study locations as in the previous 2 years of study (Golden and Holden 2001, 2002): LVB, EB, and TRB in Lake Mead (Figure 1), and AZB and TQC in Lake Mohave (Figure 2). As in 2001 some of the study sites within the Lake Mead locations had to be changed in 2002 because lower lake elevations left some of the 2000 and 2001 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 2002 were distributed from the new Las Vegas Wash inflow to the south shore of LVB around Pitch Fork Cove (Figure 3). Only site 1 had to be completely moved from its 2001 location, but dropping water levels made parts of sites 1, 2, 4, and 5 unsampleable in May 2002. In EB the 2002 sites were relocated from what was site 2 in 2001 on the north shore to the Pumpphouse Bay area (Figure 4). At EB parts of site 1 were unsampleable in May because of dropping water levels. In TRB sites were relocated from the back of the bay against the wash to just outside the mouth on the south side (Figure 5). The sites in AZB remained similar to previous years being located from the southeast corner of AZB to the first cove north of Yuma Cove (Figure 6). As in previous years, 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 in 2002 occurred during March and May months when larval razorback sucker are typically available in both Lake Mead and Lake Mohave. Water quality measurements and zooplankton samples were taken at three locations within each site. 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 Lake Mohave. Therefore, we used the HydroLab Datasonde 4a and Surveyor 4 to measure turbidity and took some secchi disk depths during 2001 and 2002. We took one water 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. Net size was changed to 80 μm from 153 μm to conform more closely with other researcher's methods. 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 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.

Data Analysis

We used the statistical program SYSTAT to perform all analyses. We used an Analysis of Variance (ANOVA) to compare nutrient zooplankton and cover between sites, locations, and years. We used Tukey's Honestly Significant Difference follow-up procedure to examine all possible comparisons between means.

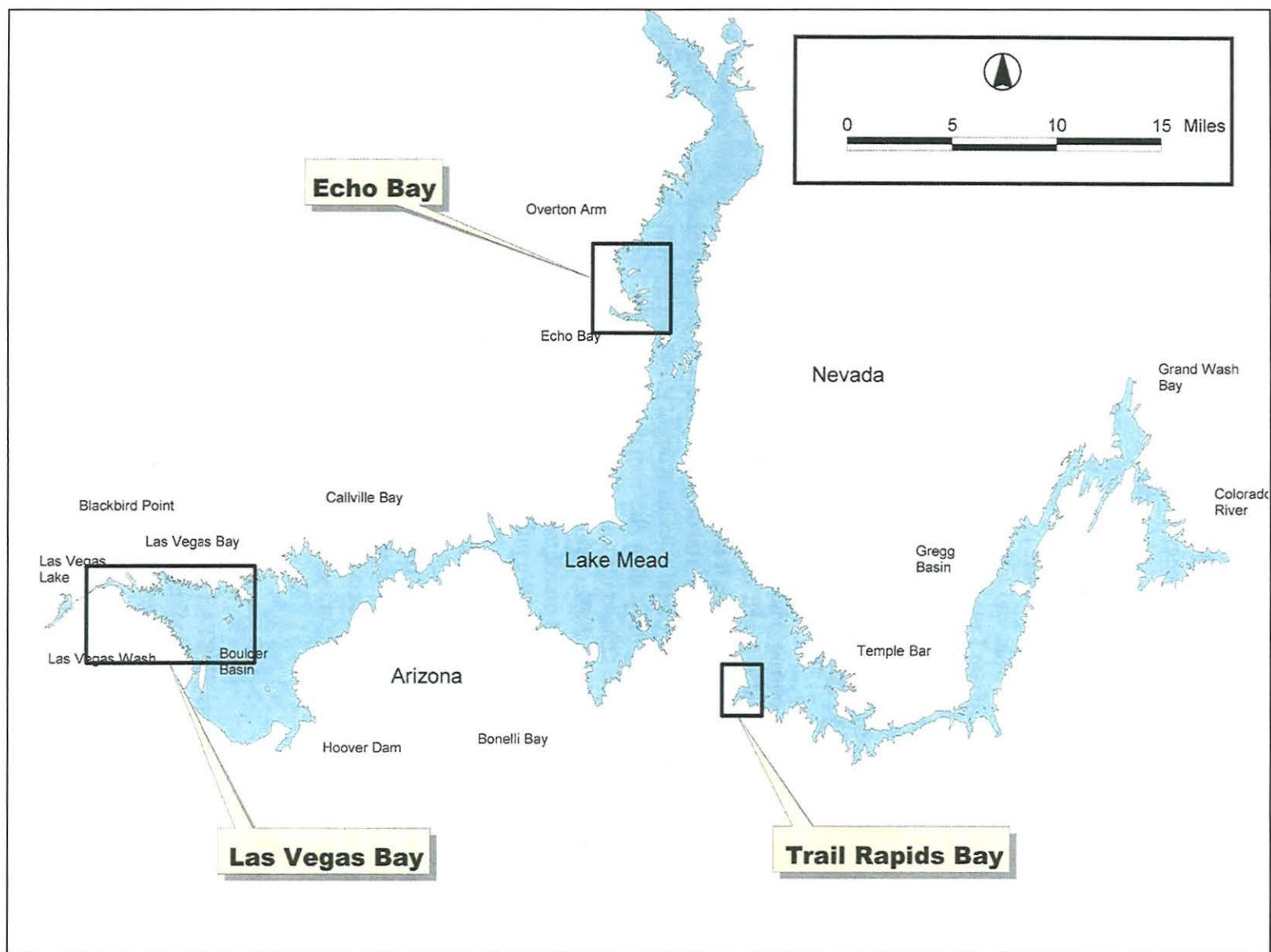


Figure 1. General sampling areas on Lake Mead.



Figure 2. General sampling areas on Lake Mohave.

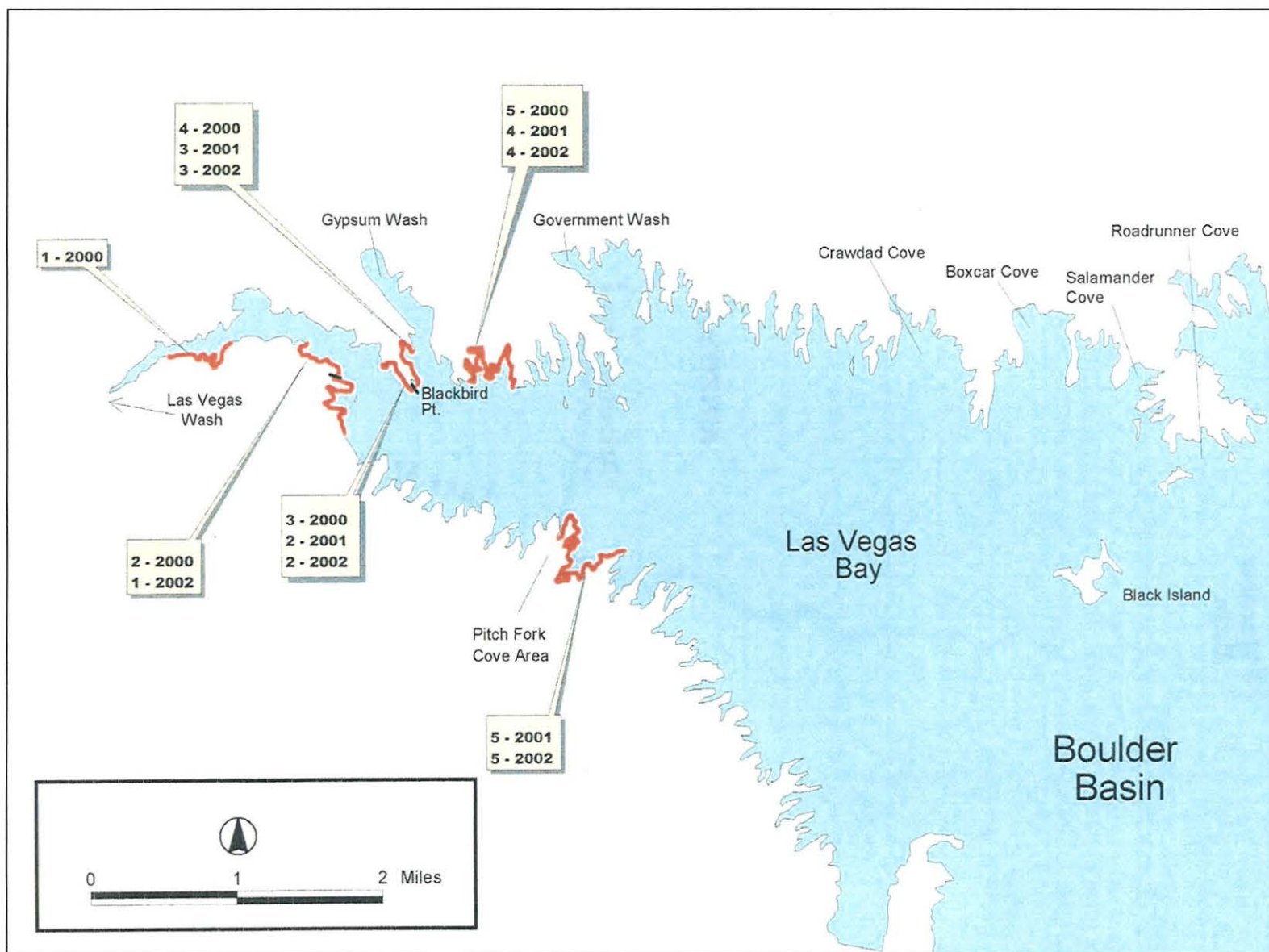


Figure 3. Las Vegas Bay (LVB) sampling areas in 2000-2002.

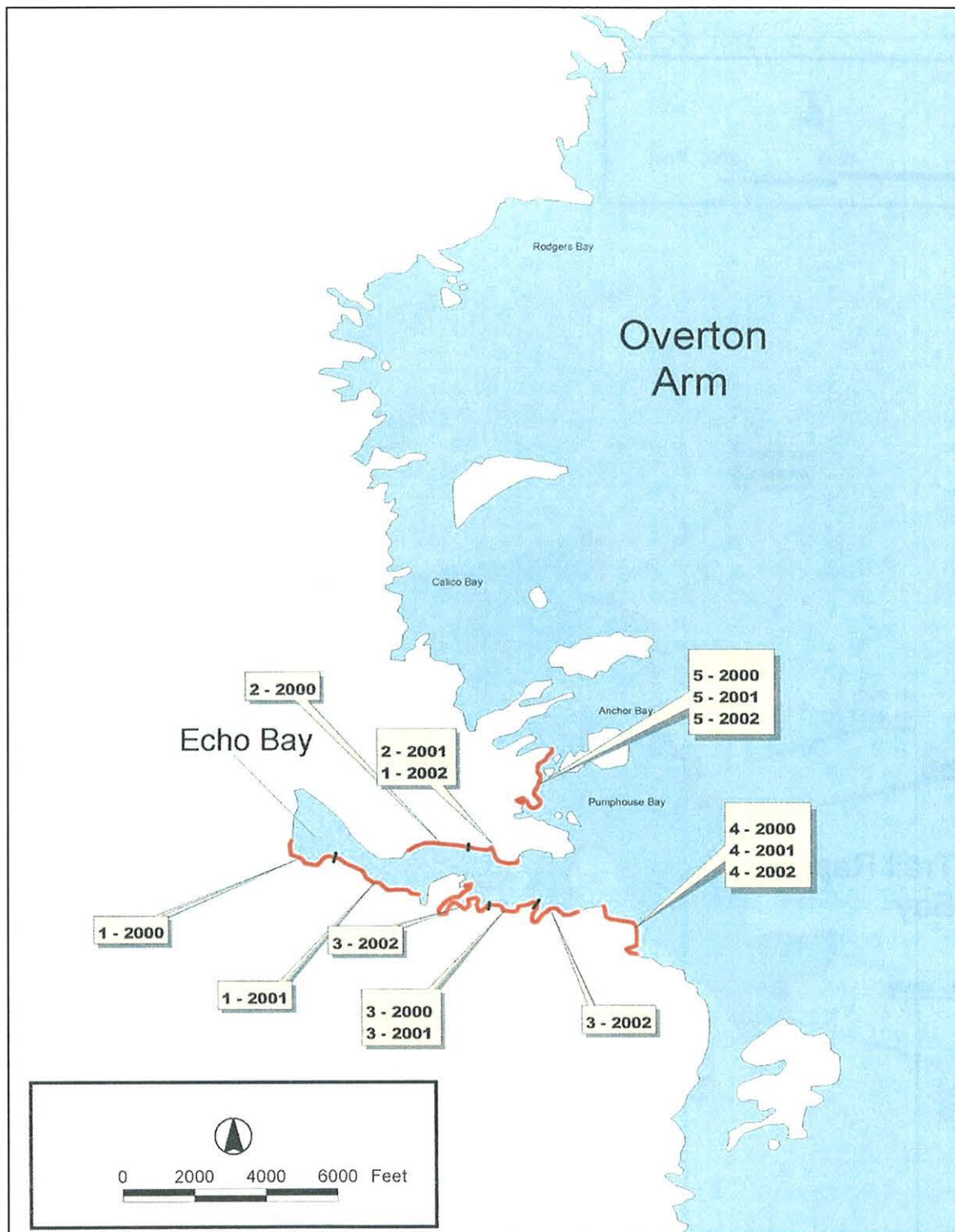


Figure 4. Echo Bay (EB) sampling areas in 2000-2002.

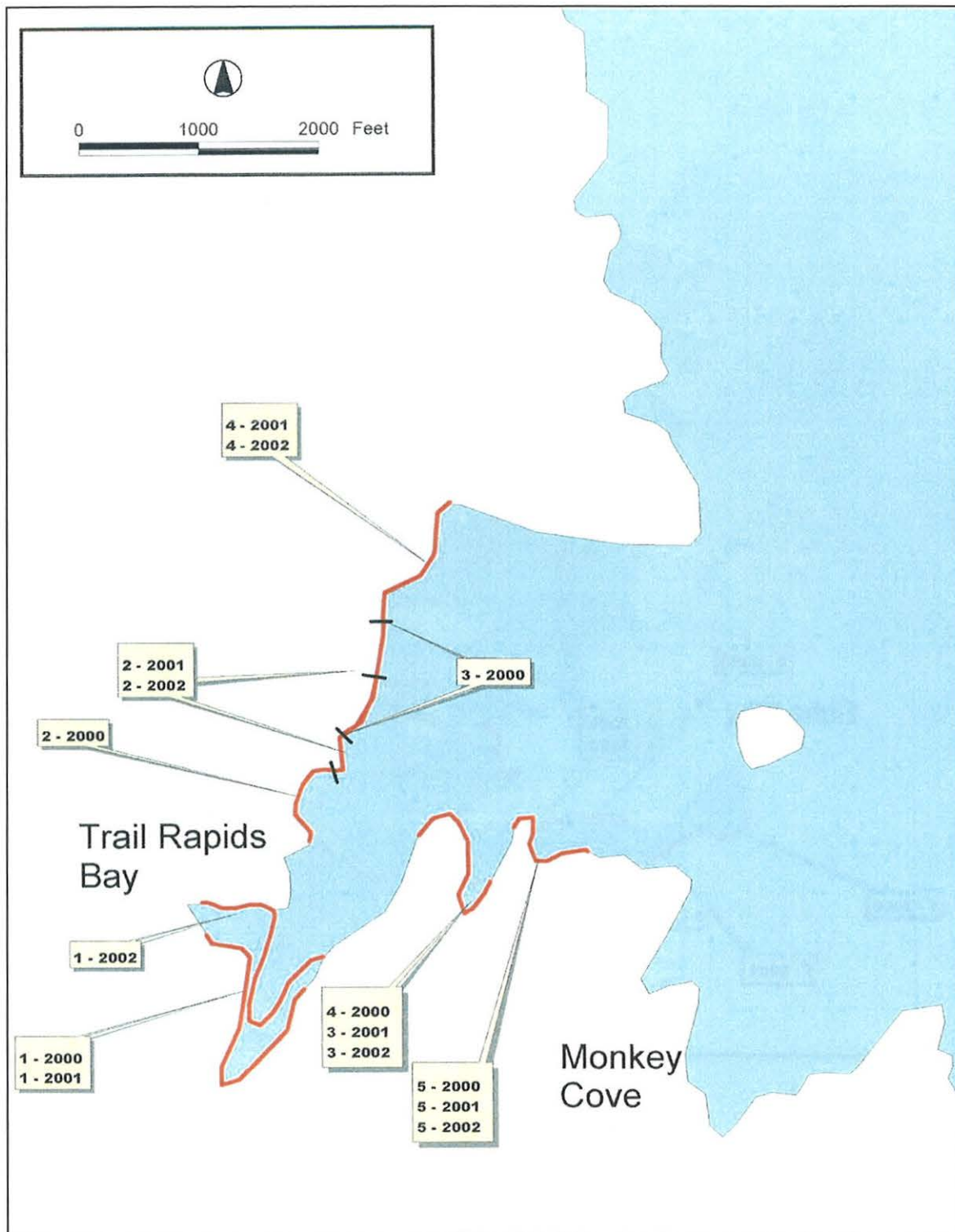


Figure 5. Trail Rapids Bay (TRB) sampling areas in 2000-2002.

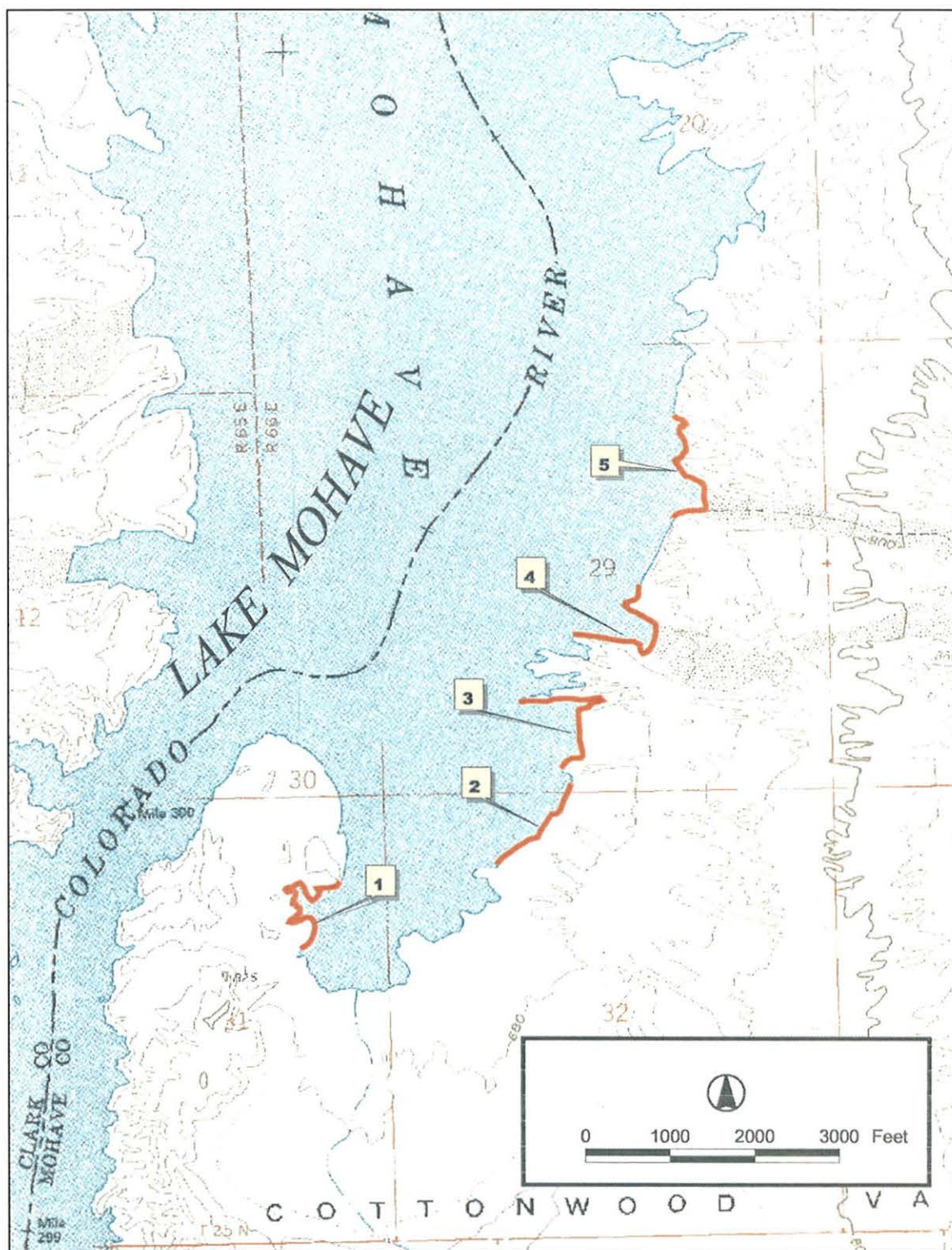


Figure 6. Arizona Bay (AZB) sampling areas in 2000-2002.

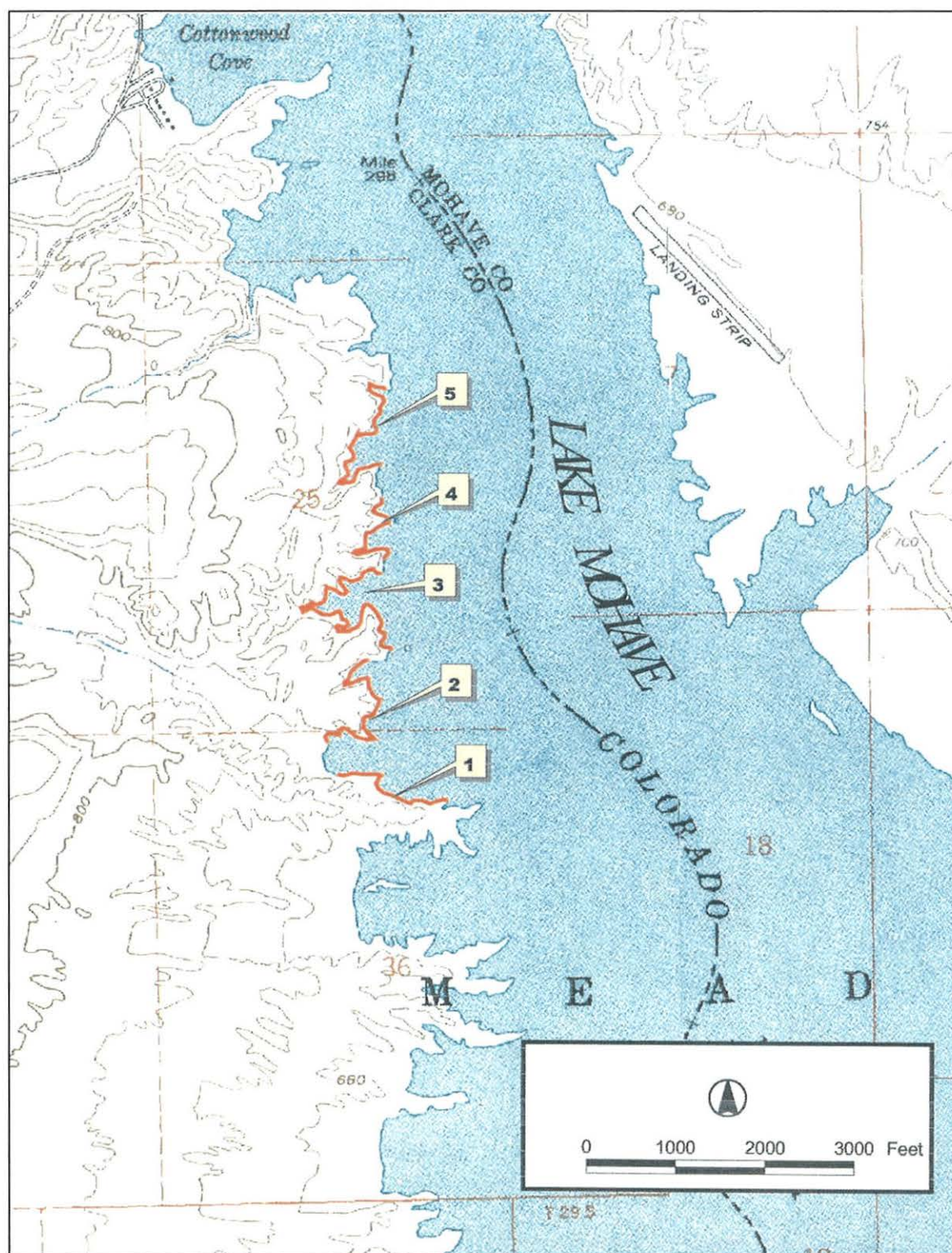


Figure 7. Tequila Cove (TQC) sampling areas in 2000-2002.

RESULTS

Water Quality

The 2002 water quality results were similar to those in 2000-2001. Las Vegas Bay generally had higher values for nutrients and dissolved solids than the remaining locations. Levels of nitrogen as nitrate ($\text{NO}^3\text{-N}$) were significantly higher at LVB sites 1-3 than at any sites in the other four locations in March 2002 (Figure 8; $p \leq 0.005$), and LVB sites 1-2 nitrate levels were significantly higher than LVB sites 3-5 ($p < 0.001$). In May 2002, LVB sites 1-4 had significantly higher nitrate levels than all sites from other locations ($p < 0.001$). Within LVB the sites ranked in the following order site 2 > site 1 > site 3 and site 4 > site 5 ($p \leq 0.007$). When we compared the total mean value for $\text{NO}^3\text{-N}$ at each location during each year of the study, we found that LVB always had the highest concentration of $\text{NO}^3\text{-N}$, but that no differences were seen between years. Additionally, when we combined all years of the study we found that LVB had a significantly higher mean concentration of $\text{NO}^3\text{-N}$ in March and May (Figure 9; $p < 0.001$).

Nitrogen as ammonium ($\text{NH}^4\text{-N}$) followed similar trends to $\text{NO}^3\text{-N}$, in both March and May 2002 (Figure 10). LVB sites 1-2 had significantly higher $\text{NH}^4\text{-N}$ levels than all other sites ($p \leq 0.03$) in March and May 2002. In May LVB site 3 also showed elevated levels of $\text{NH}^4\text{-N}$ over some sites at AZB, EB, and TRB. Over the three years of the study $\text{NH}^4\text{-N}$ levels were significantly higher at almost all locations in both March and May in 2001 than in 2000 or 2002 (Figure 11; $p < 0.001$). In 2002 LVB had similar $\text{NH}^4\text{-N}$ levels to EB and TRB in 2001. Again, we found that when data for all years was analyzed, LVB had a significantly higher concentration of $\text{NH}^4\text{-N}$ than all other locations in March and May (Figure 12; $p < 0.05$).

Detectable levels of total phosphorus (P) were found at a variety of places in March 2002 (Figure 13). Unlike the first two years of the study, LVB did not have the site with the highest concentration of total P. Sites at TQC and TRB had levels higher than all of the LVB sites. However, the LVB sites continued to have detectable levels of P, and the May 2002 sites from LVB had the highest concentrations. Over the three year period, the mean level of P in March was significantly higher at LVB in 2001 than at all other sites in all other years (Figure 14; $p < 0.001$). In March we found higher levels of total P at LVB and EB in 2001 than in the other two years ($p \leq 0.05$). Conversely, TQC had higher levels of total P in 2002 than in 2000 or 2001 ($p \leq 0.04$). In May we saw no significant differences between years for the mean level of P. When we combined data for all years (Figure 15) we found that LVB had a significantly higher concentration of total P than all other locations in March ($p < 0.001$), but it was only significantly higher than EB and TQC in May ($p \leq 0.008$).

Conductivity and total dissolved solids (TDS) were also significantly higher at LVB than at other locations in 2002 (Figures 16 and 17). Las Vegas Bay sites 1-4 had significantly higher levels of TDS than all AZB, TQC, and TRB sites in March ($p \leq 0.03$). The same was the case for LVB sites 1-3 in May ($p \leq 0.002$). In March and May LVB sites 1 and 2 had significantly higher levels of TDS than LVB sites 3-5 and EB sites 1-5 ($p < 0.05$). Additionally, EB site 1 had significantly higher TDS levels than all AZB, TQC, and TRB sites in May ($p < 0.003$). When we compared yearly differences

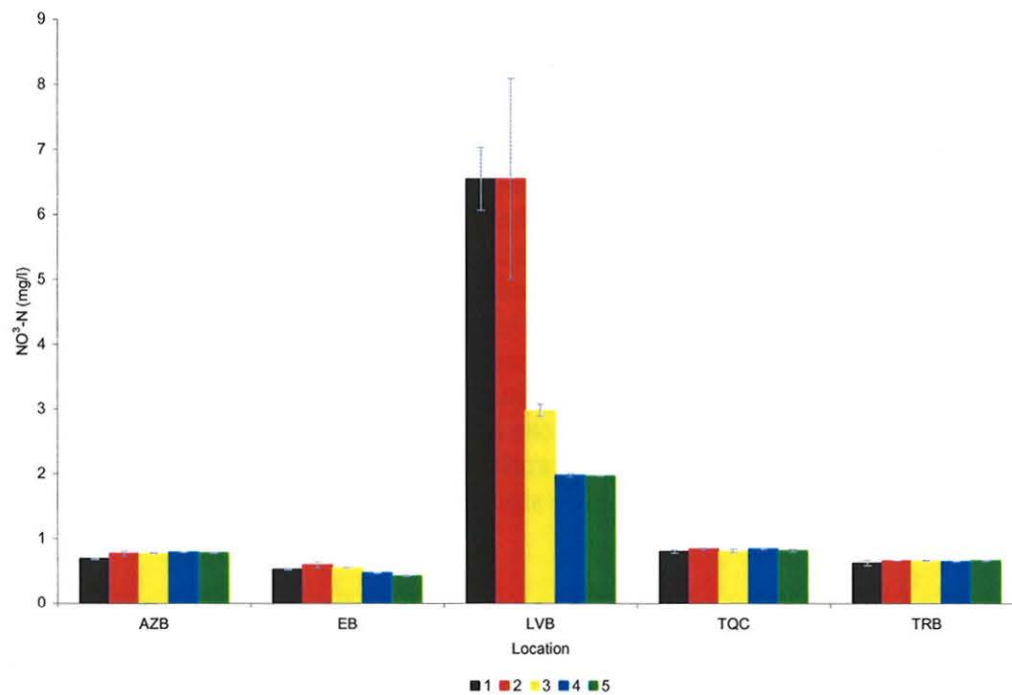
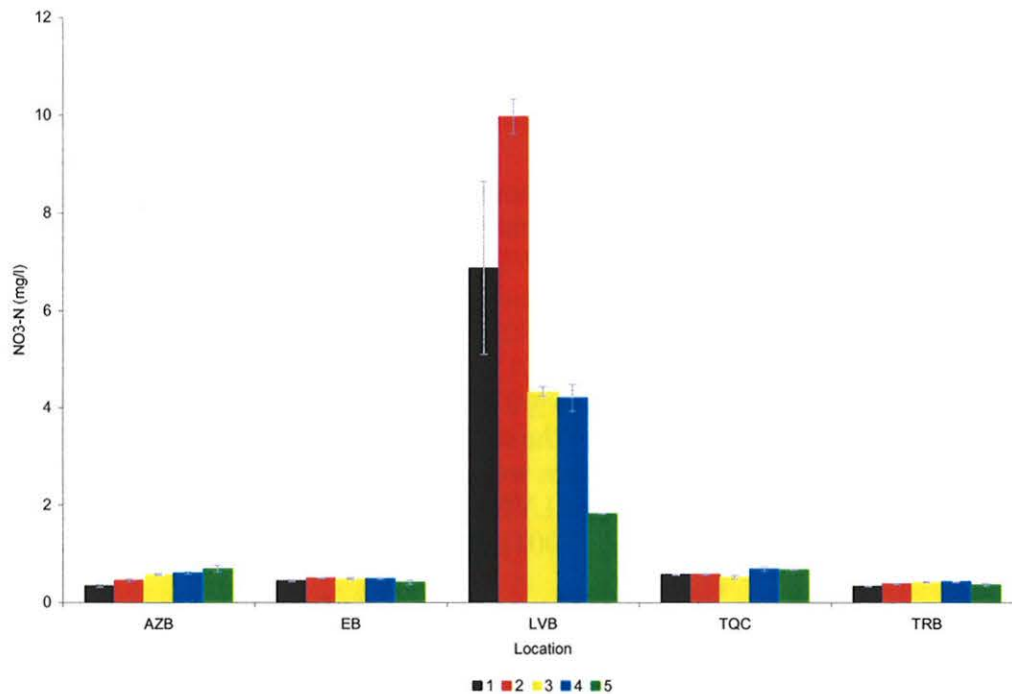


Figure 8. Mean amount of nitrogen as nitrate ($\text{NO}_3\text{-N}$) at all sites in (a) March 2001 and (b) May 2001.

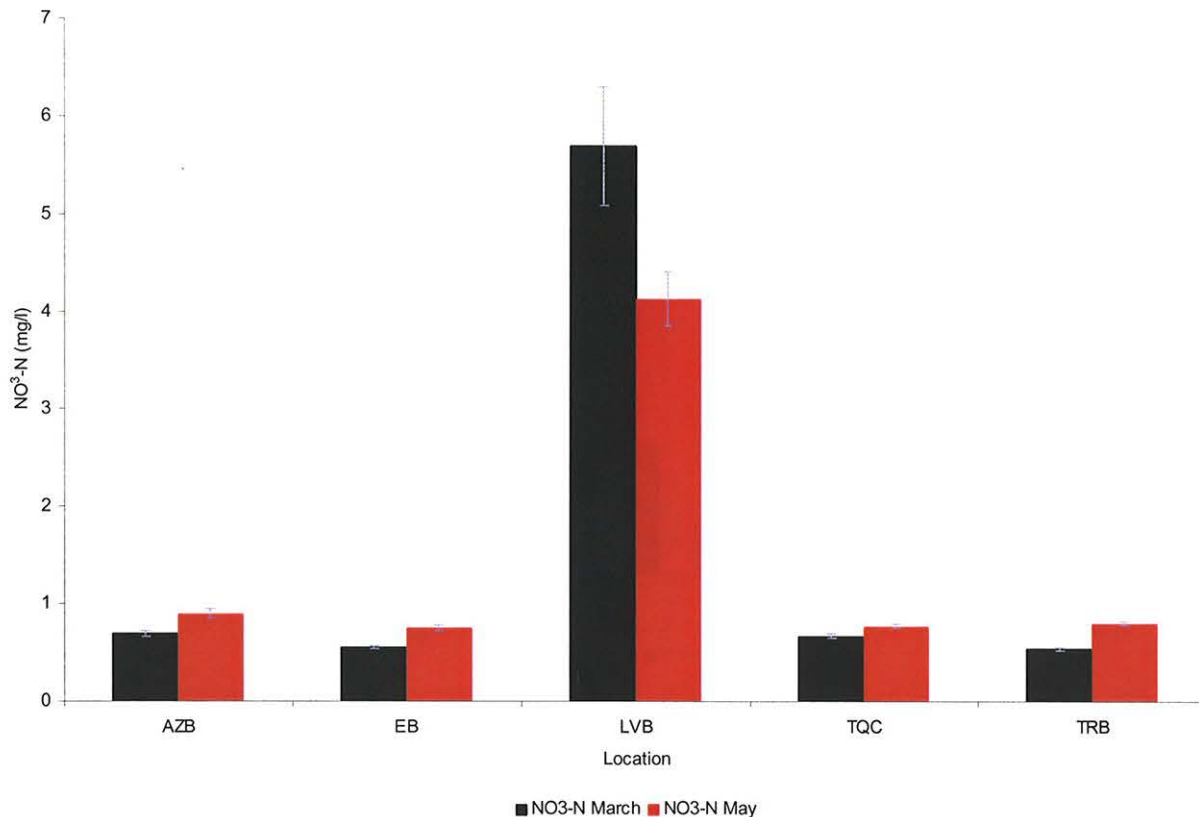


Figure 9. Mean amount of nitrogen as nitrate (NO³-N) at each location in March and May from 2000-2002.

for TDS, we found no differences in March. In May LVB had significantly higher levels of TDS than all other sites in 2000, 2001, and 2002 (Figure 18; $p < 0.001$), and TDS levels at LVB in 2001 were significantly higher than in 2000 or 2002 ($p < 0.001$). In general, 2002 seemed to have slightly higher values at all locations other than LVB.

As with the nutrient values, when data for all years was combined LVB had a significantly higher concentration of TDS than all other locations in both March and May (Figure 19; $p < 0.001$).

In March and May 2002, conductivity levels were significantly higher at LVB sites 1 and 2 than at all other sites from the other locations ($p \leq 0.02$). Additionally, LVB site 3 had significantly higher conductivity than all sites at TRB and TQC in May ($p \leq 0.002$). In May, we also saw elevated levels of conductivity at EB. Echo Bay site 1 had significantly higher levels of conductivity than all the AZB, TQC, and TRB sites ($p \leq 0.003$). Echo Bay site 2 had significantly higher levels of conductivity than all TRB sites in May, as well ($p \leq 0.04$). When we compared difference between locations and years, we found that LVB had significantly higher conductivity in both years than all other locations (Figure 20; $p < 0.001$). When all years were combined LVB had significantly higher conductivity levels than all other locations in March and May (Figure 21; $p < 0.001$).

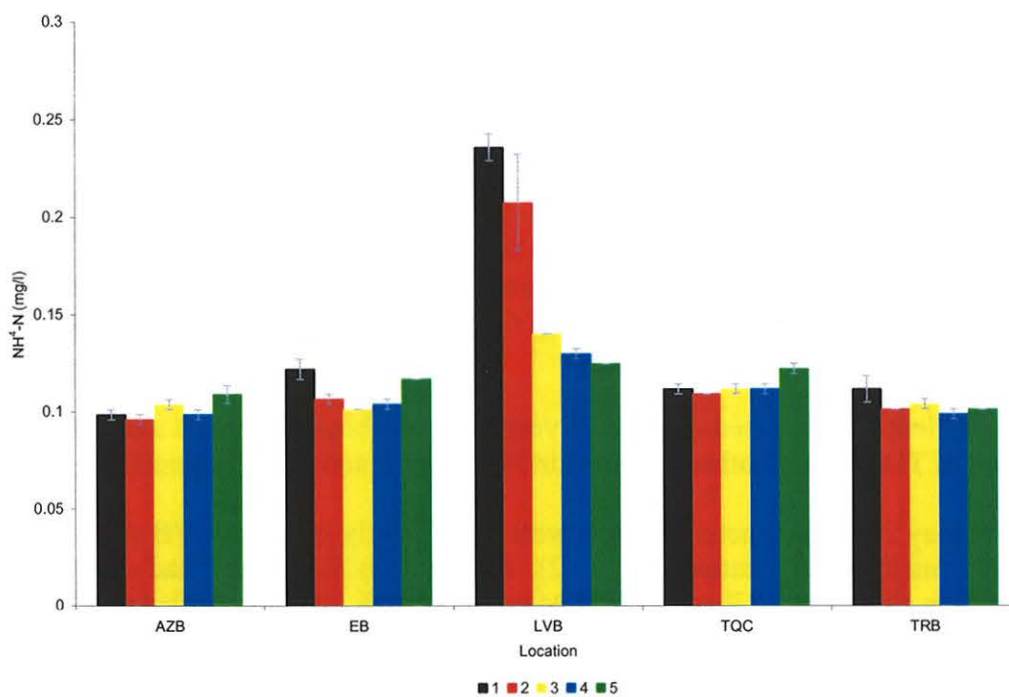
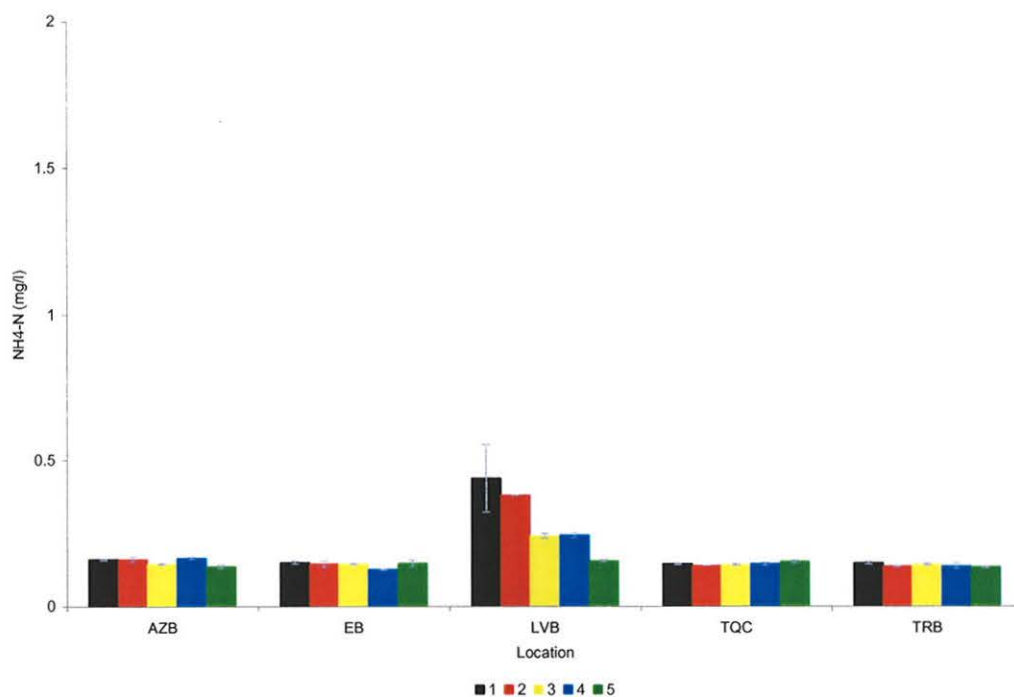


Figure 10. Mean amount of nitrogen as ammonium ($\text{NH}_4\text{-N}$) at all sites in (a) March 2002 and (b) May 2002.

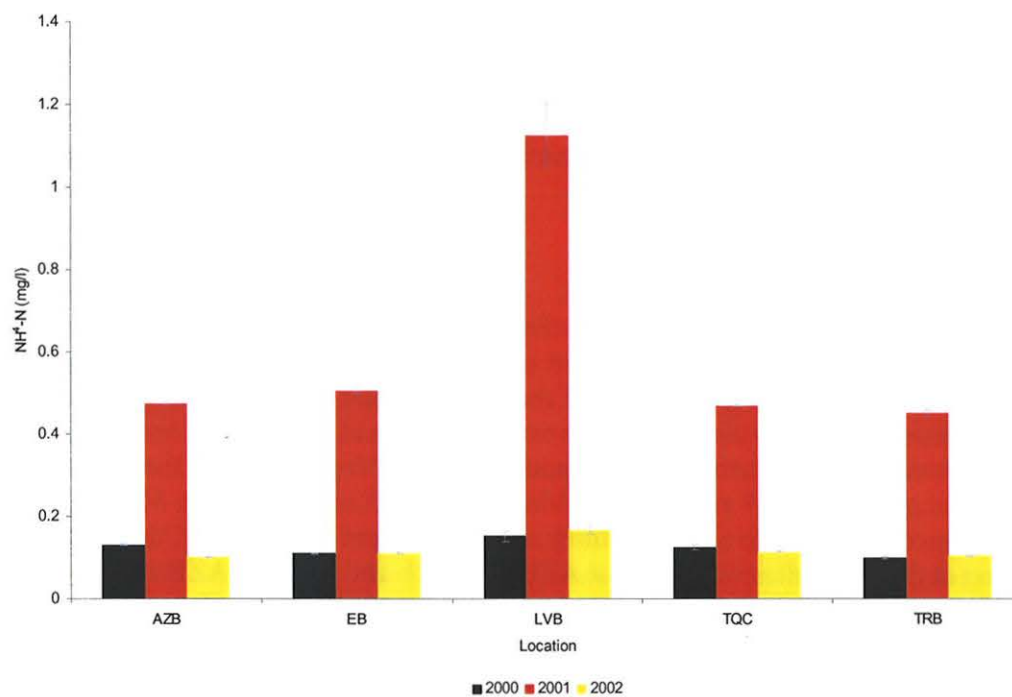
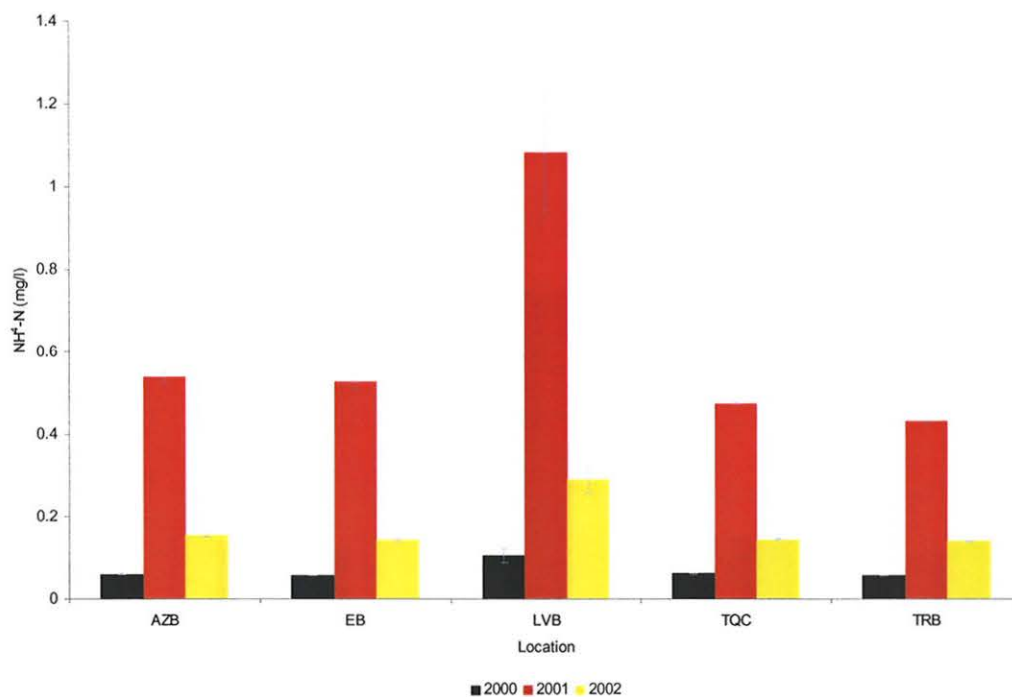


Figure 11. Mean amount of nitrogen as ammonium ($\text{NH}_4\text{-N}$) during each year at each location in (a) March and (b) May.

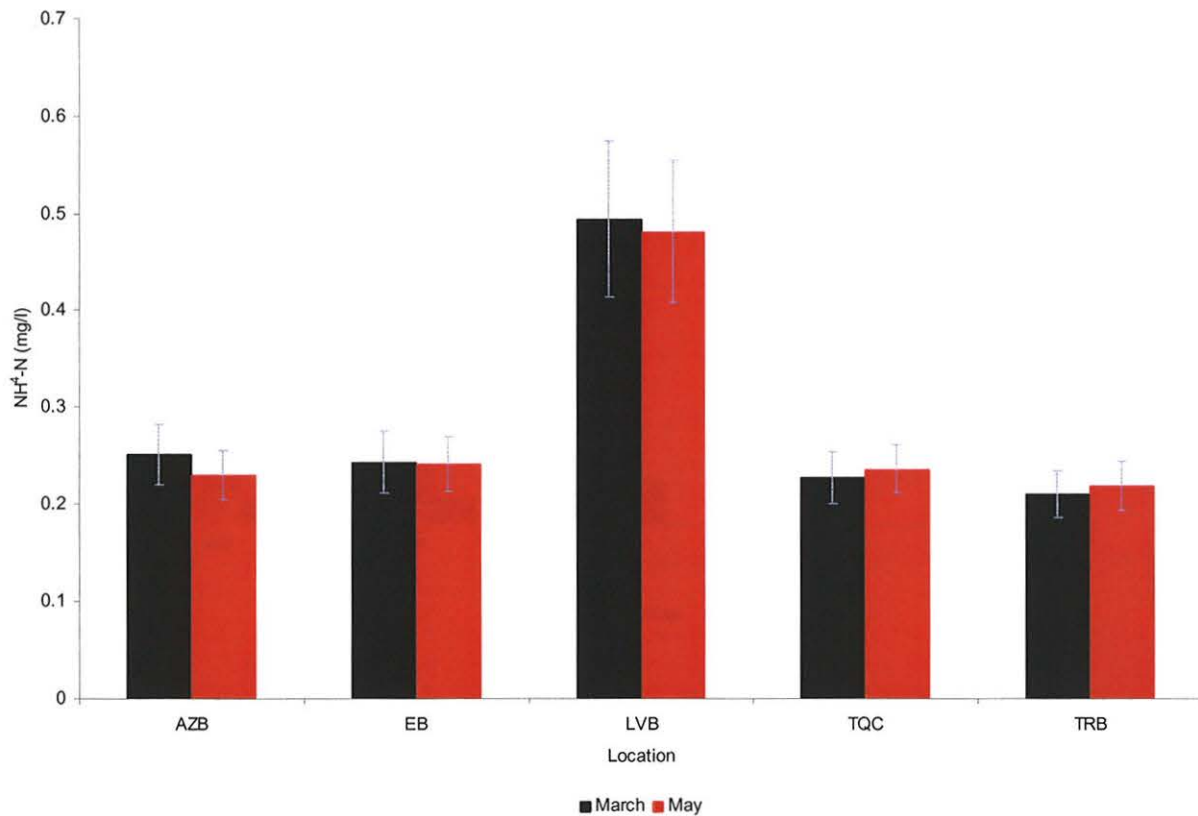


Figure 12. Mean amount of nitrogen as ammonium ($\text{NH}_4\text{-N}$) at each location in March and May from 2000-2002.

Turbidity levels at LVB and EB were higher than at the other locations sampled (Figure 22). In March and May, LVB site 1 and EB site 1 had significantly higher turbidity levels than all AZB, TQC, and TRB sites ($p < 0.001$), and some of the other EB and LVB sites. LVB sites 2-5 and EB site 2 also showed significantly elevated levels over most sites at AZB, TQC, and TRB. Secchi disk depths also showed increased turbidity at EB and LVB. Las Vegas Bay had the lowest clarity with secchi depths ranging from 0.9 m to 8 m in March and 0.85 m to 3.5 m in May. Echo Bay had secchi measurements of 1.3 m to 6.8 m in March and similar reading in May. Conversely, the lowest secchi reading at the other sites was 6.7 m at AZB in March and 9.1 m at AZB in May. The highest secchi reading were 13.3 m at TRB in March and 12.4 m at AZB in May. We found no differences in turbidity between years in March, but in May we saw that both the Lake Mohave sites had significantly higher turbidity levels in 2001 versus 2002 (Figure 23; $p < 0.001$). When data for both years were combined (Figure 24), we found that LVB had significantly higher turbidity levels than all other locations in March ($p < 0.001$) and all locations but EB in May ($p < 0.001$). While EB had higher turbidity levels than all locations except for LVB in March and May, the difference was only significant in May ($p < 0.001$).

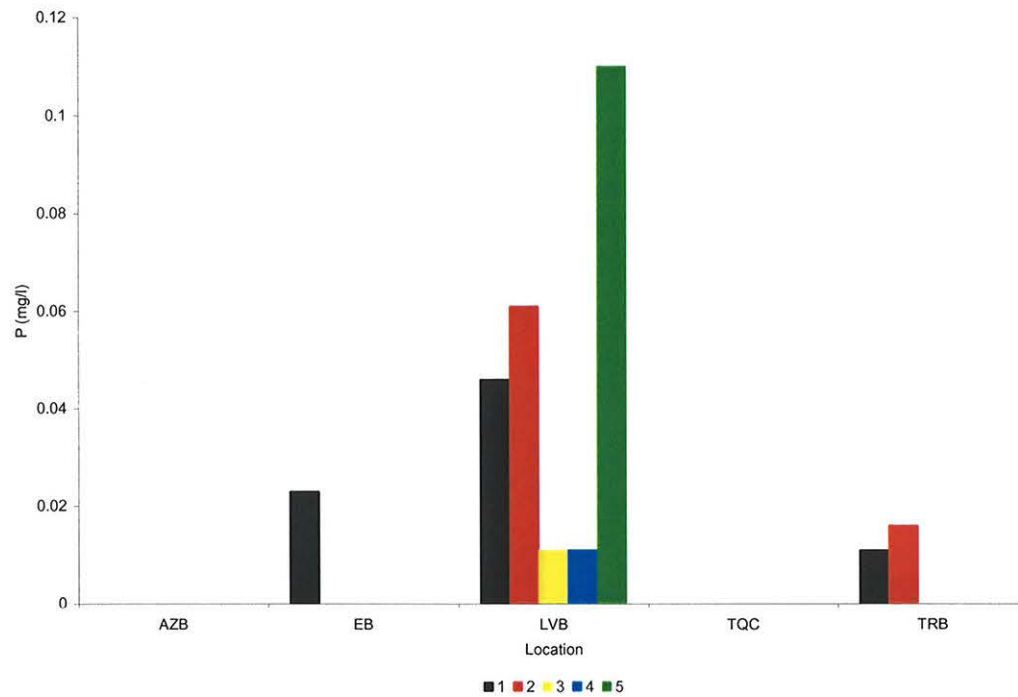
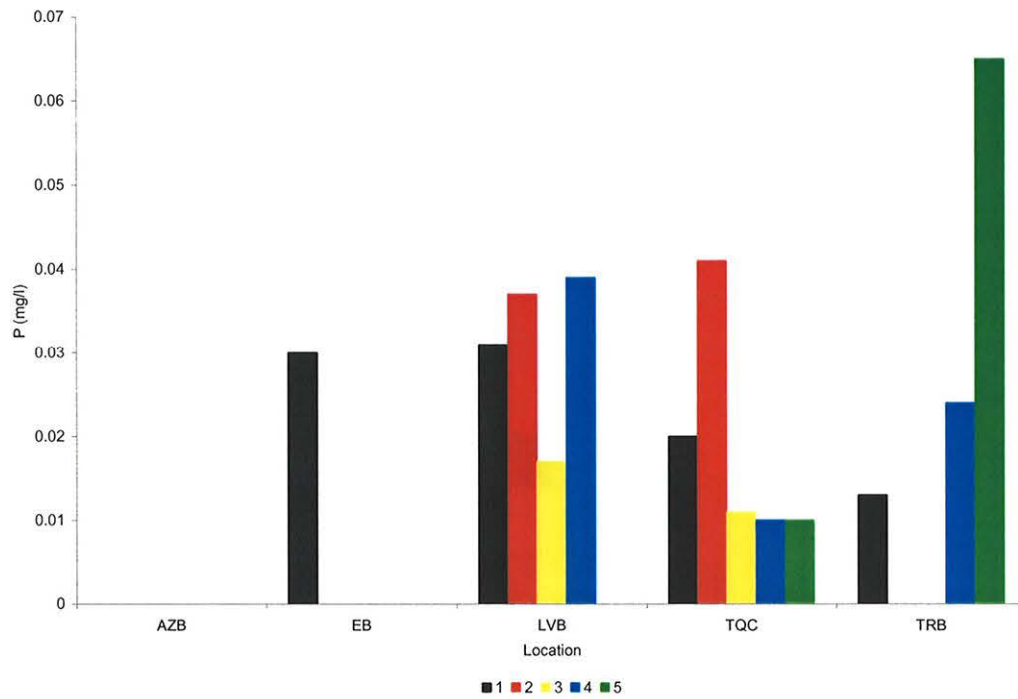


Figure 13. Total phosphorus (P) levels at all sites in (a) March 2002 and (b) May 2002.

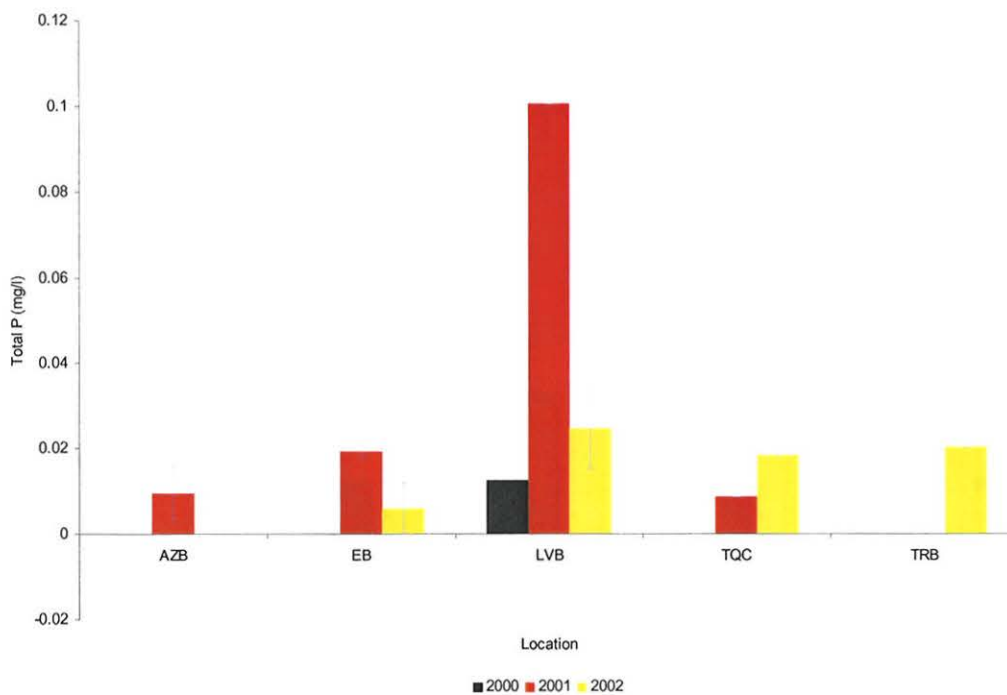


Figure 14. Total phosphorus (P) levels at each location during each year in March.

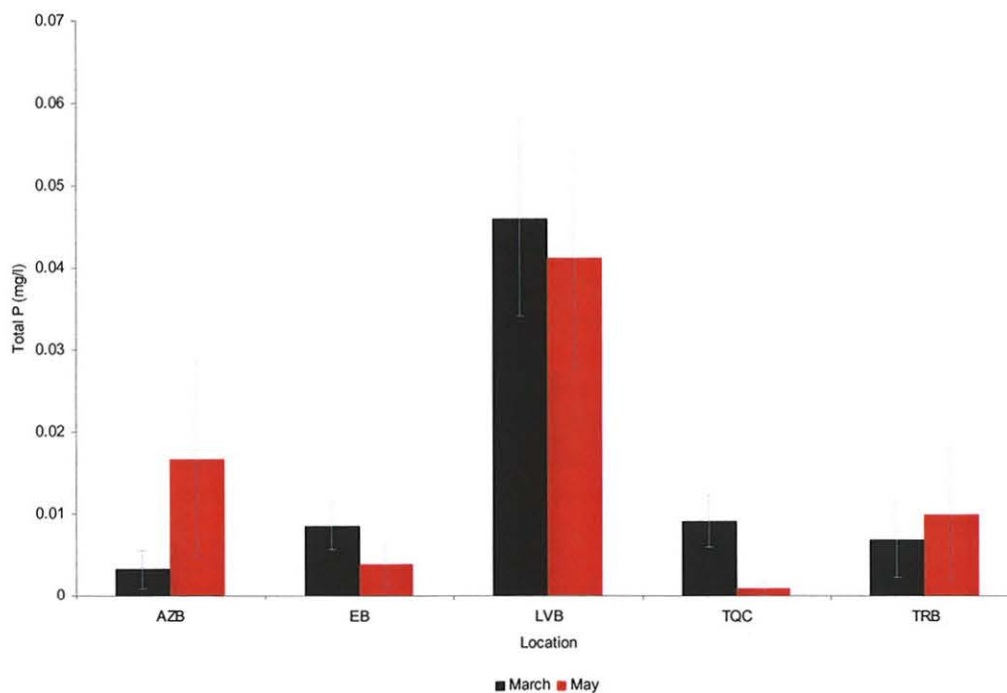


Figure 15. Total phosphorus (P) levels at each location in March and May from 2000-2002.

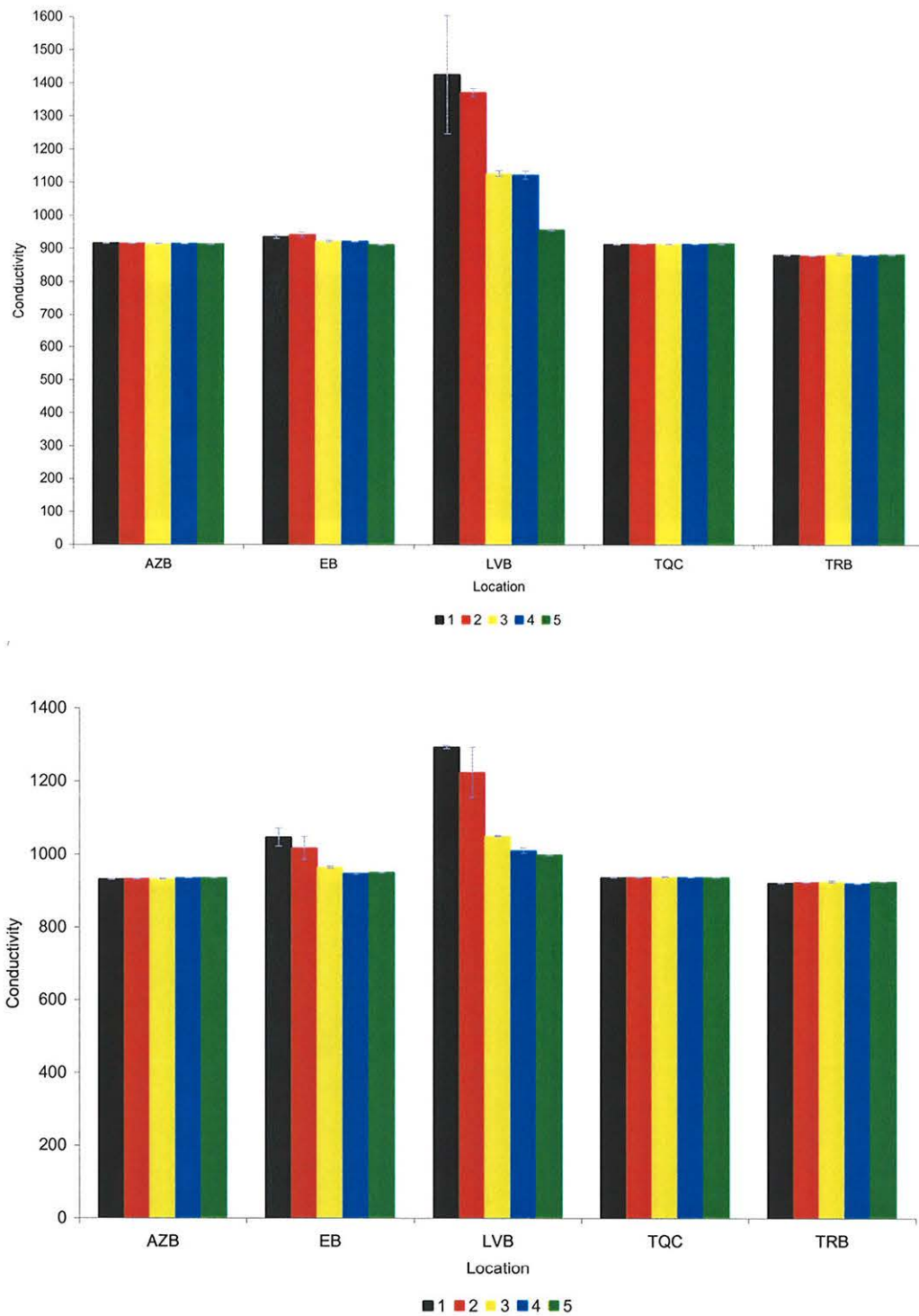


Figure 16. Conductivity levels at all sites in (a) March 2002 and (b) May 2002.

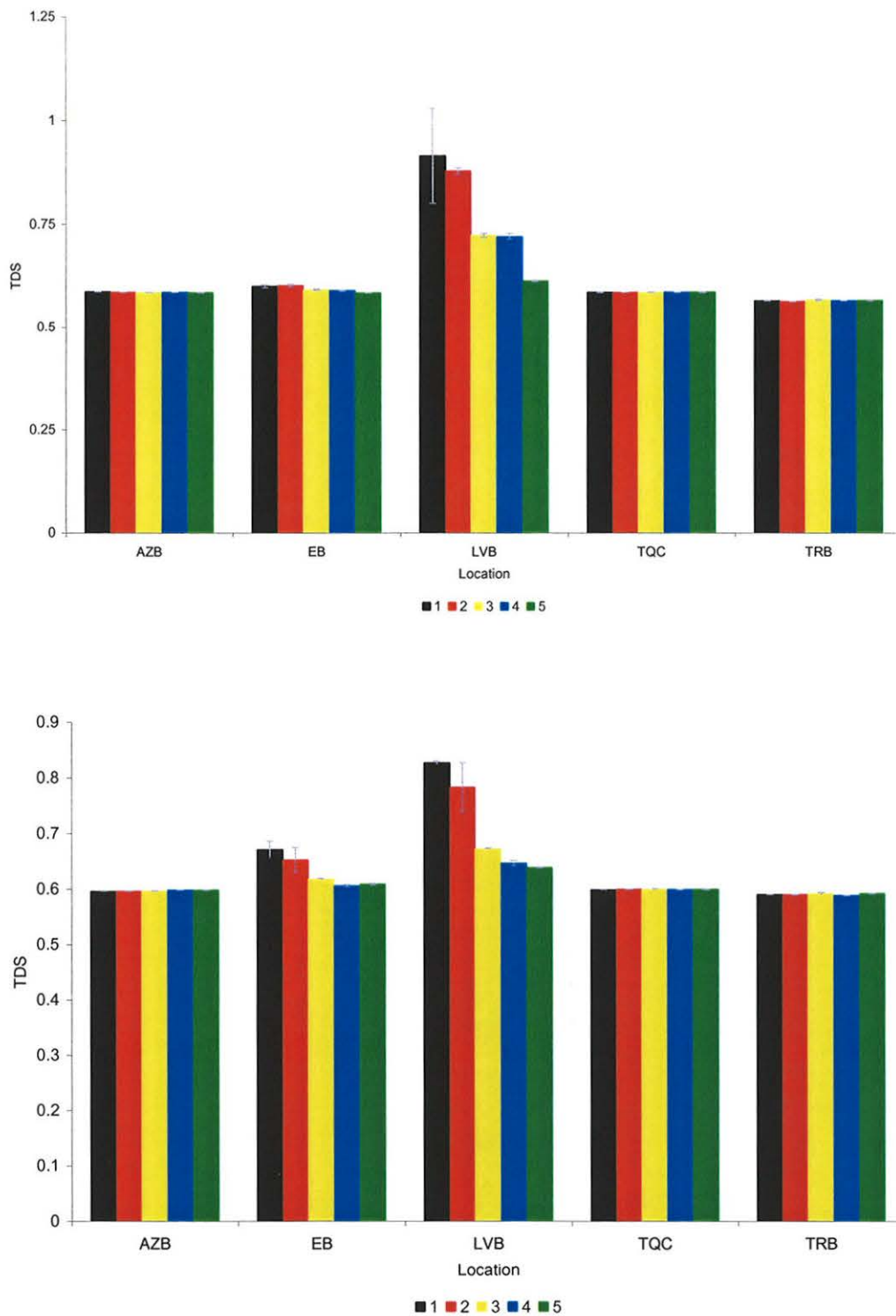


Figure 17. Total dissolved solids (TDS) levels at all sites in (a) March 2002 and (b) May 2002.

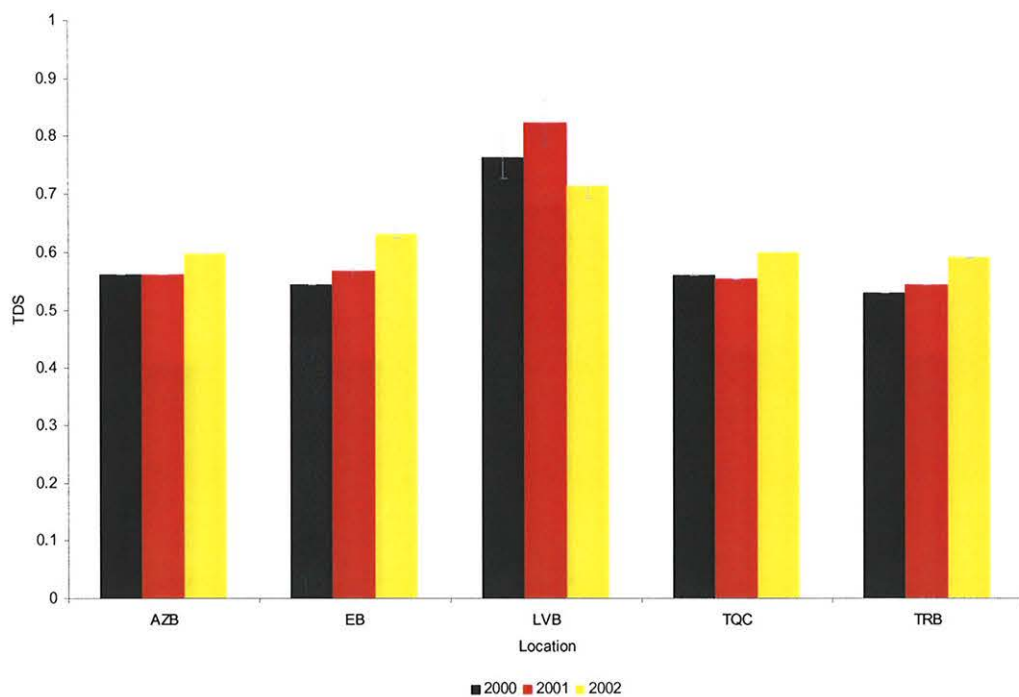


Figure 18. Mean amount of total dissolved solids (TDS) during each year at each location in May.

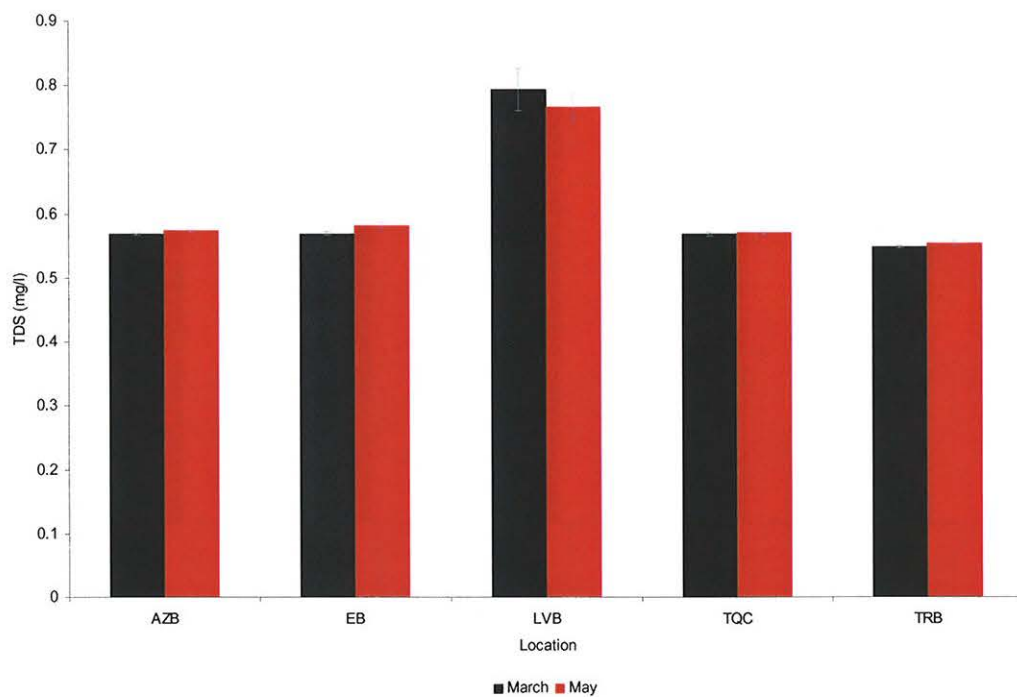


Figure 19. Mean amount of total dissolved solids (TDS) at each location in March and May from 2000-2002.

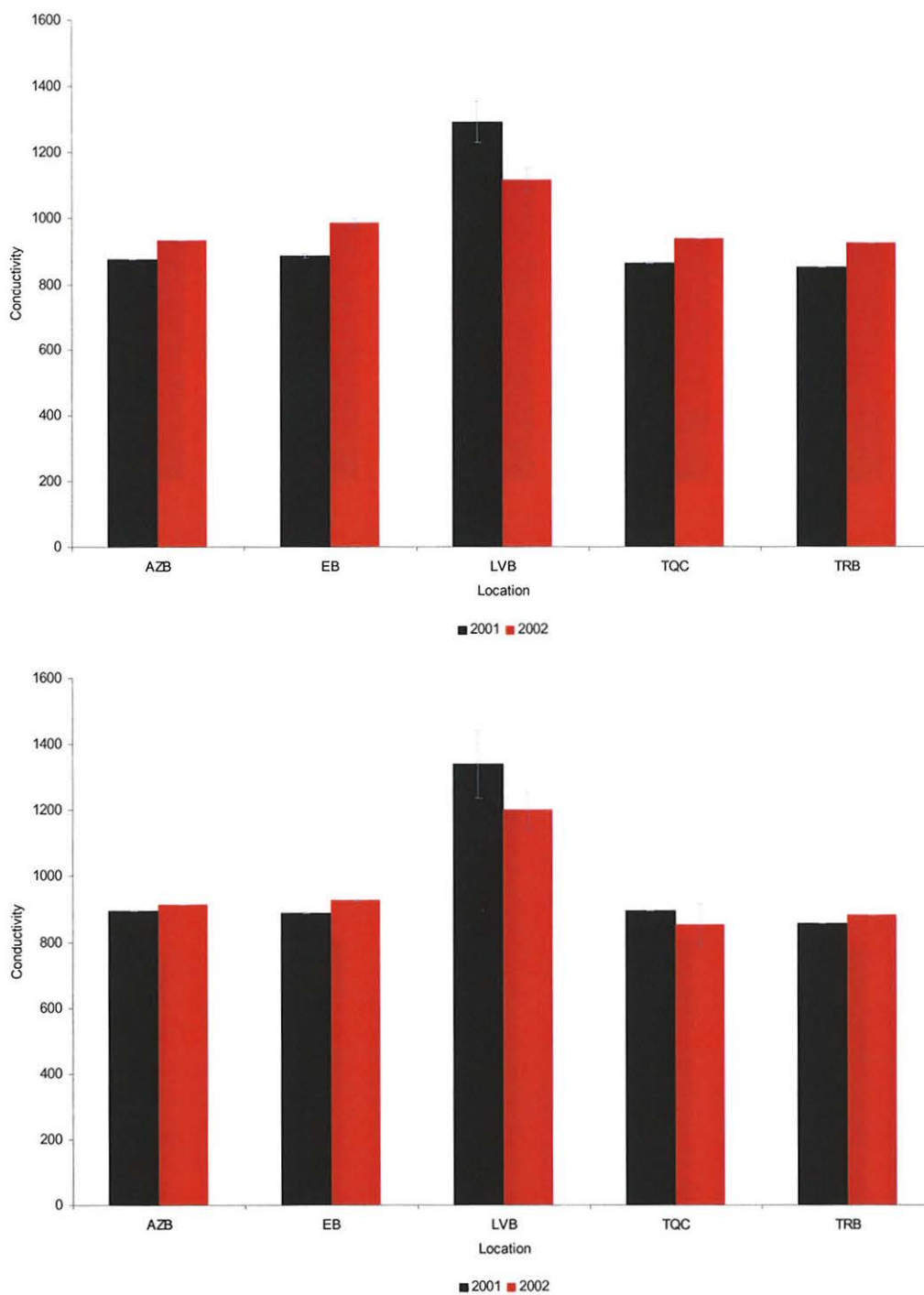


Figure 20. Mean conductivity levels at each location during each year in (a) March and (b) May.

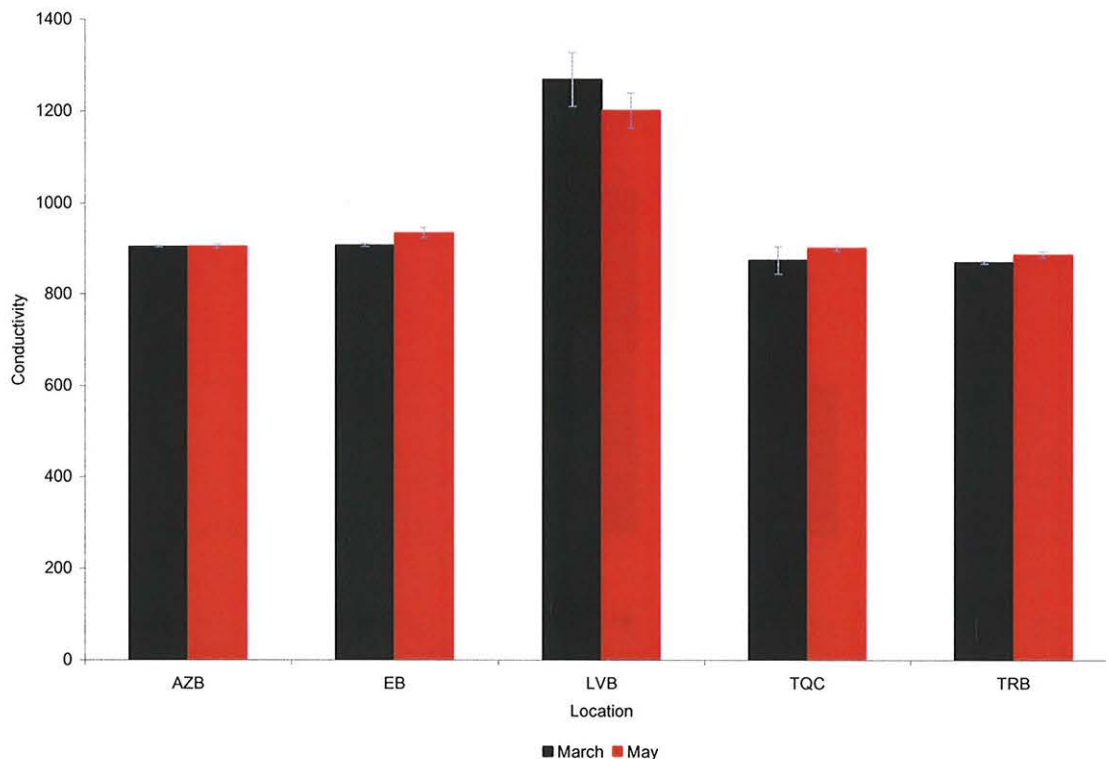


Figure 21. Mean conductivity levels at each location in March and May from 2000-2002.

Zooplankton

In March 2002 mean density of zooplankton was significantly higher at LVB than all other stations (Figure 25; $p < 0.001$). Additionally, AZB had significantly higher mean zooplankton density than TRB ($p < 0.05$). Once again variability between sites was high. At LVB individual replicate samples varied from 7 to 41 zooplankton per liter (zooplankton/l). When sites were examined for individual differences the location*site interaction term in the ANOVA was not significant. In May we saw even more variability with densities ranging from 9 - 200 zooplankton/l in individual replicate samples at AZB. Mean density of zooplankton was significantly higher at AZB than TRB ($p = 0.003$). However, when individual sites were examined, we found that only AZB site 4 had a significantly higher density of zooplankton, but the density at AZB site 4 was higher than all other sites at all other locations ($p < 0.04$).

When we compared zooplankton densities at each location between years we found that 2001 seemed to have the highest overall zooplankton density in March, while 2002 had the highest densities in May (Figure 26). In March 2001 LVB had significantly higher zooplankton density than all locations in 2000 and 2002 ($p < 0.02$), and TQC had significantly higher zooplankton density in 2001 than all locations in 2002 and all locations except for TQC in 2000 ($p < 0.001$). Additionally,

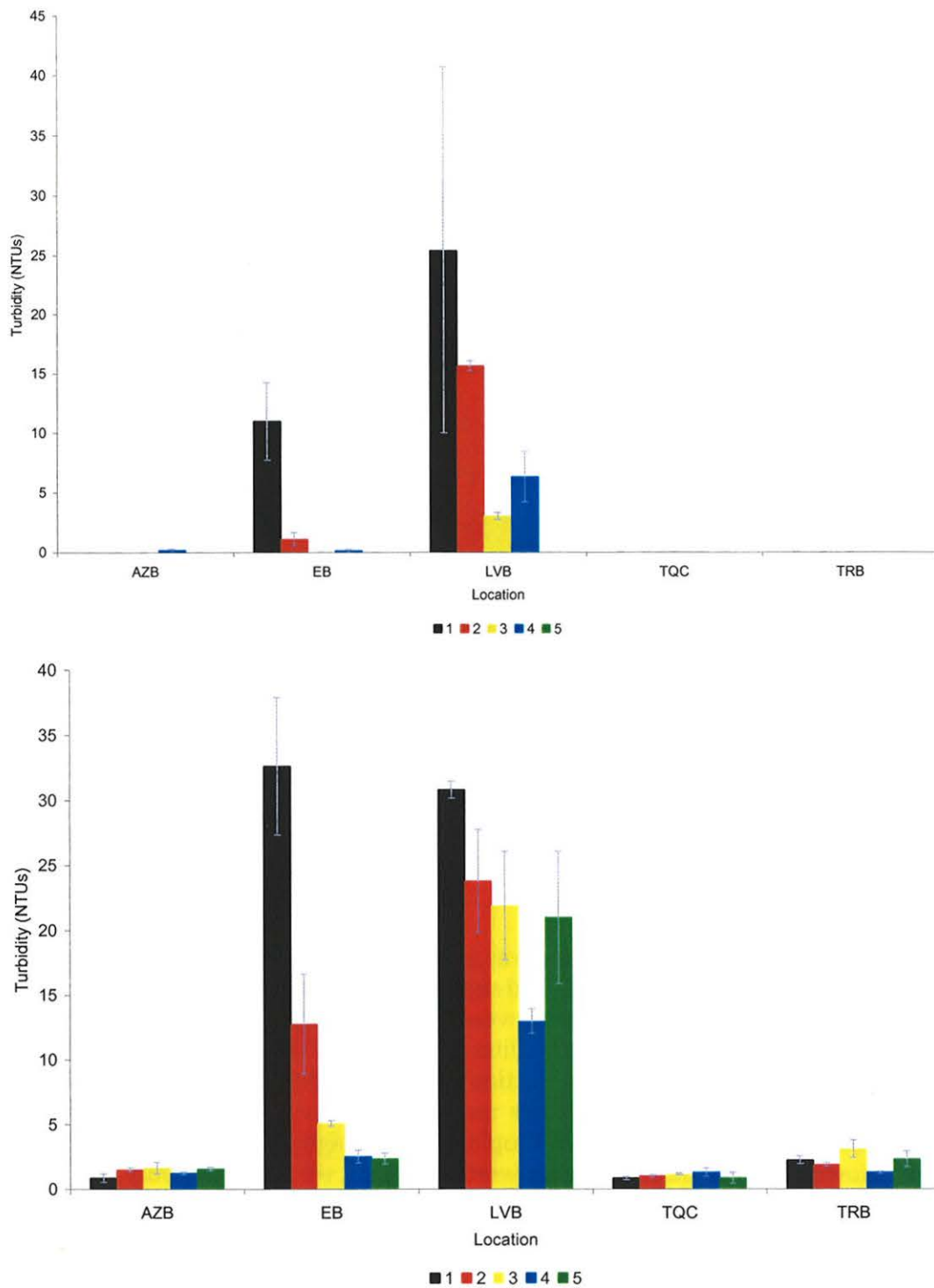


Figure 22. Mean turbidity levels in Nephelometric turbidity units (NTUs) at all sites in (a) March 2002 and (b) May 2002.

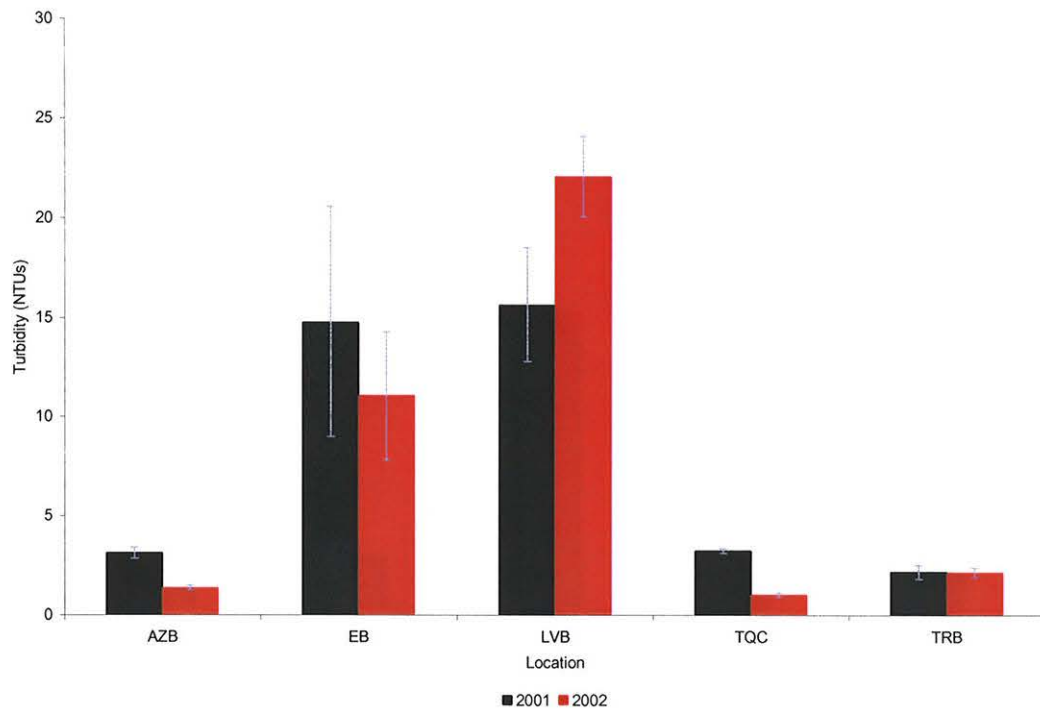


Figure 23. Mean turbidity levels at each location during each year in May.

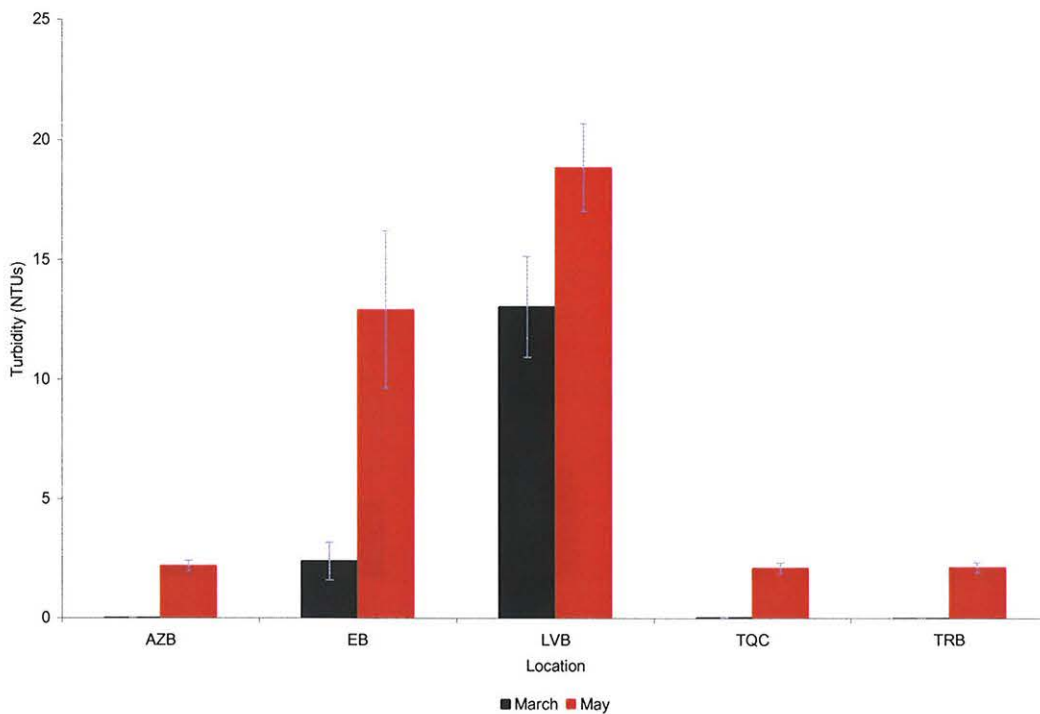


Figure 24. Mean turbidity levels in Nephelometric turbidity units (NTUs) at each location in March and May from 2001-2002.

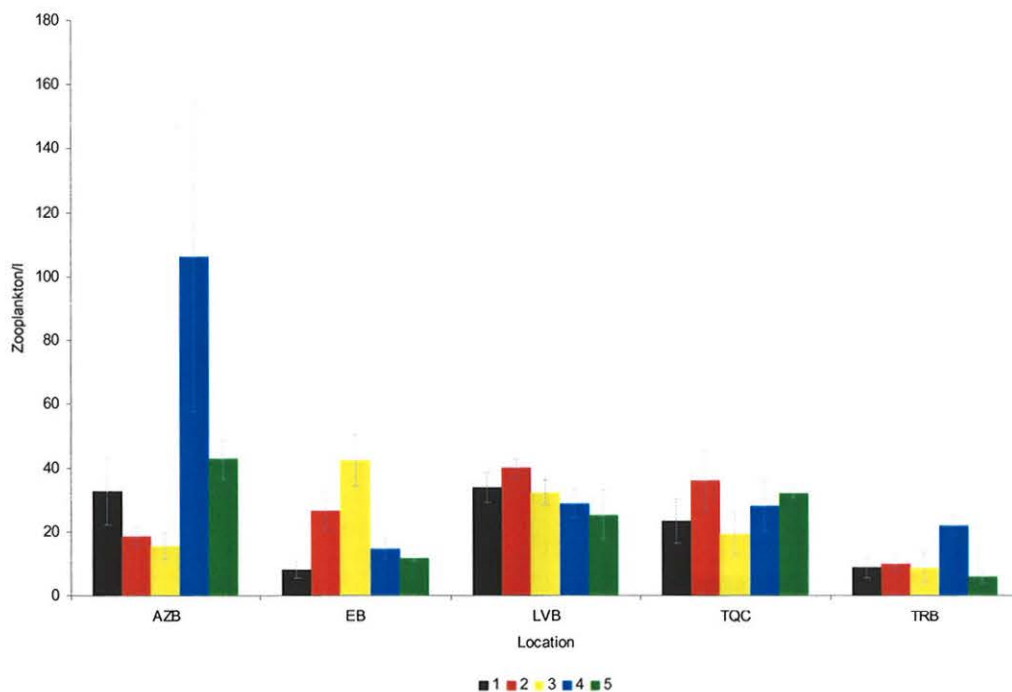
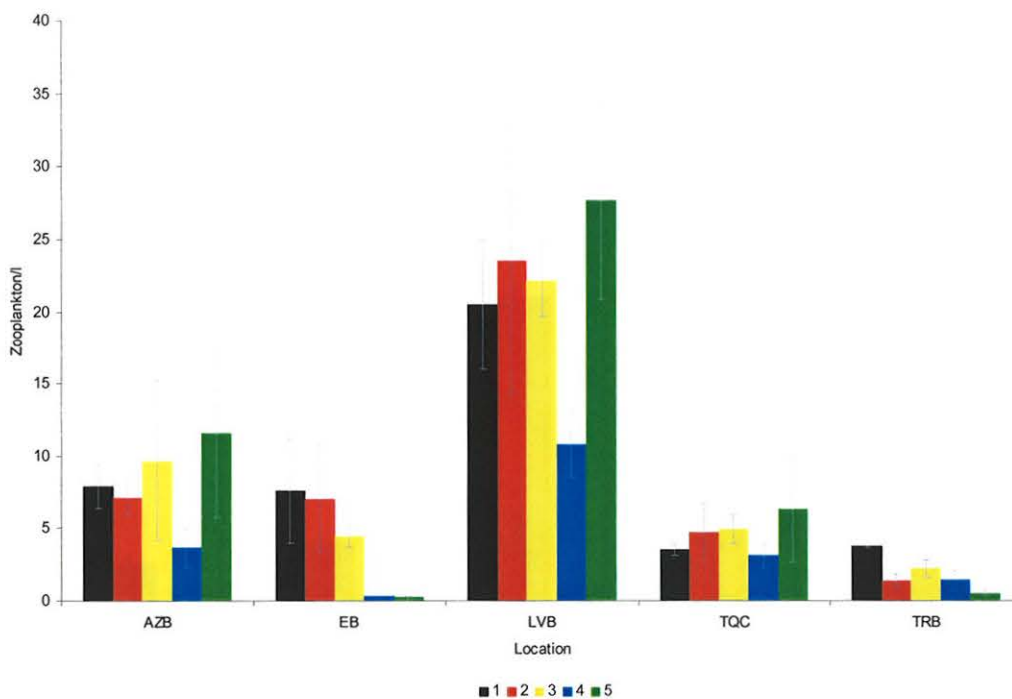


Figure 25. Mean number of zooplankton per liter (zooplankton/l) at all sites in (a) March 2002 and (b) May 2002.

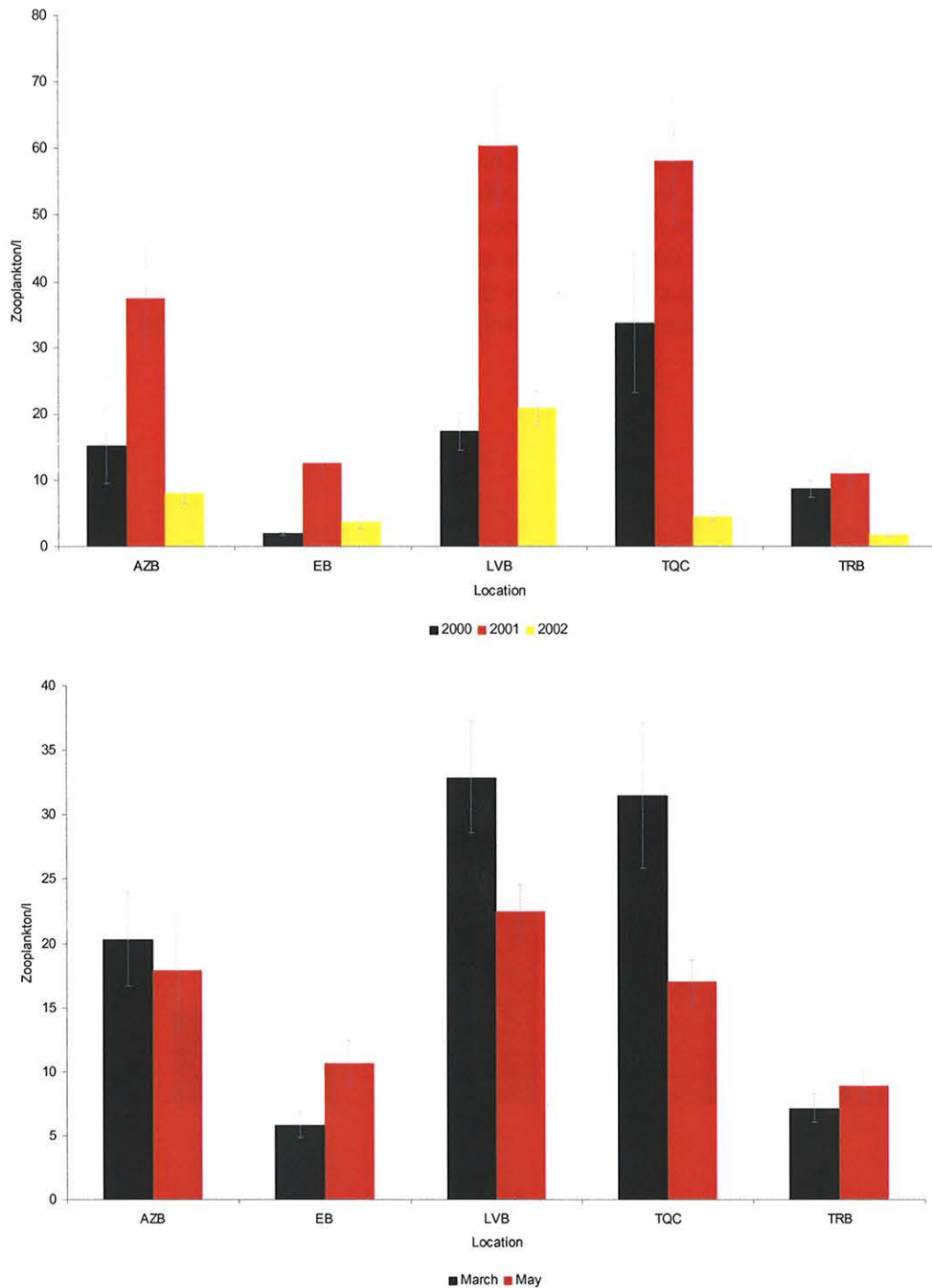


Figure 26. Mean number of zooplankton per liter (zooplankton/l) at all locations during each year in (a) March and (b) May.

AZB had significantly higher zooplankton density in 2001 than EB and TRB in 2000 and all locations except LVB in 2002 ($p \leq 0.005$). March 2002 had the lowest density of zooplankton. The zooplankton density in March 2000 at TQC was significantly higher than all locations except LVB in 2002 ($p < 0.03$). While zooplankton density in March seemed lowest in 2002, the May 2002 samples had the highest zooplankton density. Zooplankton density at AZB, LVB, and TQC in 2002 was significantly higher than all locations in 2000 and AZB, EB, and TRB in 2001 ($p < 0.04$). May 2000 had the lowest zooplankton density, and density at LVB in 2001 was significantly higher than all locations in May 2000 ($p \leq 0.001$). When we combined the data from all years (Figure 27), LVB had a significantly higher zooplankton density than EB and TRB in March and May ($p \leq 0.009$). Additionally, TQC had significantly higher total density than EB and TRB in March and TRB in May ($p < 0.05$).

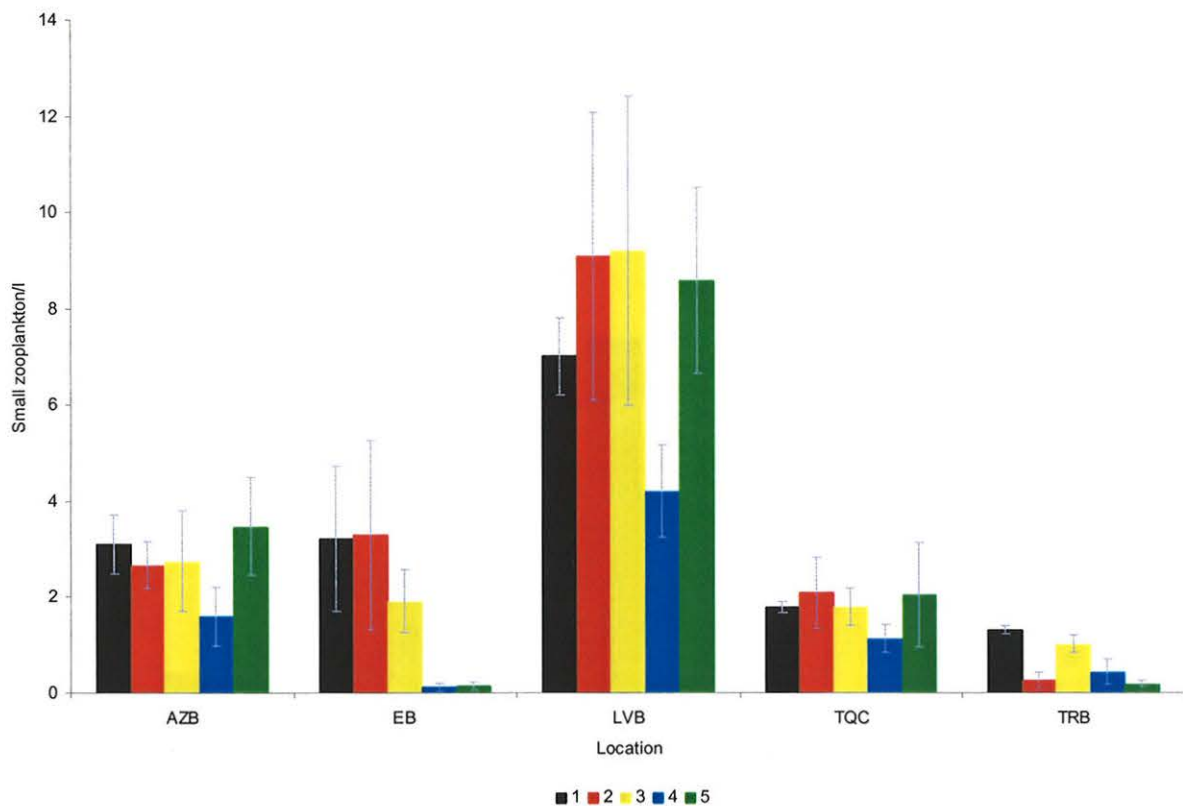


Figure 27. Mean number of zooplankton per liter (zooplankton/l) at each location in March and May from 2000-2002.

March trends in small zooplankton density were similar to those in total zooplankton (Figure 28). Las Vegas Bay had the highest mean density of small zooplankton ($p < 0.001$). When individual sites were examined LVB sites 2, 3, and 5 had significantly higher mean small zooplankton density than all sites at TQC and TRB, as well as EB sites 3-5 and AZB site 4 ($p < 0.05$). In May, we found that mean small zooplankton density was highest at LVB and AZB. Las Vegas Bay had significantly higher mean small zooplankton density than EB and TRB, and AZB had significantly higher density than TRB ($p \leq 0.008$). Comparing individual sites we found that AZB site 4 had significantly higher densities than the following: TRB sites 1-3, and 5; EB sites 1, 4, and 5; and TQC site 3 ($p \leq 0.04$). Las Vegas Bay site 2 had a significantly higher density than EB site 5 and TRB sites 1, 2, 3, and 5 ($p \leq 0.04$).

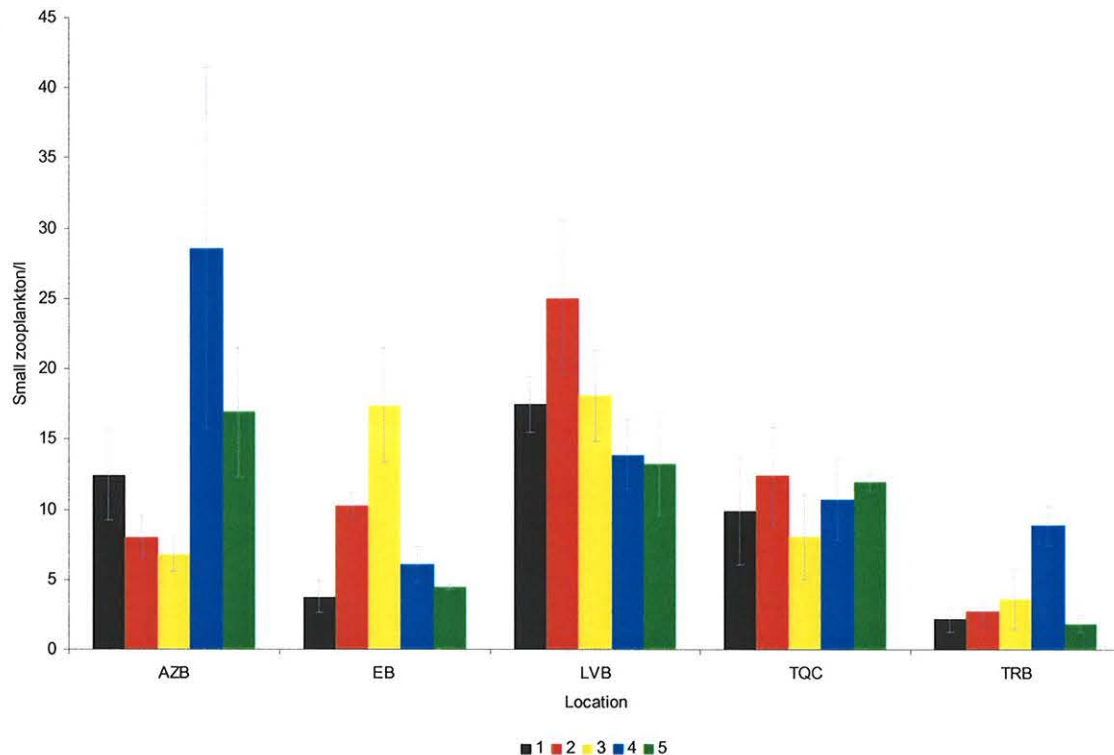


Figure 28. Mean density of small zooplankton at all sites in (a) March 2002 and (b) May 2002.

Comparing the density of small zooplankton at each location between years revealed trends similar to total zooplankton (Figure 29). In March we saw that 2001 seemed to have the highest density of small zooplankton overall, with AZB, LVB, and TQC having higher mean small zooplankton densities than all other locations in 2000 and 2002 ($p < 0.05$). As with total zooplankton density, 2000 had the lowest and 2002 had the highest density of small zooplankton in May. In 2002 AZB, EB, LVB, and TQC had significantly higher small zooplankton density than all locations in 2000,

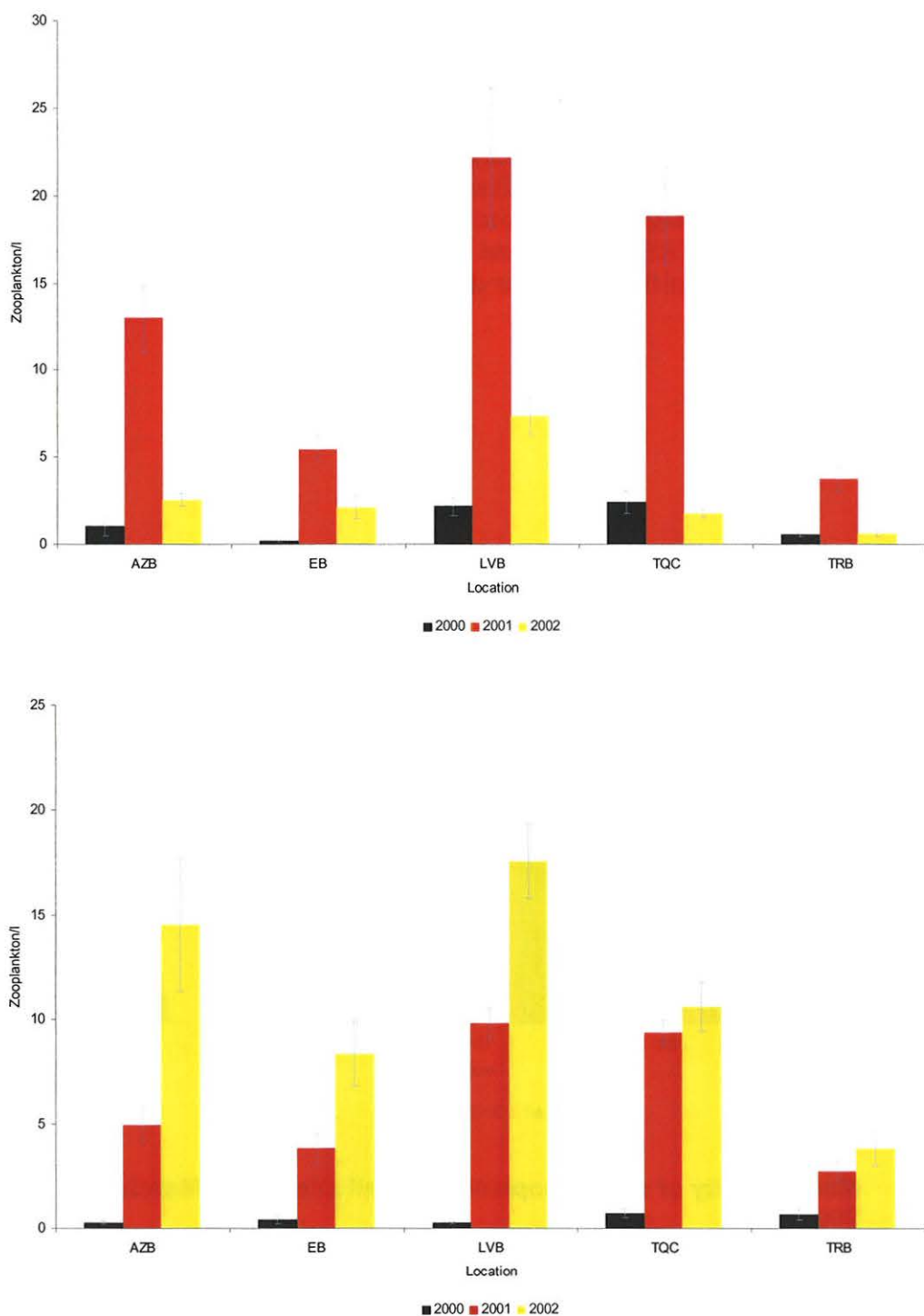


Figure 29. Mean density of small zooplankton at all locations during each year in (a) March and (b) May.

and LVB 2002 had higher density than all 2001 locations ($p < 0.001$). Additionally, in 2002 AZB and TQC had significantly higher densities than AZB, EB and TRB in 2001 ($p < 0.05$). When we combined data from all 3 years we found that, as with total zooplankton density, EB and TRB had the lowest density of small zooplankton (Figure 30). Las Vegas Bay and TQC had significantly higher small zooplankton density than EB and TRB in March ($p < 0.04$), and LVB had significantly higher density than both EB and TRB in May ($p \leq 0.003$). Additionally, AZB and TQC had a higher density of small zooplankton than TRB in May.

We saw significant differences in the percent composition of different taxa in both March and May 2002 (Figure 31). In March we saw differences between locations but nothing consistently differentiating Lake Mead locations from Lake Mohave locations. Las Vegas Bay had significantly higher percent Daphnidae than all other locations except AZB ($p < 0.001$). The Lake Mohave sites had a higher percentage of Bosminidae, with AZB having a significantly higher percentage than all other locations and TQC having a higher percentage than EB and LVB ($p < 0.05$). Trail Rapids Bay had a significantly higher percentage of Copepoda than AZB, LVB, and TQC; EB had a significantly higher percentage of Copepoda than AZB ($p < 0.02$). Copepod nauplii were lowest at TRB and EB, and TQC had a significantly higher percentage of Copepod nauplii than TRB ($p < 0.03$). Las Vegas Bay had a significantly higher percentage of combined Cladoceran and Copepod eggs than the other Lake Mead sites ($p < 0.03$). No Rotifera were found in the March samples.

We also found no real compositional similarities differentiating Lake Mead from Lake Mohave locations in May 2002. All locations with the exception of TRB were dominated by Copepod nauplii. Echo Bay and LVB had a large proportion of adult Copepods, while AZB and TQC had a fair percentage of Bosminidae. Trail Rapids Bay showed the most diverse community. Las Vegas Bay and Echo Bay had a significantly lower percentage of Bosminidae than the other three locations ($p < 0.03$). Echo Bay had a significantly higher percentage of Daphnidae and Copepoda than all other locations ($p < 0.04$). Trail Rapids Bay had a higher percentage of Copepods than all other locations except for EB ($p \leq 0.001$). Las Vegas Bay had the highest percentage of Copepod nauplii, and had a significantly higher percentage than all locations except TQC ($p \leq 0.004$). Conversely, TRB had a lower percentage of nauplii than all other locations ($p < 0.001$). Trail Rapids Bay had a significantly higher percentage of Rotifera than all other sites ($p < 0.001$). No differences were seen in the percentage of Cladoceran and Copepod eggs found at each location.

As in 2001 adult Copepoda and Copepod nauplii dominated the zooplankton at all locations in March 2002 and at all locations except TRB in May. However, we saw a slightly larger percentage of Daphnidae and Bosminidae at some locations in 2002 than we saw in 2001, but the percentages were still not as high as in 2000. Generally, the Lake Mohave locations and TRB had a higher percentage of Bosminidae, and the Lake Mead locations had a higher percentage of Daphnidae. An ANOVA showed both of these to be accurate. In 2000 LVB had a significantly higher percentage of Daphnidae than all other locations in all other years during March ($p < 0.001$), and AZB, EB, and LVB had a significantly higher percentage of Daphnidae than all other locations in all other years during May ($p < 0.03$).

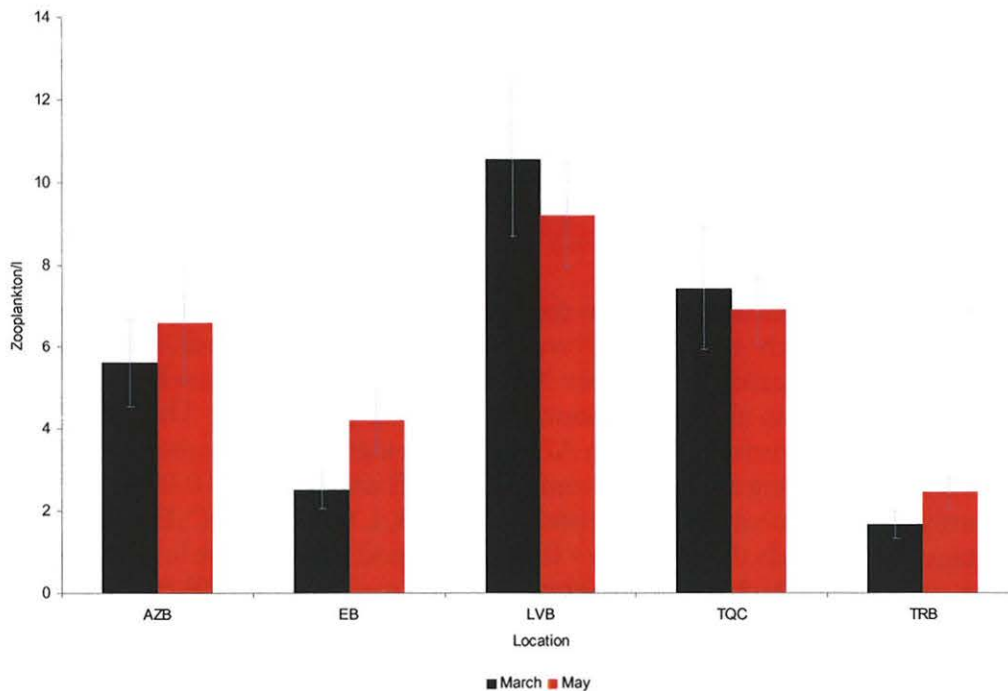


Figure 30. Mean density of small zooplankton at each location in March and May from 2000-2002.

We found the highest percentage of Bosminidae in March and May of 2000. Tequila Cove and TRB had a significantly higher percentage than all 2001 and 2002 locations except for AZB in March 2002 ($p < 0.001$). In 2002 AZB and TRB had significantly higher percentage of Bosminidae than all 2001 locations except TRB ($p < 0.001$). The percentage of adult Copepoda was highest in May 2000. In May 2000 AZB, EBV, LVB, and TQC had a significantly higher percentage of adult Copepoda than all other locations in 2001 and 2002, except for Echo Bay in 2002 ($p < 0.02$). The collections made in March over the three years of study showed similar trend in the percentage of Copepoda between years, except for a few differences between individual locations.

Unlike the Ostracoda and adult Copepoda, which had their highest proportions in 2000, the percentage of Copepod nauplii was significantly higher in 2001 and 2002 at all locations except TRB ($p < 0.001$). No significant differences were seen for the percentage of Rotifera in March, but in May 2002 the percentage was significantly higher than all locations in 2000 and 2001 ($p < 0.001$). The higher percentage of Rotifera in May 2002 was primarily the result of the high percentage at TRB. The percentage of combined Daphnidae and Copepoda eggs in March did not show a major difference between years, except for variability within certain locations. However, in May the Lake Mohave sites contributed to a generally higher percentage of eggs in 2001. In 2001 AZB and TQC both had a significantly higher percentage of combined Daphnidae and Copepoda eggs than all other locations in all other years, except for AZB in 2000 ($p < 0.05$).

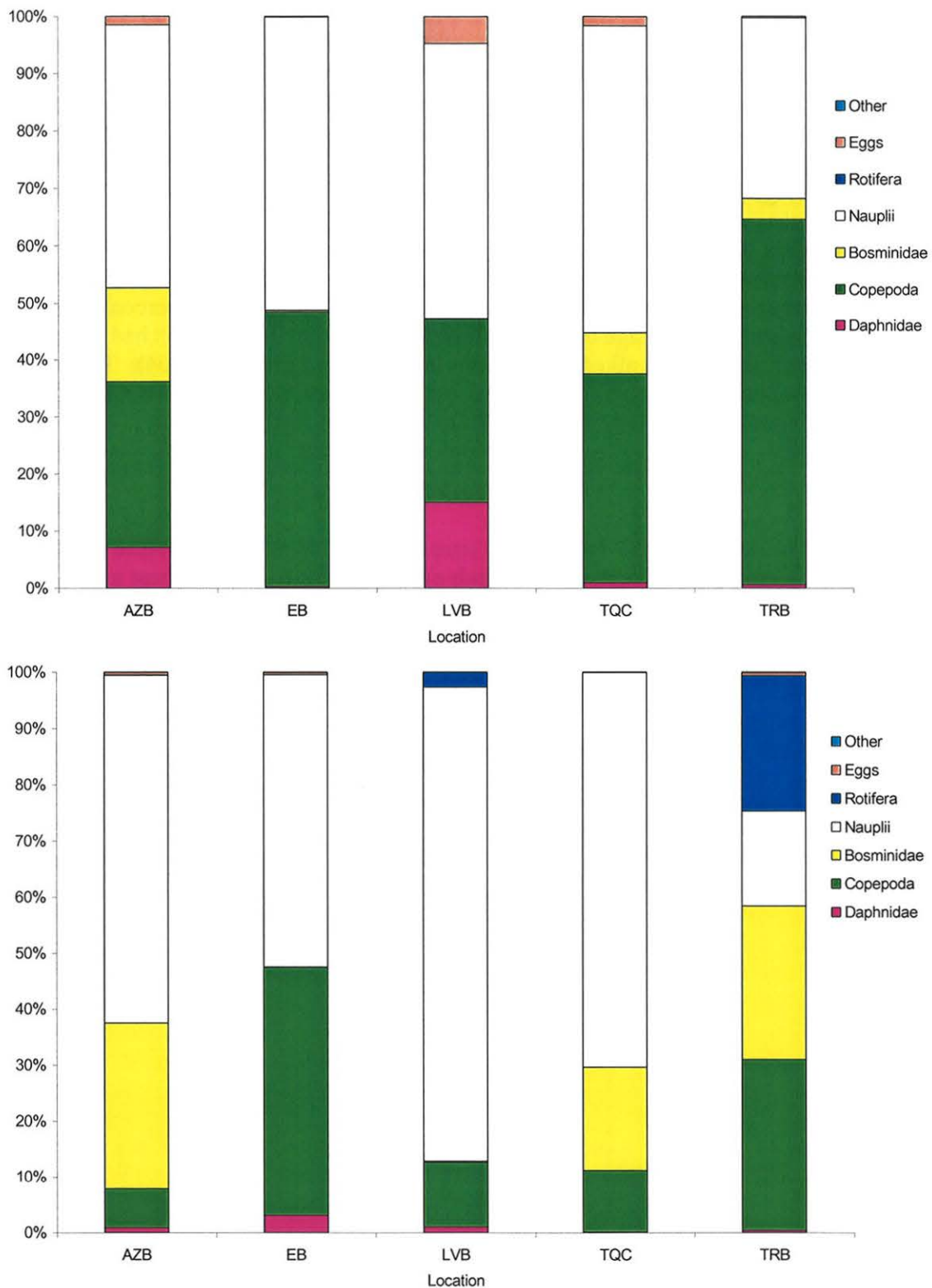


Figure 31. Percent composition of different taxa at each location in (a) March 2002 and (b) May 2002.

When we combined the data from all years we found that LVB had a significantly higher percentage of Daphnidae than all other locations in March ($p < 0.001$) but that no differences were seen in May (Figure 32). As we suspected from the other analyses, the Lake Mohave sites had a significantly higher percentage of Bosminidae than the Lake Mead locations in March ($p < 0.001$). However, in May TRB had the highest percentage of Bosminidae ($p < 0.001$), and only TQC from Lake Mohave was significantly higher than EB and LVB ($p < 0.02$).

Conversely, the Lake Mead locations had a higher percentage of adult Copepoda when data from all years were combined. All three Lake Mead locations had a significantly higher percentage of Copepods in March ($p < 0.001$), but in May only EB had a significantly higher percentage ($p < 0.02$). All stations had a similar percentage of Copepod nauplii except for TRB, which had a significantly lower percentage of nauplii than all other locations in March and May ($p < 0.04$). The percentage of Copepod and Daphnidae eggs was only significantly higher at AZB in May ($p < 0.004$), and the percent Rotifera was significantly higher at TRB in May ($p < 0.001$).

Cover

Cover continued to decline at the Lake Mead sites in 2002 (Figure 33). While no significant differences were seen between locations in March or May, AZB had the highest average percent cover and LVB and TQC had the lowest average percent cover (Table 1). At the onset of the study in 2000, EB and LVB had the highest average percent cover (Figure 34). Comparing the March data all years and locations, we found that mean percent cover at EB in 2000 was significantly higher than at AZB, LVB, TQC, and TRB in 2001 ($p < 0.04$) and higher than all locations in 2002 ($p < 0.04$). Additionally, the mean percent cover at LVB in 2000 was significantly higher than the mean percent cover at LVB and TRB in 2002 ($p < 0.05$). In May 2000 EB had significantly higher mean percent cover than LVB, TQC, and TRB in 2001 ($p \leq 0.02$), and EB, LVB, TQC, and TRB in 2002 ($p \leq 0.004$).

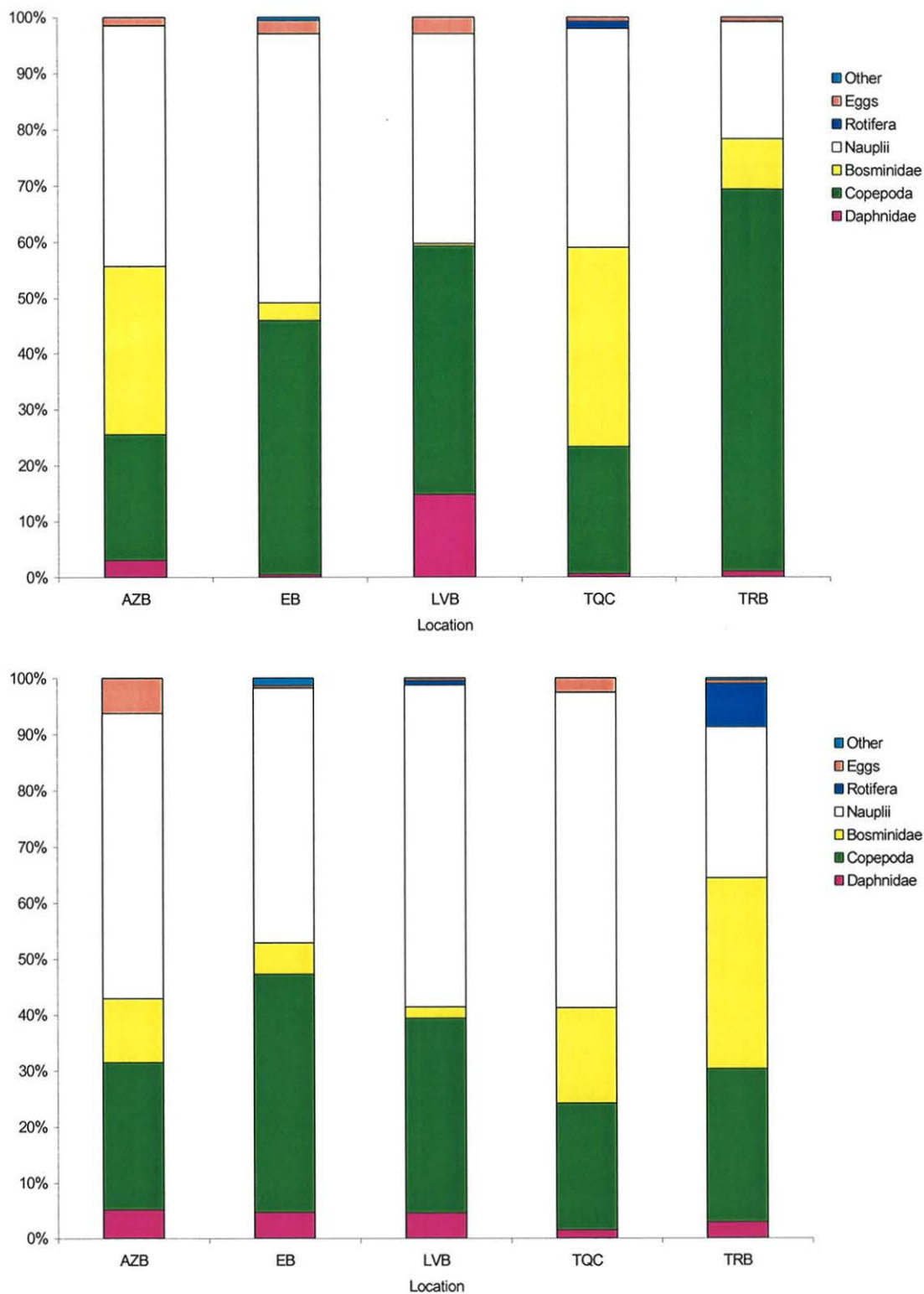


Figure 32. Percent composition of different taxa at each location in (a) March and (b) May from 2000-2002.

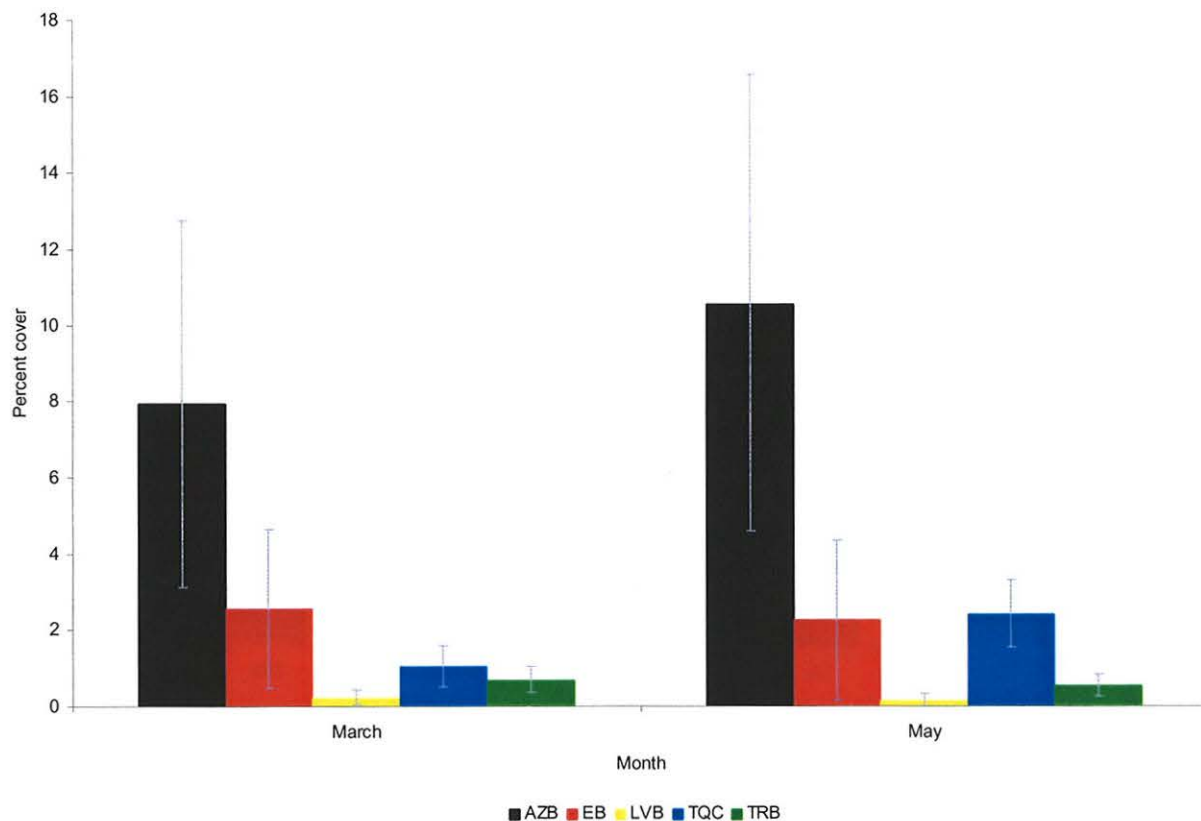


Figure 33. Mean percent cover at all locations in March and May 2002.

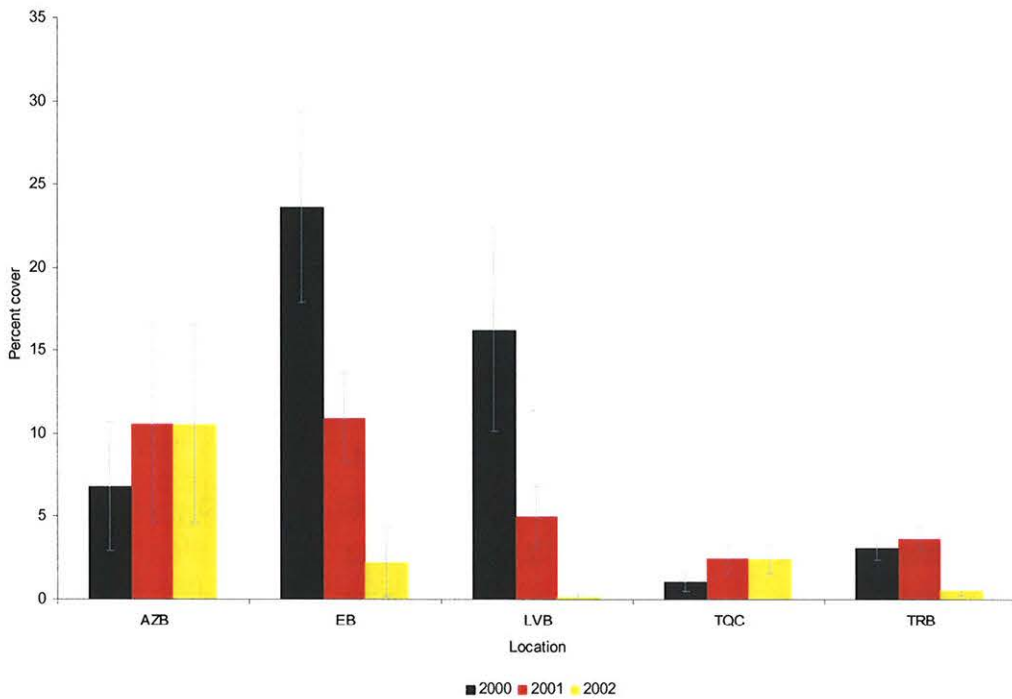
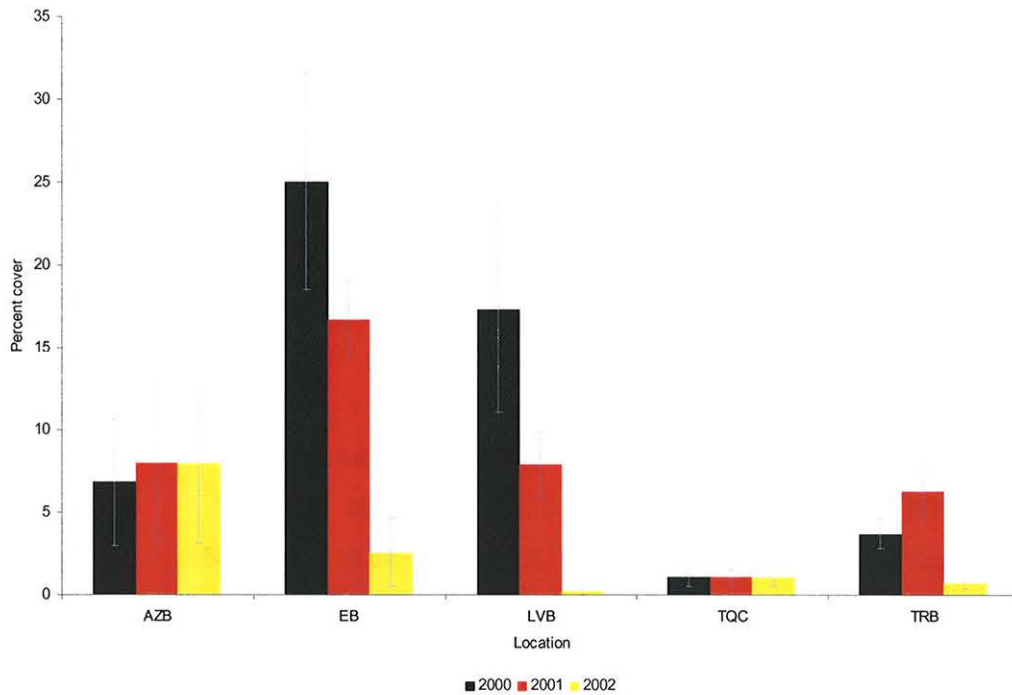


Figure 34. Mean percent cover at all locations from 2000-2002 in (a) March and (b) May.

Table 1. Area, area with cover, and percent cover estimates for all sites within each location in March and May 2002.

Year	Location	Site	March Area	May Area	March Cover	May Cover	March Percent Cover	May Percent Cover
2002	AZB	1	3,900	3,900	28.5	28.5	0.73	0.73
2002	AZB	2	4,000	4,000	533.4	771.8	13.3	19.29
2002	AZB	3	4,000	4,000	981.25	1195	24.53	29.88
2002	AZB	4	4,000	4,000	0	0	0	0
2002	AZB	5	4,000	4,000	47.7	118.95	1.19	2.97
2002	EB	1	2,425	1,700	10.94	0	0.45	0
2002	EB	2	2,590	2,259.5	2.09	0.7	0.08	0.03
2002	EB	3	4,000	3,688	15.8	10.05	0.4	0.27
2002	EB	4	3,950	3,554	39.39	9.75	1	0.27
2002	EB	5	3,500	3,256	379.75	347	10.85	10.66
2002	LVB	1	2,960	1,644.5	2.375	0	0.08	0
2002	LVB	2	2,975	2,550	0	0	0	0
2002	LVB	3	4,000	3,850	0	0	0	0
2002	LVB	4	4,000	3,620	0	0	0	0
2002	LVB	5	2,450	1,840	24.85	14.35	1.01	0.78
2002	TQC	1	3,800	3,800	73	201.25	1.92	5.3
2002	TQC	2	4,000	4,000	108	138.88	2.7	3.5
2002	TQC	3	3,500	3,500	4	52.92	0.11	1.5
2002	TQC	4	2,700	2,700	7.2	44.25	0.27	1.6
2002	TQC	5	3,400	3,400	7.2	7.2	0.21	0.21
2002	TRB	1	3,000	2,571	44.05	26.8	1.47	1.04
2002	TRB	2	3,445	3,173	1.4	0	0.04	0
2002	TRB	3	3,300	2,902.5	53.85	41.63	1.63	1.43
2002	TRB	4	2,940	2,700	2.13	0	0.07	0
2002	TRB	5	2,940	2,913	8.58	6.09	0.29	0.21

DISCUSSION

Evidence that recent razorback sucker recruitment has taken place in the lower Colorado River is limited. Many of the reservoirs, including Senator Wash Reservoir had an initial pulse of recruitment immediately after the reservoirs were filled (Minckley et al. 1991). Reproduction and even survival to the juvenile stage has been noted in several irrigation canals throughout the lower Colorado River (G. Mueller, United State Geological Survey, personal communication). However, the LVB and EB areas of Lake Mead appear to be the only areas with recent documented razorback recruitment into the adult life stage. The purpose of this pilot study was to try to isolate some of the factors that may be different at LVB and EB, and could potentially be creating conditions beneficial for razorback sucker recruitment. A review of the available literature suggested that at least LVB may have increased nutrients and food availability (Golden and Holden 2001). Additionally, Holden et al. (in press) also hypothesized that increased cover at LVB and EB may play a role in increased recruitment.

During the past three years Lake Mead reservoir elevations have decline substantially as a result of drought. Elevations were highest in 2000 and lowest in 2002. These changes in reservoir elevations couples with yearly variations in temperature and other weather conditions had some influence on the parameters we measured between years. Ammonium showed the most conclusive difference between years of all our water quality parameters. The level of ammonium was higher in 2001 during March and May at all sites. We attributed that difference to the large algal bloom and associated decomposition processes (Golden and Holden 2002). The other changes we saw between years were less consistent. Total P was higher at some sites in 2001 and at others in 2002. Differential amounts of wave action causing sediments to be stirred up on the day of sampling could account for the changes in total P levels. TDS and conductivity were higher at LVB in 2001 than all other years and locations. Increased flow from Las Vegas Wash during our sampling or increased ions in suspension associated with the algal bloom in 2001 could be responsible for this. In all cases, except for ammonium, the differences seen between years were variable and restricted to one or a few locations. By conducting sampling only twice in the spring, we can not account for short-term increases or decreases in nutrients caused by outside sources.

While some water quality parameters may have been varied over the 3 years of the study, the trends were generally similar. As we suspected from our original literature review (Golden and Holden 2001), LVB had the highest concentrations of nutrients and dissolved solids of all the locations examined. Sites from LVB, particularly the ones closest to Las Vegas Wash, had the highest NO₃-N, NH₄-N, and TDS measurements during each sampling period. Additionally, LVB usually had the highest total P measurement and the most sites with detectable total P. The influence of Las Vegas Wash on Las Vegas Bay is responsible for the higher nutrient levels in this location. We originally hypothesized that elevated nutrient levels in LVB may have been responsible for the razorback sucker recruitment seen there. However, EB and TRB had similar, and in some cases lower, nutrient levels than the sampled Lake Mohave locations. Since recruitment has been documented from the early 1990s at EB (Holden et al. 1999, Abate et al. 2002), increased nutrients do not appear to be the only factor responsible for razorback sucker recruitment in Lake Mead.

Zooplankton numbers were lower at most locations in March 2002 than they were in 2001 and even in 2000. The high numbers of zooplankton in March 2001 resulted from the large algal bloom that occurred during this time period, because increase in secondary productivity generally follows an increase in primary productivity. However, the fact that zooplankton numbers were lower at some locations in March 2002 than March 2000 is somewhat puzzling because we switched to a finer-sized mesh net after 2000. By using the smaller-sized mesh net, we expected to continue to catch increased numbers of zooplankton. However, we found that in May 2002 zooplankton numbers were higher than 2000 and 2001 at almost all locations. While we would have expected the May 2002 numbers to be higher than the 2000 numbers because of the change in mesh size, the 2001 algal bloom of 2001 continued well into May, which we expected to result in higher numbers of zooplankton.

However, the differences in zooplankton density also illustrate the limitations of our sampling protocol. Sampling on one discrete day at each location does not give a complete picture of the zooplankton community. Additionally, zooplankton are patchy in distribution, and traditional pelagic sampling methods sample several depth layers in order to encompass layers in which plankton may be clumped (Lind 1985). Sampling the littoral zone with horizontal tows, as we did, runs the risk of occasionally hitting dense patches of zooplankton. The variability in our replicate samples at individual locations, and even sites, from all years shows this.

Despite the variability in the data, a few trends in zooplankton density were evident over all 3 years. Echo Bay and TRB had lower total numbers of zooplankton than the LVB and Lake Mohave sites. The lower nutrient levels at these sites may explain the lower plankton densities. Mean density at EB and TRB averaged between or below the 10-20 zooplankton per liter identified as the critical food density for larval razorback sucker (Papoulias and Minckley 1990). Conversely, after we switched to the 80 μ m mesh net plankton, mean densities at the other three locations averaged between or above the 10-20 zooplankton/l. Of most importance was that mean zooplankton density at LVB and EB did not vary significantly from the Lake Mohave sites over the course of the study.

Several researchers have showed that larval razorback sucker may also prefer certain taxa or size classes of food items (Marsh and Langhorst 1988, Papoulias and Minckley 1992). Papoulias and Minckley (1992) showed that larval razorbacks around 20 mm in length preferred food items in the 0.3 mm range. Since razorback sucker are seldom found in Lake Mead between the time they are 18-20 mm and subadults, this length may be a critical point in the life cycle. Therefore, the density of zooplankton 0.3 mm and smaller may be more important than the total zooplankton density. However, the trends in small zooplankton density were quite similar to total zooplankton density: EB and LVB did not differ substantially from the Lake Mohave locations in a consistent way. Las Vegas Bay often had a slightly higher small zooplankton density, and EB often had a slightly lower zooplankton density than the Lake Mohave locations. However, LVB was the only location that averaged close to the 10 zooplankton/l mark for small zooplankton. Therefore, as with nutrient levels, razorback sucker larvae at LVB may be at a slight advantage when it comes to the density of food items. However, this is certainly not the case at EB.

In many of the collections we did see a difference in the taxonomic composition of the zooplankton communities at EB and LVB from the other locations and from each other. The LVB zooplankton community was comprised of more of Daphnidae than all other locations, and LVB and EB had a

larger component of adult Copepoda than the Lake Mohave locations. However, the Lake Mohave sites had a significantly greater component of Bosminidae than EB or LVB. Marsh and Langhorst (1988) found that larval razorbacks from Lake Mohave seemed to preferentially select Bosminidae over adult Copepoda, so the differences we saw in zooplankton community structure should favor Lake Mohave sites. However, community composition is ill represented by our sampling regime, perhaps even more so than zooplankton density. Many other researchers have noted the successional change in species composition that take place over the different seasons in these two systems (Baker et al. 1977, Paulson et al. 1980, Sollberger and Paulson 1992, Holdren et al. 1998, LaBounty et al. 1998). Therefore, it's possible that Lake Mohave and Lake Mead may have similar communities overall but may have been at different points in the seasonal succession when we have sampled them.

Our data show that nutrient and food availability differed between the five locations we sampled. However, EB had less nutrients and lower numbers of zooplankton than the Lake Mohave locations. The increased productivity of LVB may play a role in the razorback sucker recruitment we see at that location, but some other factor must be influencing recruitment at EB. We feel that cover from depredation is the important factor common to both EB and LVB that might allow increased recruitment at those locations. In the first year of the study, EB and LVB had convincingly higher levels of vegetative cover. As long-term drought and human water-use changes caused the levels of Lake Mead to drop over the course of the study, the amount of cover at all three Lake Mead locations declined substantially. Since Lake Mohave fluctuates on a more annual basis, cover at AZB and TQC remained relatively similar over the course of the study. Nevertheless, when Lake Mead was at higher levels, LVB and EB supported more cover than all other locations sampled.

While we found that the areas of Lake Mohave we sampled did not have large amounts of cover, dense submerged aquatic vegetation, including spiny naiad and *Potamogeton* sp. beds, has been noted in parts of Lake Mohave (G. Mueller, United State Geological Survey, personal communication). Submerged aquatic vegetation in both Lake Mead and Lake Mohave is generally seasonal in abundance, but the consistent elevations of Lake Mohave allow for more established beds. The inundated terrestrial vegetation we noted in EB and LVB is a year-round form of cover for young fish. The larval and juvenile stages of razorback sucker appear to be the most susceptible to depredation from nonnative fishes. The presence of cover throughout the duration of those critical life stages may be what distinguishes EB and LVB from Lake Mohave sites.

Additionally, LVB and EB had significantly higher turbidity levels than the other locations sampled. At LVB we can again attribute much of this to the influence of Las Vegas Wash, but at EB the cause of the increased turbidity is not easily discernable. One of the major factors attributed to the lack of recruitment in Lake Mohave is depredation on razorback sucker larvae by nonnative fishes (Marsh and Langhorst 1988, Minckley et al. 1991, Mueller 1995). Since Lake Mead and Lake Mohave do not differ substantially in their abundance of nonnative predators, then predator avoidance mechanisms for prey fish, including young razorback sucker, would seem critical to facilitate recruitment. Increased vegetative cover and turbidity could provide that mechanism. Several researchers have discussed how larval fish can use increased turbidity as cover (Stanley 1978, Gregory 1993), and Johnson and Hines (1999) showed increased survival of larval razorback sucker in experimental chambers with native and nonnative predators with increasing turbidity.

Cover in the form of submerged and emergent vegetation, or turbidity, appears to be an important variable that distinguishes LVB and EB from the locations we sampled in Lake Mohave, as well as TRB in Lake Mead. While cover was diminished at the Lake Mead locations in 2001 and 2002, the large, long-term fluctuations of Lake Mead that caused this reduction are also probably responsible for the higher amounts of cover we saw in 2000. After the initial sampling in 2000, we hypothesized that the climate-controlled water level of Lake Mead allowed more vegetation to grow on the shore while the lake level remained low in drier periods (Golden and Holden 2001). When a wetter cycle begins to fill Lake Mead, the vegetation is inundated as the lake rises. The vegetation growing along the recently dry shoreline of Lake Mead in 2001 and 2002 supports this assertion (Figure 35). Conversely, the annual 10-foot variation in the water level of Lake Mohave does little to promote large amounts of vegetation growing along the shoreline.



Figure 35. Vegetation growing on the recently dewatered shoreline of Echo Bay (EB) in 2002.

If increased cover is the variable allowing for recruitment at LVB and EB, then some years are probably better for recruitment than others. Periods of higher lake levels following periods of more prolonged, lower lake levels presumably would provide the most cover. A large proportion of the current razorback sucker population we've aged in Lake Mead appears to have recruited during the 1980s, a period of relatively higher water levels (Figure 36, Abate et al. 2002). Additionally, nine subadult razorback sucker have been caught in LVB during sampling from November through March

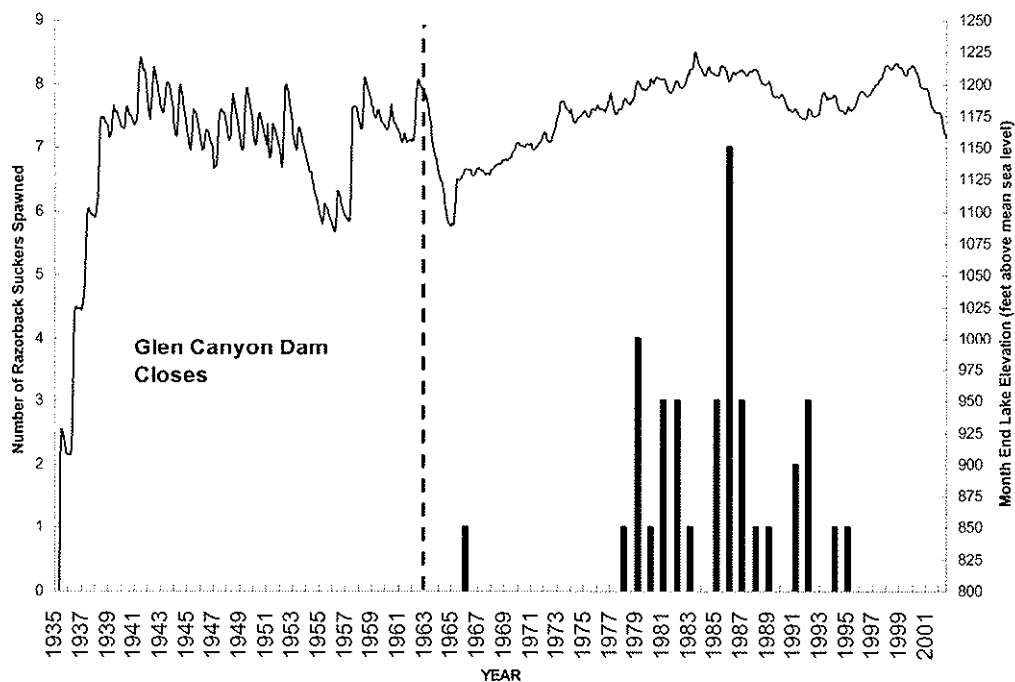


Figure 36. Number of razorback sucker thought to be spawned in each year based on pectoral fin ray analysis versus reservoir elevation.

2003. Based on the size of these fish and our past aging data (Holden et al. 1999, Holden et al. 2000a, Holden et al. 2000b, Holden et al. 2001, Abate et al. 2002), we would expect that they were probably spawned in 1997-1998, another period of rising lake levels. Thus, the large, long-term water level fluctuations in Lake Mead may be critical in providing vegetative cover, which benefits razorback sucker recruitment at LVB and EB.

CONCLUSIONS AND RECOMMENDATIONS

Data from this pilot study indicate that while higher nutrient levels and increased food availability may help to increase razorback sucker recruitment at LVB, they are certainly not responsible for the recruitment seen at EB. Instead, a reduction in depredation on larval and juvenile razorback sucker, resulting from increased cover, seems to be the more probable mechanism allowing recruitment in these two locations. Examining the lake level records and any water quality measurements relating to turbidity should allow us to determine what years were probably good cover years for razorback sucker larvae and juveniles. Continuing to collect and age adult razorback sucker from LVB and EB and comparing these data to lake level and water quality information will enable us to determine if larger numbers of razorback sucker have recruited in years when more cover was present. Compiling this evidence should solidify the link between cover and recruitment.

Additionally, Lake Mead has an abundance of bays and coves with cover. Understanding the type and density of cover necessary for recruitment success would be critical in any future management actions. Comparing cover types and density, as well as turbidity, at EB and LVB with other coves that do not support a population of razorback sucker would help elucidate that information. Additionally, gathering information on cover and turbidity in bays throughout the lake would provide helpful information for any future attempts to repatriate hatchery-reared razorback suckers, or attempts to locate additional populations of razorback suckers throughout Lake Mead.

Lake-wide surveys for larval razorback sucker in spring 1999 and 2000 only revealed one area outside of EB and LVB with larval razorback suckers (Holden et al. 2000a, Holden et al. 2000b). Eleven razorback sucker larvae were captured at the Colorado River inflow and Grand Wash Bay area in spring 2000. Subsequent intensified sampling conducted in this area in 2001 located 22 more razorback sucker larvae (Holden et al. 2001). No adults have been found, and no larvae were captured in 2002 (Abate et al. 2002). However, the dropping reservoir levels dramatically changed conditions in this part of the lake, which may have altered razorback sucker spawning behavior in this area (Abate et al. 2002). The influence of the Colorado River does provide turbidity, and under higher reservoir levels the inflow area had a large amount of inundated vegetation, so conditions were similar to what we found in EB and LVB. Comparable conditions probably occur in other areas of the lake, as well. We recommend concentrating on cataloguing the type and density of cover present in EB and LVB, and attempting to identify other areas in Lake Mead that might be suitable for maintaining a razorback sucker populations during any future study.

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