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HYDROACOUSTIC SUBSTRATE CLASSIFICATION ACCURACY AND
FAUNAL ASSEMBLAGE VARIATION BETWEEN ARTIFICIAL AND
NATURAL ROCK REGIONS: BEAR LAKE, UTAH/IDAHO

by

Mike Moon

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Ecology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

2007

ABSTRACT

Hydroacoustic Substrate Classification Accuracy and Faunal Assemblage
Variation Between Artificial and Natural Rock Regions: Bear Lake, Utah/Idaho

by

Mike Moon, Master of Science

Utah State University, 2007

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Department: Watershed Sciences

Research designed to elucidate artificial reef efficacy in attraction and production is lacking. Delineation of the rock reef habitat, coupled with faunal patterns of substrate use within artificial and natural reef regions, will allow elucidation of the potential of artificial reefs to attract sport fishes, and function as surrogate natural habitat for the conservation of endemic fish species. We compared faunal assemblages and habitat complexity between artificial and natural reefs to assess the efficacy of artificial reefs in conservation of the native community, and attraction of sport fishes.

We used hydroacoustics to map artificial and natural rock reefs within Bear Lake. We compared the accuracy of Visual Bottom Typer (VBT, BioSonics, Seattle, WA) software to observed substrate in three regions of varying slope and rock complexity within Bear Lake. VBT demonstrated an ability to distinguish substrates regardless of rock complexity and slope, although inaccuracies were present. VBT biased classification towards predominant substrate in the survey regions.

We compared benthic invertebrate and fish catch in natural and artificial reef regions to assess the utility of artificial reefs in fisheries management. We assessed the potential of artificial reefs to function as foraging habitat for endemic fishes within Bear Lake. We compared benthic invertebrate taxa abundances and diversity between one region of artificial reefs, and two natural reefs in spring and summer. The artificial reefs hosted prey consumed by endemic Bonneville whitefish and Bear Lake sculpin. We assessed the potential of artificial reefs to function in attraction of sport fishes, and conservation of endemic fishes. We compared differences in fish catch per unit effort (CPUE) and diversity on rock and soft substrate between one artificial and two natural reef regions. Sport fishes attraction to the artificial reefs was minimal. Winter cisco and whitefish used the artificial reefs similarly to natural reefs. Fall lake trout, crayfish, and yellow perch used artificial and natural reefs dissimilarly.

(156 pages)

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Mike Moon

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CHAPTER 1

INTRODUCTION

Artificial reefs are structures placed in a body of water to influence the aquatic community. Desired influences on the community include attraction of fish to increase catchability, and indigenous fauna use of artificial reefs as surrogate habitat (Bohnsack 1989, Lindberg 1997). The degree artificial reefs function to concentrate fish for angling versus the degree they benefit fish production affects fish populations (Bohnsack 1989). Artificial reefs may be less complex than natural reefs (Grove et al. 1991), and may not support indigenous faunal assemblages (Bulleri and Chapman 2004, Perkol-Finkel and Beneyahu 2007), since the complexity of benthic habitat influences fish assemblage (Tonn and Magnuson 1982; Pratt and Smokorowski 2003).

Research designed to elucidate artificial reef community ecology, production, and population life histories and dynamics (Steimle and Meier 1997), as well as research incorporating ecological theory (Lindberg 1997), are lacking. Quantitative comparisons of artificial and natural reefs use by fish are problematic due to the complexity and variability of aquatic systems, the scale necessary for sampling, and the accuracy of the measurements required (Lindberg 1997). Delineation of the rock reef habitat, coupled with faunal patterns of substrate use within artificial and natural reef regions, will allow elucidation of the potential of artificial reefs to attract sport fishes, and function as surrogate natural habitat for the conservation of endemic fish species. The attraction and production potential of the artificial reefs relate to artificial reef theory. We compare faunal assemblages and habitat complexity between artificial and natural reefs to access

the efficacy of artificial reefs in conservation of the native community, and attraction of sport fishes.

The attraction versus production issue relates the degree artificial reefs function to concentrate fish for angling, versus the degree they function to increase fish recruitment (Bohnsack 1989). The attraction versus production issue is described by two hypothetical responses to artificial reefs, production and attraction, which are detailed by Bohnsack (1989). The production hypothesis predicts the additional foraging, spawning, and shelter offered by artificial reefs will increase fish biomass. The attraction hypothesis predicts initial increases in catchability from attraction to artificial reefs, without increases in recruitment, will reduce fish populations (Bohnsack 1989). The attraction versus production issue has been difficult to answer due to the complexity and variability of aquatic systems, the scale necessary for sampling, and the accuracy of the measurements required (Lindberg 1997).

Artificial reefs may not function as surrogate natural habitat for indigenous communities due to differences in reef complexity (Bulleri and Chapman 2004, Perkol-Finkel and Beneyahu 2007). Faunal parameters vary with natural habitat complexity (Tonn and Magnuson 1982; Eadie and Keast 1984; Stang and Hubert 1984; Brazner and Beals 1997; Weaver et al. 1997; Pratt and Smokorowski 2003), and artificial reef complexity (Freitas and Petrere 2001; Nanami and Nishihira 2003a and 2003b; Gratwicke and Speight 2005). The association of species and assemblages to natural and artificial habitat allows assessment of the suitability of artificial reefs to host flora and fauna.

The facilitation of data collection over large spatial scales, via hydroacoustic technology, is advantageous to fisheries managers since aquatic communities are influenced from processes operating at small to large scales (Lewis et al. 1996). Current hydroacoustic methodologies allow rapid data collection on aquatic substrate, flora, and faunal characteristics over large areas (Hoffman et al. 2002), but studies on measurement accuracies are limited. Field sampling methods, such as videography and substrate sampling via benthic grabs, are labor intensive and cost-prohibitive for large scale sampling (Vis et al. 2003). Methods that allow large scale mapping of terrestrial habitat, such as satellite remote sensing and aerial photography, are frequently inept in mapping underwater habitat (Vis et al. 2003; Valley et al. 2005; Nelson et al. 2006). Habitat Suitability Indices (HSI) use habitat parameters to assess compatibility of an organism to an area (United State Fish and Wildlife Service 1981). Variability in HSI input parameters, such as substrate composition, affect the performance of HSI models (Roloff and Kernohan 1999; Van der Lee et al. 2006). Hydroacoustics can contribute to HSI by quantifying substrate, but the accuracy of the information needs verification.

The Bear Lake artificial reefs provide an opportunity to assess the accuracy of hydroacoustics. Anthropogenic use of Bear Lake as a reservoir, coupled with drought, dewatered rock habitat located near the shoreline, altering the habitat available to the aquatic fauna. The reduction of rock habitat alters the habitat complexity within the lake. To alleviate the loss of rock habitat four artificial reefs were constructed on a gentle slope in Bear Lake in October 2005. There are two large natural reefs within Bear Lake. One forms a gentle slope, while the other a steep slope. Thus, the accuracy of hydroacoustic substrate classification in relation to rock complexity (area) and slope can be evaluated.

Bear Lake also provides an opportunity to evaluate the potential of artificial reefs in conservation of endemic fishes, and attraction of sport fishes, by comparing biological assemblages between artificial and natural reefs. Bear Lake is rock and macrophyte limited and located in an arid region prone to drought. Drought dewateres rock along the eastern shore, which reduces rock habitat within the lake. Bear Lake contains four endemic fish species, all of which show a preference for spawning on rock habitat (Bouwes and Luecke 1997, Ruzyski 1998, Albrecht 2004). The artificial reefs are located in an area not historically subjected to dewatering in Bear Lake. Thus, the artificial reefs should compensate for rock habitat loss during drought and provide additional habitat during normal water levels.

Hydroacoustic data, coupled with global information systems (GIS) and faunal data, will aid management of the Bear Lake fish community. GIS maps produced from hydroacoustic substrate data will allow quantification of habitat availability as lake levels fluctuate. Faunal data associated with habitat within Bear Lake will allow predictions of the fauna response to water level perturbation. Difference between artificial and natural reef fish assemblages will elucidate the potential of artificial reefs in conserving endemic fishes and attracting sport fishes.

The hydroacoustic objectives for this study were to test two hypotheses. The first hypothesis was that hydroacoustic classification accuracy will decrease as slope of the sampled substrate increases. Specifically, we predicted that classification accuracy over a steep lake bottom region will be lower than two gentle slope regions within Bear Lake. The second hypothesis was that hydroacoustic classification accuracy would not be influenced by the rock complexity of the surveyed areas. Specifically, we predicted no

significant difference in accuracy between one region with a small rock area and two regions with comparably larger rock areas within Bear Lake.

Faunal objectives focused on benthic invertebrates and fish catch and diversity. The benthic invertebrate objective of this study was to assess the potential of artificial reefs to function as foraging habitat for endemic fishes within Bear Lake, UT/ID. We compared benthic invertebrate taxa abundances and diversities between one region of artificial reefs, and two natural reefs. We predicted similar abundances on the artificial and natural reefs. Patterns of benthic invertebrates on artificial and natural reefs were evaluated in relation to the diet of endemic fishes.

The objectives of the fish study were to determine the potential of artificial reefs to function as conservation agents and to attract sport fishes. We hypothesized that fish catch will show a similar pattern in relation to rock and soft substrate within an artificial reef region, as to substrate catch pattern within two natural reef regions. Additionally we hypothesized that diversity differences between rock and soft substrate in natural reef regions, will be similar to the diversity pattern on different substrates in the artificial reef region. Specifically we tested for differences in fish catch per unit effort (CPUE) and diversity between artificial and natural regions, and rock and soft substrates. Measurements of parameters were compared on different substrates within each region to assess the utility of artificial reefs.

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CHAPTER 2

HYDROACOUSTIC SUBSTRATE CLASSIFICATION ACCURACY
BETWEEN LAKE REGIONS OF VARYING TOPOGRAPHY AND
ROCK COMPLEXITY, BEAR LAKE, UTAH/IDAHO¹

Abstract.—We compare the accuracy of Visual Bottom Typer (VBT, BioSonics, Seattle, WA) software on rock and soft substrate in three regions of varying slope and rock complexity within Bear Lake, Utah/Idaho. Hydroacoustics technology is advantageous compared to field and remote sensing sampling, due to the ability of hydroacoustic to sample large areas underwater. Evaluation of the accuracy of hydroacoustic substrate classification is necessary to insure quality data for the association of habitat to measurements of lake fauna. Four artificial reefs were constructed in Bear Lake to compensate for the loss of rock habitat during drought. We determined sampling accuracies on rock and soft substrate in regions of artificial and natural reefs. These regions differed in rock area and lake bottom slope. We predicted VBT classification accuracy would decrease as slope increased, but accuracy would not change with variations in rock complexity. VBT demonstrated an ability to distinguish substrates regardless of rock complexity and slope, although inaccuracies were present. VBT classification accuracy for rock substrate was significantly better than for soft substrate. When regions of similar slope were isolated, the accuracy in the high rock complexity region was significantly higher on rock compared to the low rock

¹Coauthored by Mike Moon and Chris Luecke

complexity region. Although not significant, VBT soft classification was higher in the region with a small rock area. These inaccuracies suggested a VBT classification bias towards predominant substrate. The influence of slope on classification accuracy was less than the influence of rock area. Sampling methodology, hydroacoustic resolution, rock formation, and variation in acoustic signal may have influenced results. We discussed the implications of hydroacoustic inaccuracies to management of the Bear Lake fisheries.

Introduction

Collection of data over large spatial scales, via hydroacoustic technology, facilitates understanding of the processes that operate over large areas, and influence aquatic communities (Lewis et al. 1996), but large scale data collection is problematic for some sampling methodologies. Field sampling methods, such as videography and substrate sampling via benthic grabs, are labor intensive and cost-prohibitive for large scale sampling (Vis et al. 2003). Methods that allow large scale mapping of terrestrial habitat, such as satellite remote sensing and aerial photography, are frequently inept in mapping underwater habitat (Vis et al. 2003; Valley et al. 2005; Nelson et al. 2006). Current hydroacoustic methodologies allow rapid data collection on aquatic substrate, floral, and faunal characteristics over large areas (Hoffman et al. 2002, Vis et al. 2003), but studies on measurement accuracies are limited. Assessment of the reliability of hydroacoustic information requires verification of the accuracy of the hydroacoustic measurements. We evaluate the accuracy of hydroacoustic measurements of substrate in Bear Lake, Utah (UT)/Idaho (ID). We discuss the mechanics of hydroacoustic

measurements and the variations between hydroacoustic gear and software related to measured parameters in Appendix I.

Previous research on the accuracy of hydroacoustics included comparisons between hydroacoustic hardware and software, and comparisons between hydroacoustic and ground-truth measurements. Variation in hydroacoustic hardware included beam pattern, beam shape, and frequency. Good agreement between different hardware were reported for measurements of fish biomass (Wanzenbock et al. 2003), fish target strengths (Gauthier and Rose 2002; Guillard et al. 2004), backscatter volumes (Guillard et al. 2004), and fish density (Parkinson et al. 1994). Precision in the temporal repeatability of fish biomass measurements was obtained with similar hydroacoustic gear (Wanzenbock et al. 2003). Inaccuracies due to hydroacoustic gear variation included a single-beam transducer bias towards smaller fish targets in freshwater (Rudstam et al. 1999), and significantly poorer submerged aquatic vegetation (SAV) boundary spatial placement with a lower frequency transducer (Hoffman et al. 2002). Hydroacoustic and ground-truth measurements were similar for fish density (Parkinson et al. 1994), and SAV characteristics (Sabot et al. 2002; Winfield et al. 2007), but hydroacoustic software measurements of plant occupied water column were lower than ground-truth measurements (Valley and Drake 2005).

Studies on the accuracy of hydroacoustic substrate classification relate software classification accuracy in relation to sampling methodology and topography. Hamilton et al. (1999) observed the first hydroacoustic echo was independent of changes in ship speed for two different substrate analyzers, but the second echo displayed additional noise and variability for a multi-echo analyzer. von Szalay and McConnaughey (2002)

found substrate classification by a single-echo analyzer was unaffected for speeds between 3 and 12 knots, but classification was affected by even modest slopes.

Determining hydroacoustic measurement accuracy is important since previous research has shown the potential efficacy of hydroacoustics in aquatic research. Scheuerell (2004) analyzed hydroacoustic data to determine predator and prey relationships at varying scales and times of day. Analysis of hydroacoustic data detected changes in fish abundance and spatial distribution after discontinuation of rainbow trout stocking (Elser et al. 1995). Godlewska et al. (2004) evaluated studies with hydroacoustically determined fish densities in lakes and reservoirs and found fish densities increased as eutrophication increased, as water level flux decreased, and as artificial heating increased. Juvenile Atlantic cod (*Gadus morhua*) habitat was mapped by classifying hydroacoustic signal to ground-truth observations (Collins et al. 1996).

Researcher also inputted hydroacoustic data into Global Information Systems (GIS) to elucidate aquatic systems. GIS analyses explained more variation in fish density with landscape data than models based on site measurements (Creque et al. 2005), delineated territories of two coral reef fishes (Righton and Mills 2006), and mapped the probability of flounder (*Pseudopleuronectes americanus*) capture based on habitat measurements (Stoner et al. 2001). Coupling of hydroacoustic and GIS technologies determined shellfish habitat, where poor visibility prevented videography (Smith and Greenhawk 1998), the magnitude and direction of near shore substrate change over time in the Great Lakes (Mackey and Liebenthal 2005), and the relationship between benthic habitat and fish distribution (Lathrop et al. 2006). Interpolation of hydroacoustic data

with GIS produced accurate maps of the percent of the water column occupied by SAV (Valley et al. 2005).

Inaccuracies of hydroacoustic substrate classification may lead to incorrect interpretation of important management information. The complexity of benthic habitat has been correlated with variations in fish measurements including diversity, assemblage, abundance, and richness (Tonn and Magnuson 1982; Eadie and Keast 1984; Stang and Hubert 1984; Brazner and Beals 1997; Weaver et al. 1997; Pratt and Smokorowski 2003). The association of species and assemblages to habitat parameters allows assessment of the suitability of habitat to host flora and fauna. Habitat Suitability Indices (HSI) use habitat parameters to assess compatibility of an organism to an area (United State Fish and Wildlife Service 1981). Variability in HSI input parameters, such as substrate composition, can affect the performance of HSI models (Roloff and Kernohan 1999; Van der Lee et al. 2006). Thus, to limit inaccuracies entering models, it is necessary to evaluate the tools used in measurements, such as hydroacoustics.

The installation of four artificial reefs within Bear Lake allows comparisons of hydroacoustic substrate measurements between regions of different rock complexity and slope. There are two natural reefs within Bear Lake, one on a gentle slope, and the other on a steep slope. The artificial reefs are located on a gentle slope, but have a small area of rock compared to the natural reefs.

Delineation of Bear Lake reef substrate will aid in the management of fisheries. Use of Bear Lake as a reservoir, coupled with drought, dewatered rock habitat located near the shoreline, altering the habitat available to the aquatic fauna. The reduction of rock habitat alters the habitat complexity within the lake, which may alter the faunal

community (Tonn and Magnuson 1982; Eadie and Keast 1984; Stang and Hubert 1984; Brazner and Beals 1997; Weaver et al. 1997; Pratt and Smokorowski 2003). In Bear Lake, there are four endemic fish species all of which primarily spawn on rock (Albercht 2004; Bouwes and Luecke 1997; Ruzycki 1998). GIS maps produced from hydroacoustic substrate data will allow quantification of the change of habitat type as lake levels fluctuate. Faunal data associated with habitat within Bear Lake will allow predictions of the fauna response to water level perturbation. This information will elucidate recruitment and fitness changes based on available habitat. To insure quality data is provided for management decisions, the accuracy of the hydroacoustic substrate classifications needs to be verified.

We used hydroacoustics and videography to assess the utility of hydroacoustic substrate classification in delineating regions containing artificial and natural reefs. The objectives of this study were to test two hypotheses. The first hypothesis was hydroacoustic substrate classification accuracy will decrease as slope of the lake bottom increases. Specifically, we predicted that classification accuracy in a region with a large natural reef and steep slope will be lower than two gentle slope regions, one with a large rock reef, and the other with the artificial reefs. The second hypothesis was that hydroacoustic substrate classification accuracy would not be influenced by the difference in rock complexity between the surveyed areas. Specifically, we predicted no significant difference in accuracy between the artificial reef region, with a small rock area, and two natural reef regions with comparably larger rock areas. We compared proportions correctly classified, accuracies, and agreement to elucidate differences based on regional slope and rock complexity.

Methods

Study site.—Bear Lake is an oligotrophic lake, approximately 282 km² in area, containing 7.86 km³ of water and is 1,805 meters in elevation at full pool. It is located in northeast Utah and southwest Idaho at latitude 42° 00' North and longitude 111° 20' West (Figure 2-1). Bear Lake is oval shaped, with the longer axis laying north to south and bisected by the Utah/Idaho boarder. The western shore slopes gradually to its maximum depth of approximately 63m; the mean depth is 28m at full pool. The eastern shore drops abruptly and the lake displays classic tilt-block morphology.

Four artificial reefs were built in October 2005 on sites located 200-1,000m north of Bear Lake marina at approximately 10m depth. The reefs were built to attract sport fishes and for conservation of endemic Bear Lake fish fauna. A total of 720m³ of rock was used in construction, with each reef being built from 180m³ of rock. Mean intermediate length for the artificial reef rock was 0.119m with a standard deviation of 0.030m (N = 100). From south to north, the artificial reefs were labeled as AR1, AR2, AR3, and AR4.

Data were collected in three regions of Bear Lake, the artificial reef region (*Artificial*) and two natural reef regions (*Natural 1* and *Natural 2*) (Figure 2-1). The four artificial reefs were the only hard substrate within the *Artificial* region, and were located on a gentle slope. The *Artificial* region represented the low rock complexity and a gentle slope region. The *Artificial* region survey site encompassed an area approximately 123,000m² and depth ranged from approximately 5 to 17m for lake elevation of 1,801.675m. *Natural 1* was located along Bear Lake's steep eastern shore and contained

a large area of rock. *Natural 1* represented a high rock complexity and the steep slope region. The *Natural 1* survey site encompassed an area approximately 995,500m², and depth ranged from approximately 1 to 53m for lake elevation of 1,801.675m. *Natural 2* (locally referred to as the *rockpile*) contained a large area of rock. *Natural 2* represented a high rock complexity and a gentle slope region. The *Natural 2* survey site encompassed an area 549,600m² and depth ranged from approximately 4 to 24m for lake elevation of 1,801.675m.

Benthic substrate data collection.—A split-beam BioSonics DE 6000 420 kHz echo sounder with an elliptical transducer (BioSonics, Seattle, Washington, USA), and a JCR digital GPS were used to map the bottom in three regions of Bear Lake. Threshold was set at -80dB. Ping rate was set to one ping per second and pulse duration was set at 0.4 milliseconds. The transducer was lowered from the bow of a 7.62m ALMAR research vessel and towed approximately 0.5m below the surface at 1m per second. Data were recorded with a laptop using BioSonics Visual Acquisition Software version 4.02.

The transducer transmitted a signal with a 6 degree apex in the direction of travel, and a 2 degree apex perpendicular to the direction of travel. The receiving elements formed a circular cone with an apex of 15 degrees. Thus, each ping of data represented an area of substrate beneath the boat equivalent to the equation:

$$Area = \pi[(Depth \bullet \tan(1))(Depth \bullet \tan(3))],$$

where 1 and 3 represented half of the ellipse apex angles, and depth was the distance from the transducer to the bottom.

Hydroacoustic surveys were conducted on April 09 and 13, August 10, and September 16, 2006 for the *Artificial* region. *Natural 1* hydroacoustics were done on

August 2 and 10, and September 16, 2006. *Natural 2* hydroacoustics were done on April 13, August 2 and 10, and September 8 and 16, 2006. The research vessel traveled north-south and east-west transects for *Artificial* and *Natural 2* surveys. The vessel traveled north-south transects, and a zig-zag pattern from north to south, for the *Natural 1* survey.

Hydroacoustic data were analyzed for substrate type using BioSonics Visual Bottom Typer 1.10 (VBT) software, method B4. The B4 method analyzed the first bottom echo with fractal dimension and cluster analysis to group similar signals (Burczynski et al. 2005). The groups were classified by training data obtained over known substrate type. Training data substrate type was verified with underwater video. Rock and soft training data from *Artificial* was used in VBT analyses of *Artificial* and *Natural 2*. This data was obtained at approximately 10m depth. Due to the possibility of the steep eastern slope distorting the echo signal, rock and soft training data obtained on *Natural 1* were used in VBT analysis of *Natural 1*. VBT software was set to average 10 pings to damping variation in echoes, partially caused by lake surface conditions altering the transducer angle to the bottom (Burczynski 2001). The vessel traveled approximately 10m during the 10 ping average.

VBT output files consisted of the ping number, sample date, time, latitude, longitude, depth, substrate code (0 = soft, 1 = rock, 2 = unidentified), and echo parameters. The echo parameters were: E0 (energy of sediments echo), E1 (energy of second part of 1st bottom echo), E2 (energy 2nd bottom echo), E12 (energy of first part of 1st bottom echo), Sediment (thickness of the sediment layer), and FD (fractal dimension) (Burczynski et al. 2005). VBT unidentified substrate classifications were omitted from analyses.

VBT output files were modified in two ways. First, data for duplicate GPS coordinates were averaged. Hydroacoustic data latitude and longitude were converted to Universal Transverse Mercator (UTM) zone 12 with North American Datum (NAD) 1983. The mean substrate type, depth, elevation, and echo parameters were determined for duplicate coordinates. Duplicate coordinates with different substrate classification produced values between 0 (soft) and 1 (rock) classification. Assignment to a substrate occurred by values less than 0.5 classified as soft and values greater than or equal to 0.5 classified as rock. Second, the elevation of each datum collected was determined by taking the weighted mean of elevations for the date before and after the sample date. Reported elevations were obtained from Bear Lake Watch, Inc (<http://www.bearlakewatch.com>). Depths and elevations were adjusted for transducer depth and standardized to surface elevation on April 09, 2006 (1801.675m).

Videography was used to collect observed substrate in the three lake regions. An underwater video camera, mounted approximately 1.5m above a 1 x 1m quadrat, was lowered from the lake surface onto the substrate below in each of the three hydroacoustic regions (Figure 2-2a). The selection of quadrat sites never exceeded 15m due to decreasing visibility with increasing depth. *Artificial* videography occurred on and near the artificial reefs sites to insure some videography observations were on the small rock area in the region. *Natural 1* videography ranged from VBT classified soft substrate, south of a large rock stretch, to VBT classified soft substrate north of the rock stretch. *Natural 2* videography occurred near predetermined rock substrate depths less than 15m in order to keep the quadrat at a visible depth, and sample both substrates. Both VBT classified rock and soft substrates were located within videography survey regions. Two-

hundred and forty video quadrats were collected in *Artificial* and *Natural 2*, and 241 were collected in *Natural 1*. Equal spacing between quadrat sites were attempted for *Natural 1* and *Natural 2*, but due to boat drift this was not always achieved. Means and standard deviation of the distances from one quadrat to the nearest quadrat were: mean 3.50m and standard deviation 2.77m for *Artificial*, 6.06m and 3.34m for *Natural 1*, and 3.34m and 1.71m for *Natural 2*.

Quadrat deployments were recorded onto miniDV, then converted to DVD to capture video stills of quadrat on bottom. All quadrat GPS locations were recorded in UTM zone 12 and NAD 1983. One pair of duplicate quadrat coordinates were found in *Artificial* and 2 found in *Natural 1* and in *Natural 2*. Duplicate quadrat coordinates were ignored since care was taken in the field not to set the quadrat down on the same site.

Classification of videography substrate occurred by collection of video stills of the quadrat on the bottom. Quadrat video stills were classified as rock (> 60% rock), soft (> 60% soft), and mixed (40-60% rock or soft). Video stills, in which a greater than 60% majority of a substrate was difficult to determine, were added as a layer in ESRI ArcMap 9.2 (Figure 2-2b). Polygons were created for the area within the quadrat, and for the soft substrate within the quadrat (Figure 2-2c). The areas of both polygons were calculated in ArcMap using default unidentified units for non-spatially referenced layers. The proportion soft within the quadrat was determined by dividing the area of the soft polygon by the area of the quadrat polygon. The proportion rock within the quadrat was then calculated by subtracting the soft proportion from 1.

VBT correct and incorrect classification.—Correct classification of substrate by VBT was determined using ESRI ArcMap 9.2. All quadrat points were associated to

their UTM coordinates and substrate classification. All hydroacoustic points were assigned a VBT determined substrate. Quadrat and hydroacoustic data were projected in UTM zone 12 with NAD 1983. Every quadrat point was associated to the nearest hydroacoustic point, and VBT and videography substrate classifications were compared. The number of VBT and videography matching classifications were recorded as correct, and the classifications not matching were recorded as incorrect. Correct and incorrect numbers and proportions were determined for each region and substrate (rock and soft). Standard deviations for binomial distributions of counts were calculated using the formula:

$$\sigma = \sqrt{npq},$$

where σ was the standard deviation, p was the proportion belonging to a group (i.e. rock, soft, both), and n was the total number of observations.

VBT classification accuracy.—Differences in VBT classification accuracy were determined using a chi-squared test of homogeneity of proportions. If proportions correctly and incorrectly classified were similar between regions and substrates, the distributions were also similar. Significant differences in distributions were determined by p-values less than or equal to 0.10. Initial chi-squared tests were run to compare differences in VBT classification accuracy between the regions using the combined substrate data (*Both*), and to test the accuracy between substrate using the combined region data (*All*). Chi-squared tests were then preformed for each substrate to compare accuracy of VBT classification for each substrate between regions. The observed substrate numbers were subtracted from the chi-squared expected numbers to explain significant chi-squared results.

VBT and videography classification agreement.—Agreement between VBT and videography classification was measured with a Cohen's kappa test (Cohen 1960) in R 2.4.0. The kappa test was developed to test the agreement between two different raters. For this study the raters were videography and VBT classification of rock and soft. The kappa test calculated the frequency of matches that would occur from chance alone from the correct and total observations. This value was then subtracted from the number of correct and total observations. The quotient of adjusted correct over adjusted total was then determined. The kappa statistics were determined for all regions combined, and within each region to find the overall and within region agreement. Ninety percent confidence intervals for each kappa value were found by bootstrapping.

Slope and rock area.—ESRI ArcMap 9.2 was used to determine the slope of the lake bottom, and estimate rock areas. Data was projected in UTM zone 12 with NAD 1983. Universal kriging was used to create elevation prediction maps from hydroacoustic data for the survey regions. The mean degree slope was determined from each region's interpolated elevation raster. The mean distance from hydroacoustic rock waypoints to the nearest hydroacoustic waypoint, rock or soft, was determined for each region. Each region's mean distance was set as a buffer length for hydroacoustic rock waypoints within the region. The area of the buffer without overlap was determined to provide an estimate of rock area within each region. This buffer allowed rock area estimates to be based on hydroacoustic resolution within each surveyed region.

Results

Proportions of substrate classified as rock and soft substrate by videography and VBT differed between regions. Approximately 51% of the total quadrats were rock (Table 2-1). Two quadrates classified as mixed substrate were found within *Artificial* and *Natural 2*, and 4 within *Natural 1*. Comparison of mixed substrate quadrats between regions was not preformed, due to the low number of mixed substrate quadrats making statistical analysis unreliable.

The number of hydroacoustic points for all three regions were similar but unidentified points, substrate classification, the number of unique coordinates, and the distance between quadrats and nearest hydroacoustic points differed between regions (Table 2-2, Figures 2-3 to 2-5). Unique UTM hydroacoustic coordinates were lowest in *Artificial* due to sampling effort being confined to a small area around the artificial reefs. VBT classified approximately 23% of the total hydroacoustic sample points as rock. A lower proportion of VBT classified rock was found in *Artificial* than in the natural regions. Distances from quadrats, to the nearest hydroacoustic point, varied by region and substrate (Table 2-3).

VBT correct and incorrect classification.—Generally, hydroacoustics and VBT demonstrated an ability to correctly classify substrate, although differences existed between regions and substrates (Figures 2-6 to 2-8). *Natural 2* had the highest proportion of substrate correctly classified, followed by *Natural 1*, then *Artificial* (Table 2-4 and Figure 2-9). Proportions correct were higher on rock except for *Artificial*, which had approximately two-thirds of rock and soft substrate classified correctly. *Natural 1* rock

was always correctly classified by VBT, but soft substrate correct classification was the lowest for all regions. The proportion of VBT rock and soft correctly classified was intermediate in *Natural 2* compared to the other regions. The number of quadrats correctly and incorrectly classified by VBT for each region and substrate are in Table AII-1, Appendix II.

VBT classification accuracy.—All chi-squared tests were significant indicating dissimilar distributions in VBT accuracy between regions and substrates (Table 2-5). VBT accuracy was higher in the natural regions than in *Artificial* when substrates were combined (Table 2-6). VBT accuracy was higher for rock substrate when regions were combined. Tests of individual substrates found *Artificial* had a lower than expected number of correct rock and a higher than expected number of correct soft. *Natural 1* displayed the opposite pattern of *Artificial*, with numbers of correct rock higher than expected and soft lower. The expected and observed were similar for both substrates for *Natural 2*.

VBT and videography classification agreement.—The kappa statistics varied between regions indicating rock and soft classifications were influenced by rock complexity and/or slope (Table 2-4 and Figure 2-10). The kappa statistic for all hydroacoustic and quadrat data combined was 0.488. *Artificial* had the lowest agreement and *Natural 1* had the highest. Ninety percent confidence intervals did not overlap between *Artificial* and *Natural 1*. *Natural 2* was intermediate the other two regions.

Slope and rock area.—Hydroacoustic information coupled with GIS captured difference in rock area and slope in surveyed regions (Table 2-7). Slope differed between regions with the highest slope in *Natural 1* and the lowest in *Natural 2*. The slope of

Artificial was closer to *Natural 2* than *Natural 1*. *Artificial* had the smallest rock area and *Natural 1* had the greatest rock area. The estimated area of individual artificial reefs was variable (Table 2-8).

Discussion

VBT substrate classification of hydroacoustics data, coupled with GIS, captured differences in rock complexity between three regions in Bear Lake. The artificial reef region displayed the expected spatial arrangement of rock substrate, based on artificial reef construction coordinates. The larger rock area of AR3 suggested rock loads may not have been equally distributed between the four artificial reefs. *Natural 1* displayed a spatial arrangement of rock similar to previous underwater video observations (personal observation). *Natural 2* displayed a spatial arrangement of rock similar to a 1993 video survey conducted without GPS (Scott Tolentino, Utah Division of Wildlife Resources (UDWR), personal communication). Although hydroacoustic delineation of substrate agreed well with previous substrate knowledge, inaccuracies were found.

Rock complexity.—Higher classification accuracy on predominant substrate, compared to non-predominant substrate, suggested VBT biased classification. The natural regions videography surveys were primarily rock substrate. The natural regions VBT classification accuracy was higher on rock substrate. The videography survey for *Artificial* was primarily soft substrate. Although the artificial reef region had similar proportions of correctly classified rock and soft substrates, chi-squared results for *Artificial* had a higher than expected number of correct soft classifications. Because the chi-squared analyses included all three regions, the influence of rock complexity and

slope were indistinguishable. We conducted a post hoc test between *Artificial* and *Natural 2* to elucidate the suggested inaccuracies in VBT classification due to rock complexity. *Artificial* and *Natural 2* had similar slopes, thus significant results would indicate an inaccuracy due to rock complexity.

Post hoc chi-squared test between *Artificial* and *Natural 2* found VBT accuracy was significant higher on rock substrate, and for *Natural 2*, indicating substrate and rock complexity influenced classification accuracy (Tables 2-9 and 2-10). The higher accuracy for rock substrate meant *Natural 2*, with a large formation of rock, was better delineated. VBT classification biased towards predominant substrate for *Artificial* and *Natural 2*. Although soft correct classification was not significantly different between the regions, the p-value was low. The bias may have resulted from sampling methodology and variation in regional rock complexity.

Hydroacoustic classification inaccuracies and biases between regions of different rock complexity may have resulted from regional rock formation and hydroacoustic resolution. Natural regions of rock were formed from geological processes, which likely produced large areas of rock, clearly delineated from soft. The artificial reefs were built by releasing rock from a barge into 10m of water. This method may have disseminated the rock and created heterogeneous substrate. The ten ping average used in VBT analyses may have decreased accuracy along rock/soft borders. *Natural 2* contained a large amount of rock, which led to an increase in the number of pings over rock along the rock/soft boarder, when compared to the artificial reef region. *Artificial* contained a large amount of soft substrate, and a scattered rock formation, which lead to an increase in the number of pings over soft substrate. Thus, the rock complexity of the regions, coupled

with the 10 ping average, may have biased substrate classification towards the predominant substrate of the region.

Slope.—Higher than expected rock classification accuracy, in *Natural 1*, suggested an inaccuracy in classification related to slope. We performed a post hoc test between *Natural 1* and *Natural 2* to elucidate the suggested inaccuracy in VBT classification due to slope. *Natural 1* and *Natural 2* had large rock areas, thus significant results would indicate an influence of slope.

Post hoc chi-squared results between natural regions found inaccuracies in VBT rock classification from slope. Non-significant differences in VBT accuracy between regions for combined substrates suggested similar rock complexities reduced inaccuracies, or resulted in comparable biases for both regions. VBT classification accuracy was significantly higher on rock substrate (Tables 2-9 and 2-10). Rock substrate classification accuracy for *Natural 1* (steep) was significantly higher than for *Natural 2*. Insignificant soft classification accuracy between regions indicated VBT accuracy on soft classification was invariable to slope (but see below).

Although inaccuracies in VBT rock classification between regions of different slope were found, results were equivocal as to the underlying cause. At face value, post hoc results between the natural regions indicated VBT classified the steep slope with greater accuracy. It is unlikely VBT accuracy was greater on steeper slopes, since even modest slopes distorted the first echo (von Szalay and McConnaughey 2002). Also, the ability of VBT to map non-flat slopes is a concern, since past and current versions of VBT do not use depth normalization (Dommissie and Urban 2005). BioSonics is releasing a new version of VBT in Fall 2007 that corrects this problem (Mike Burger,

BioSonics, personal communication). A more likely explanation is VBT over classified rock substrate on steep slopes.

The incongruity in rock classification in relation to slope may have resulted from abrupt depth changes in the steeper region. Changes in depth distort the shape and power of the echo return signal (Hamilton 2001). Echo distortion may have resulted from zig-zag surveys of *Natural 1*, which sampled large depth variations over small distances. The average of signals on soft substrate over large depth changes may have produced additional backscatter in the echo energy patterns. Since rock substrate produced more backscatter in the hydroacoustic signal (Hamilton et al. 1999), the soft substrate echoes may have resembled this backscatter. Thus, the topography of *Natural 1* could have increased the probability of rock classification by distorting the acoustic signal.

VBT classification bias towards predominate substrate may have masked accuracy variations due to slope. Both the natural regions videography surveys were predominantly rock. Both regions had large proportions of rock correctly classified and relatively small proportions of soft correctly classified. If a bias towards rock occurred in both regions, differences in accuracy based on slope would be difficult to detect.

kappa and caveats.—The kappa provided an accurate rating of the agreement between VBT and videography, but was unable to account for the influence of a predominant substrate bias. The kappa statistics increased with the amount of rock present, suggesting the kappa value was strongly influenced by the bias towards predominant substrate. Thus, even though soft classification was poorest in *Natural 1*, the high rock accuracy resulted in *Natural 1* having the highest kappa statistic.

The limitations of the quadrat sampling gear, in relation to the spatial arrangement of rock within the regions, may have influenced our results. Due to visibility limits, quadrat sites never exceeded 15m depth. *Artificial* and *Natural 2* had large areas of both hydroacoustic classified substrates within quadrat sampling range. *Natural 1* contained a large continuous stretch of hydroacoustically-determined rock within quadrat sampling depth range, but most hydroacoustic classified soft substrate was found out of quadrat sampling range. *Natural 1* quadrat sampling over hydroacoustic classified soft substrate was limited to the areas north and south of the large rock formation. Due to VBT averaging, discussed above, rock may have been over represented in these areas. Thus, for *Natural 1*, rock and soft classified quadrats were likely to be near hydroacoustic classified rock. Slope decreased north and south of the survey area for *Natural 1* (personal observation), thus extending the hydroacoustic survey to encompass the soft substrate present in these regions would have prevented comparisons of accuracy in relation to slope.

Conclusions.—Hydroacoustics demonstrated an ability to distinguish bottom types in relation to rock composition and slope, although inaccuracies and a bias were present. Results supported rejecting the rock complexity null hypothesis, that rock area does not affect hydroacoustic classification accuracy. Support for the alternative hypothesis included an increase in rock substrate classification accuracy in regions with large rock areas, which resulted from a bias towards predominant substrate within the video survey areas. Results did not support rejecting the slope null hypothesis, that increased slope results in decreased hydroacoustic classification accuracy, nor did they provide unequivocal information to the contrary. Although results found higher rock

classification accuracy on a steep slope compared to a gentle slope, the predominant substrate bias may have masked differences.

Implications.—A VBT bias towards classification of the predominant substrate could lead to erroneous information used in management of fisheries. Rock habitat provides interstitial space for protection of eggs against predators (Marsden et al. 1995). In Bear Lake all four endemic fish species spawn on rock (Albercht 2004; Bouwes and Luecke 1997; Ruzycki et al. 1998). In addition, one endemic fish prefers foraging on rock in winter (Chapter 4). The use of rock for shelter by the Bear Lake fish fauna has not been determined, although previous lake research found rock aids in predator avoidance (Werner et al. 1983; Tabor and Wurtsbaugh 1991; Halvorsen et al. 1997; Landry et al. 1999; Biro et al. 2003). The hydroacoustic bias leads to a lower estimate of surrogate rock provided by the artificial reefs and an overestimation of natural rock available. Further, this leads to overestimation of the quantity of eastern shore rock habitat lost during drought. Thus, the potential of artificial reefs to mitigate drought by providing surrogate habitat is underestimated and the lost of natural rock is overestimated by hydroacoustic sampling.

Inaccuracies in habitat delineation will produce erroneous patterns of fish and habitat association. A bias towards predominant substrate will reduce habitat complexity, since small patches of non-predominant substrate in the survey area will likely be classified as the predominant substrate. Variability in the measurement of substrate classification increases uncertainty in HSI models (Roloff and Kernohan 1999; Van der Lee et al. 2006), thus hydroacoustic substrate classification inaccuracies will impair the HSI models' performances.

Despite the inaccuracies of hydroacoustic habitat delineation, acoustic sampling offers benefits over field sampling and remote sensing (Vis et al. 2003). Course resolution of field sampling methods over large spatial scales, would lead to inaccuracies in the quantities of substrate, and underestimation of habitat complexity. The ability of hydroacoustic technology to map large areas underwater makes hydroacoustic a superior sampling technique despite the inaccuracies we found.

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Table 2-1: Summary of videography quadrat classification and proportion of rock observed for regions and substrates. *All* is all regions combined. *Both* is rock and soft substrate combined.

Region	Both	Rock	Soft	Proportion rock
All	713	366	347	0.513
Artificial	238	68	170	0.286
Natural 1	237	129	108	0.544
Natural 2	238	169	69	0.710

Table 2-2: Summary of hydroacoustic data and proportion VBT classified rock for regions and substrates. *All* is all regions combined.

Region	Hydroacoustic points	Unidentified points	UTM unique points	VBT rock classified points	Proportion VBT rock
All	5695	467	2102	503	0.239
Artificial	2768	40	795	49	0.062
Natural 1	2927	427	1307	454	0.347
Natural 2	2929	141	1448	306	0.211

Table 2-3: Mean and standard deviation of the nearest distance (m) from quadrat point to hydroacoustic point for regions and substrates. *All* is all regions combined. *Both* is rock and soft substrate combined.

Region	Mean			Standard deviation		
	Both	Rock	Soft	Both	Rock	Soft
All	5.76	5.71	5.81	3.42	3.16	3.68
Artificial	4.30	3.80	4.50	2.18	1.94	2.25
Natural 1	7.38	6.74	8.14	4.36	3.75	4.89
Natural 2	5.61	5.69	5.40	2.60	2.69	2.36

Table 2-4: Proportion videography correctly classified by VBT, and kappa statistics for regions and substrates. *All* is all regions combined and *Both* are substrates combined.

Region	Both	Rock	Soft	kappa
All	0.746	0.891	0.594	0.488
Artificial	0.672	0.691	0.665	0.307
Natural 1	0.776	1	0.509	0.530
Natural 2	0.79	0.888	0.551	0.462

Table 2-5: Chi-squared test of homogeneity of proportions (X^2) and corresponding p-values for regions and substrates. *All* is all regions combined and test for differences in accuracy between substrate. *Both* are substrate combined and, along with *Rock* and *Soft*, test for differences in accuracy between regions.

Test	X^2	df	p-value
All	81.4185	1	<0.001
Both	10.4081	2	0.005
Rock	43.657	2	<0.001
Soft	7.2737	2	0.026

Table 2-6: Videography number of classifications minus chi-squared expected correct numbers for each substrate and region. *All* is all regions combined and test for differences in accuracy between substrate. *Both* are substrate combined and, along with *Rock* and *Soft*, test for differences in accuracy between regions. *Artificial* had 68 rock and 170 soft quadrat observations, *Natural 1* had 129 rock and 108 soft, and *Natural 2* had 169 rock and 69 soft quadrat observations.

Substrate agreement	All	A	N1	N2
Both correct		-18	7	10
Rock correct	53	-14	14	-1
Soft correct	-53	12	-9	-3

Table 2-7: Mean distance from rock hydroacoustic point to nearest rock or soft hydroacoustic point, mean hydroacoustic survey slopes, and estimated area of rock for each survey region.

Hydroacoustic survey region	Mean near distance (m)	Area (m ²)	Slope (degree)
Artificial	5.84	4142.80	2.34
Natural 1	11.66	135314.07	7.57
Natural 2	9.62	67108.95	1.61

Table 2-8: Area of each artificial reef, mean, variance and standard deviation of artificial reef area.

Location	Area (m ²)
AR1	957.00
AR2	796.10
AR3	1515.35
AR4	874.35
Mean	1035.70
Variance	106567.47
Standard deviation	326.45

Table 2-9: Post hoc chi-squared test of homogeneity of proportions (X^2) and corresponding p-values for comparisons between *Artificial* and *Natural 2*, and *Natural 1* and *Natural 2*. *Regions* are regions *Artificial* and *Natural 2* combined (AN2), or regions *Natural 1* and *Natural 2* combined (N1N2). *Regions* tests for differences between substrates. *Both* are substrate combined and, along with *Rock* and *Soft*, test for differences in accuracy between regions.

Test	AN2			N1N2		
	X^2	df	p-value	X^2	Df	p-value
Regions	23.069	1	<0.001	107.952	1	<0.001
Both	7.79	1	0.005	0.061	1	0.805
Rock	11.969	1	0.001	13.665	1	<0.001
Soft	2.273	1	0.132	0.148	1	0.701

Table 2-10: Videography number of classifications minus chi-squared expected correct numbers of each substrate for comparisons between regions *Artificial* and *Natural 2*, and *Natural 1* and *Natural 2*. *Regions* are regions *Artificial* and *Natural 2* combined (AN2), or regions *Natural 1* and *Natural 2* combined (N1N2). *Both* are substrate combined and, along with *Rock* and *Soft* test for differences between regions. *Artificial* had 68 rock and 170 soft quadrat observations, *Natural 1* had 129 rock and 108 soft quadrat observations, and *Natural 2* had 169 rock and 69 soft quadrat observations.

Substrate	AN2	Artificial	Natural 2	N1N2	Natural 1	Natural 2
Both correct		-14	14		-2	2
Rock correct	24	-10	10	46	8	-8
Soft correct	-24	6	-6	-46	-2	2

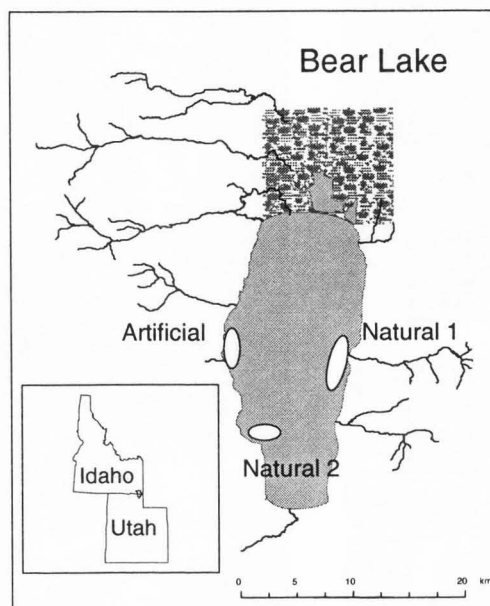


Figure 2-1: Hydroacoustic and quadrat surveys regions, Bear Lake, UT/ID. Approximate locations are represented by white ellipsoids.

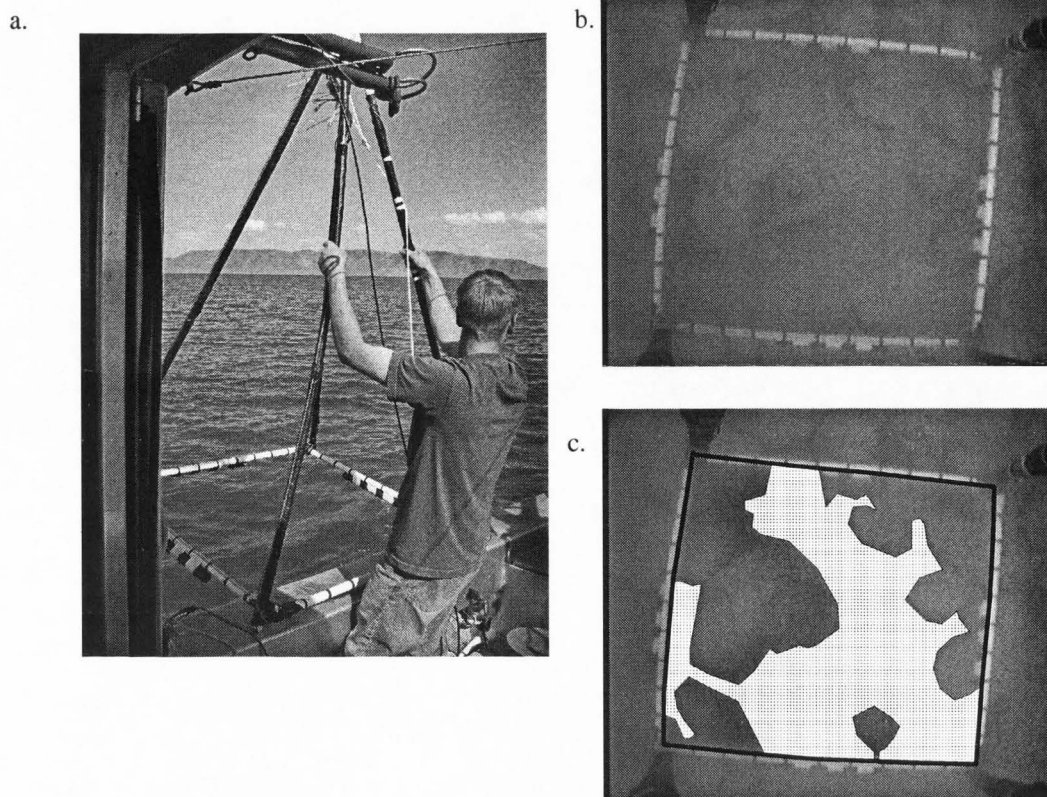


Figure 2-2: Video quadrat and substrate delineation. a) Quadrat ready to deploy, b) video still from quadrat at site E-207 (*Natural 1*), c) quadrat polygon (black) and soft sediment polygon (stippled).

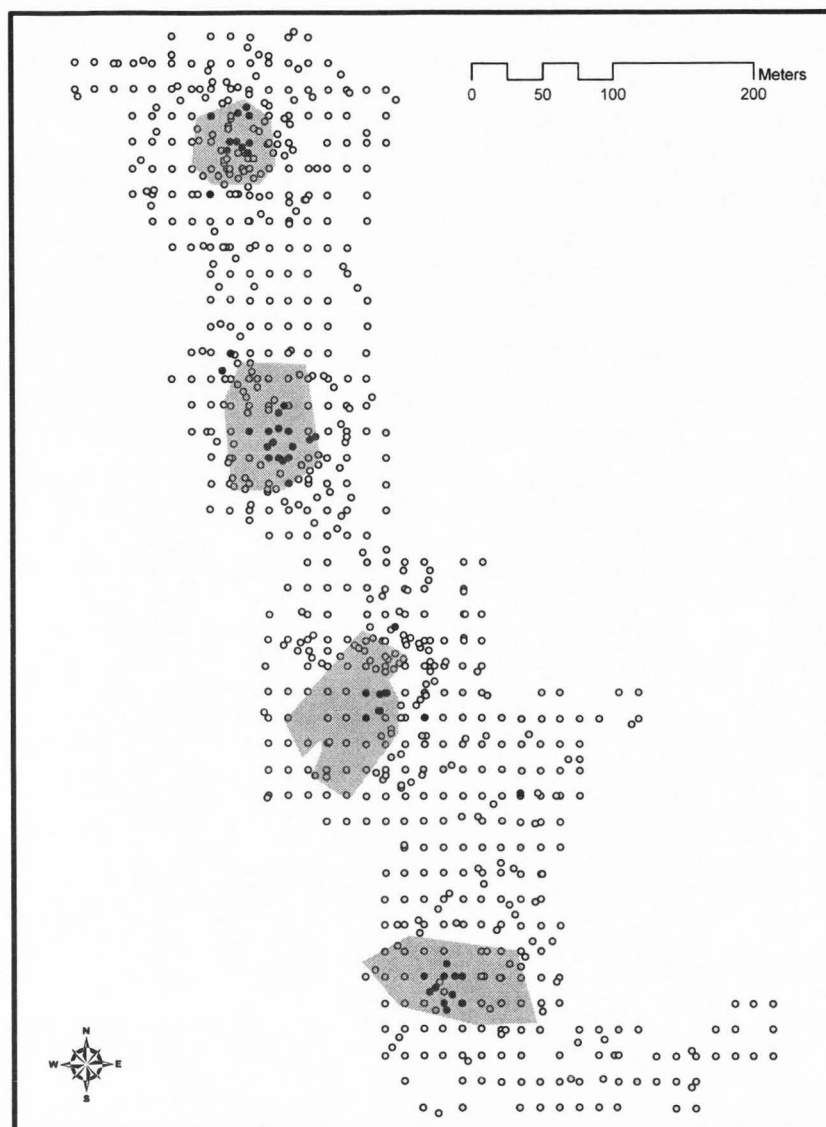


Figure 2-3: *Artificial region hydroacoustic points by VBT substrate classification.* Black circles are hydroacoustic rock, and white circles are hydroacoustic soft. Quadrat survey area shaded gray.

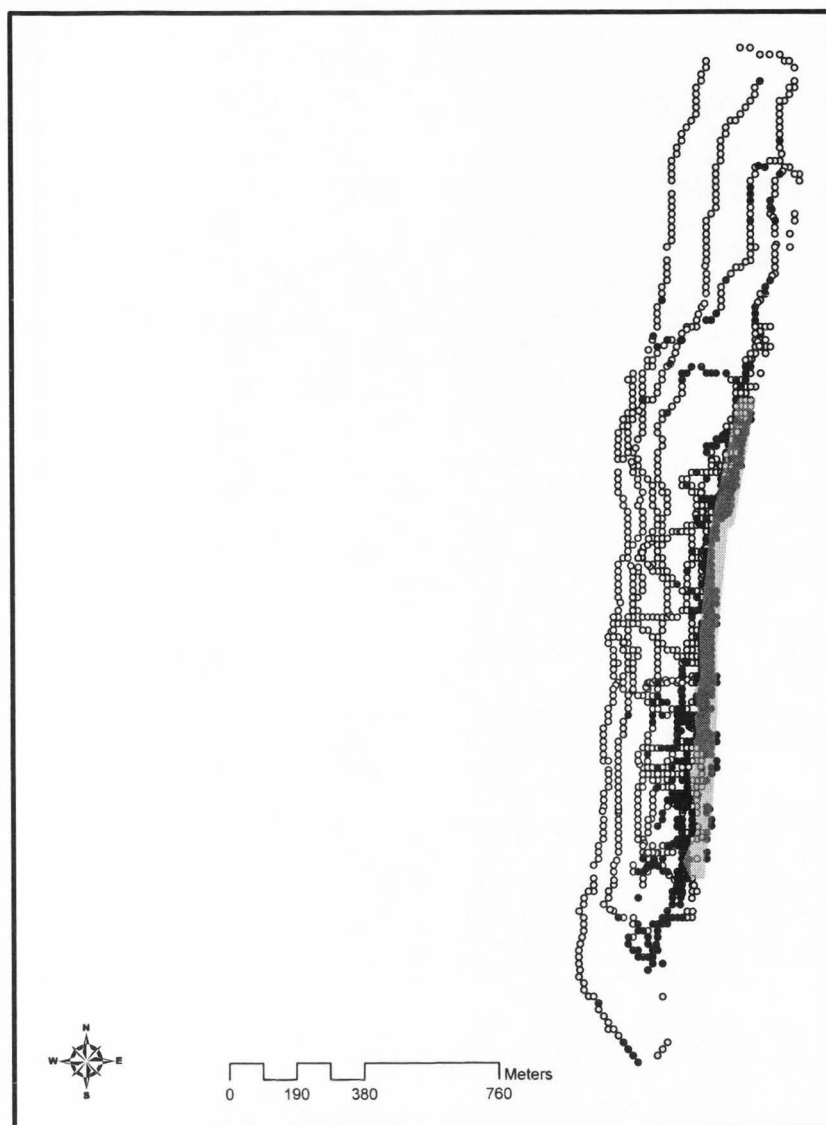


Figure 2-4: *Natural I* hydroacoustic points by VBT substrate classification. Black circles are hydroacoustic rock, and white circles are hydroacoustic soft. Quadrat survey area shaded gray.

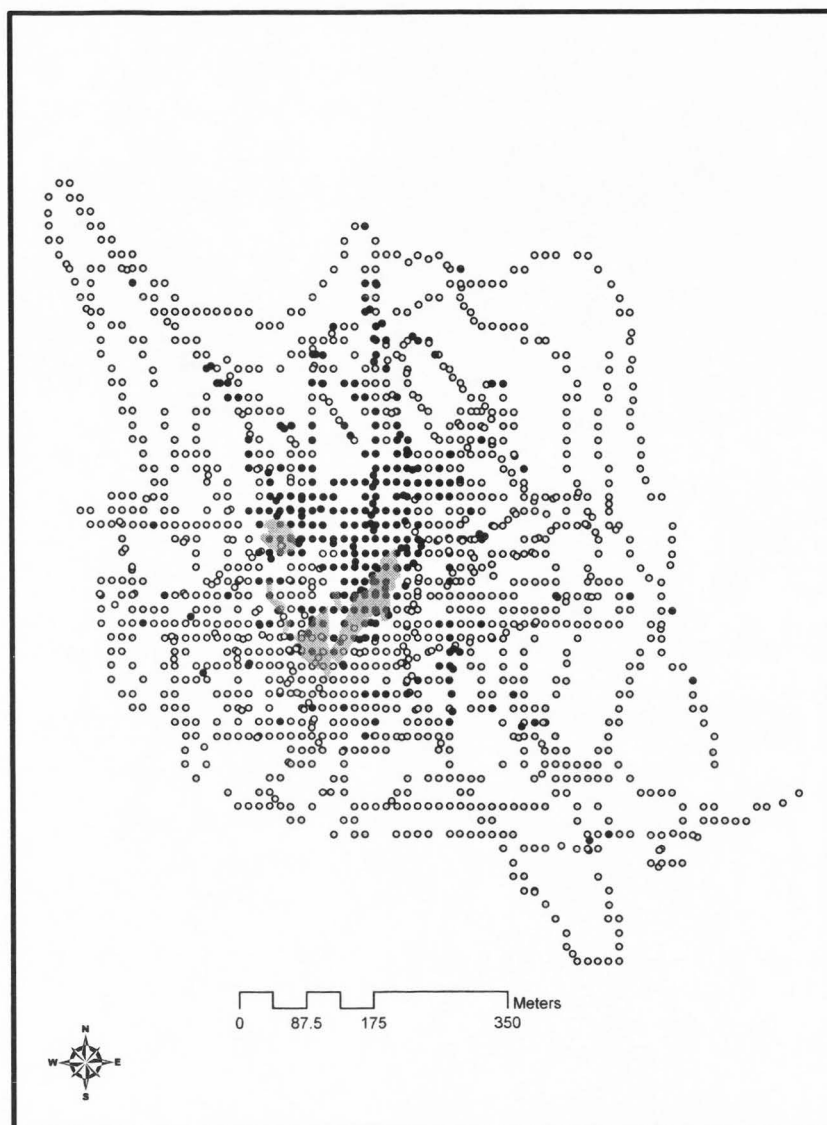


Figure 2-5: *Natural 2* hydroacoustic points by VBT substrate classification. Black circles are hydroacoustic rock, and white circles are hydroacoustic soft. Quadrat survey area shaded gray.

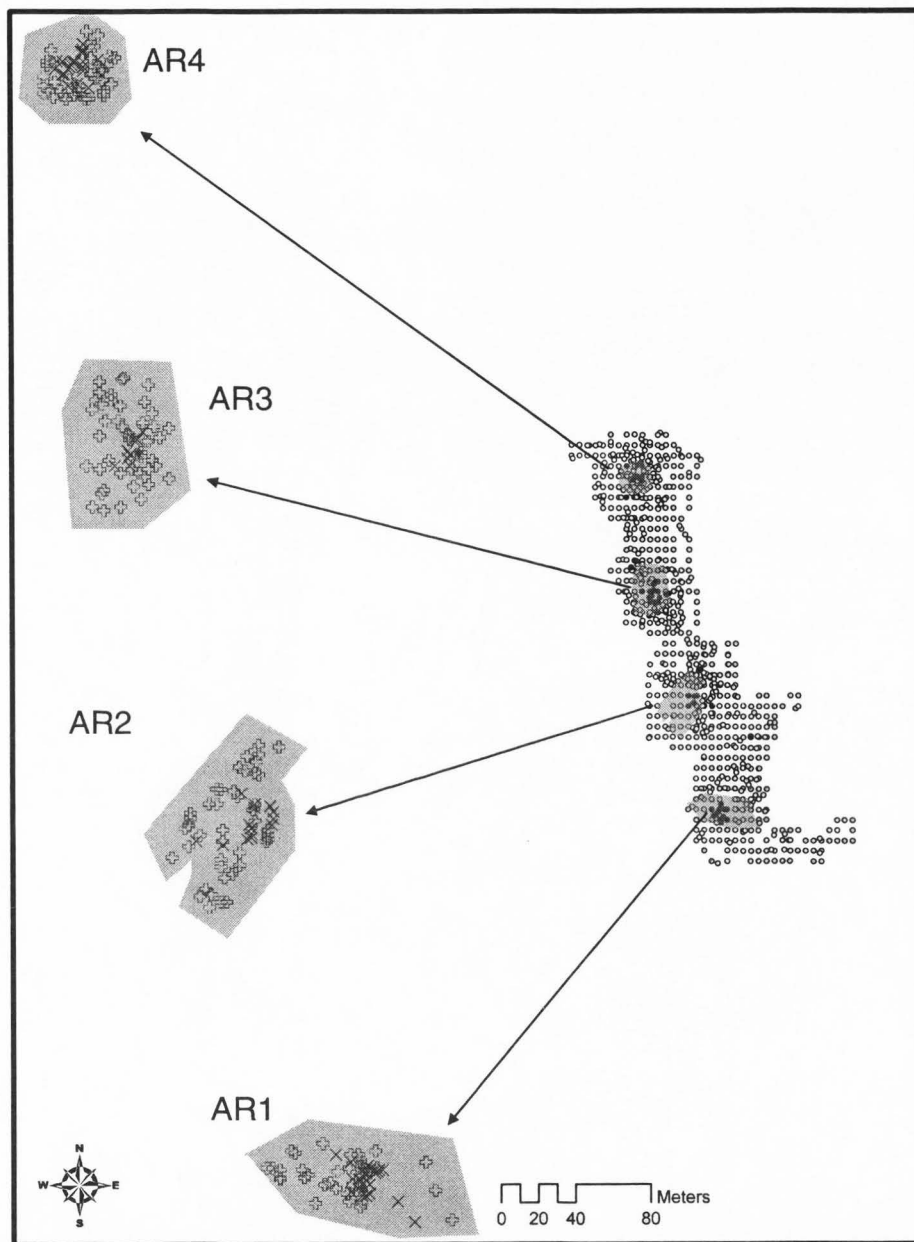


Figure 2-6: *Artificial* region quadrat points (left) in relation to hydroacoustic survey (right). Quadrat survey area is shaded gray. Black X's are quadrat rock, white crosses are quadrat soft, and black diamonds are mixed quadrat. Black circles are hydroacoustic rock, and white circles are hydroacoustic soft. Scale valid for quadrat survey.

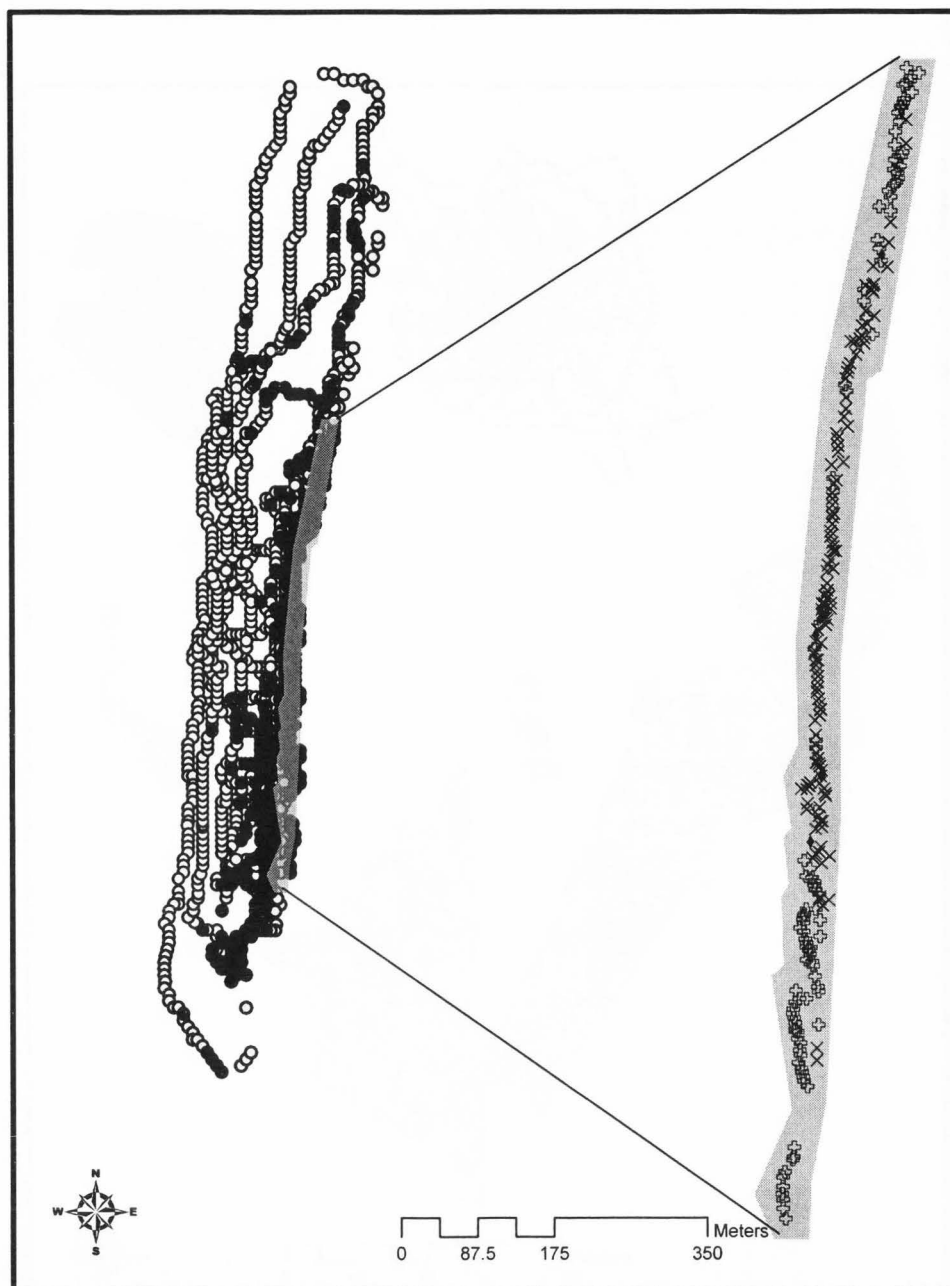


Figure 2-7: *Natural 1* quadrat survey points (right) in relation to hydroacoustic points (left). Quadrat survey area is shaded gray. Black X's are quadrat rock, white crosses are quadrat soft, and black diamonds are quadrat mixed. Black circles are hydroacoustic rock, white circles are hydroacoustic soft. Scale valid for quadrat survey.

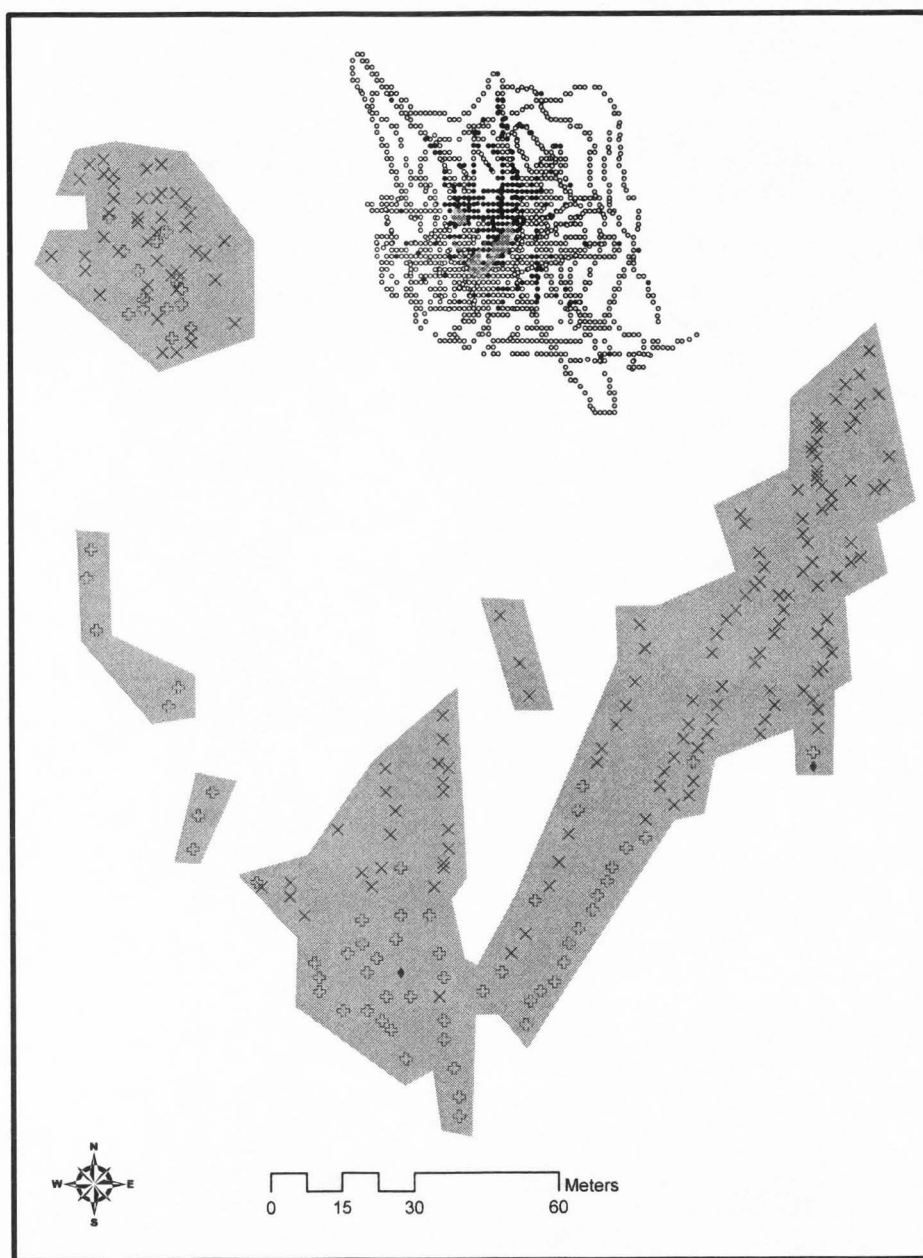


Figure 2-8: *Natural 2* quadrat survey (bottom) in relation to hydroacoustic survey (top). Quadrat survey area shaded gray. Black X's are quadrat rock, white crosses are quadrat soft, and black diamonds are quadrat mixed. Black circles are hydroacoustic rock, and white circles are hydroacoustic soft. Scale valid for quadrat survey.

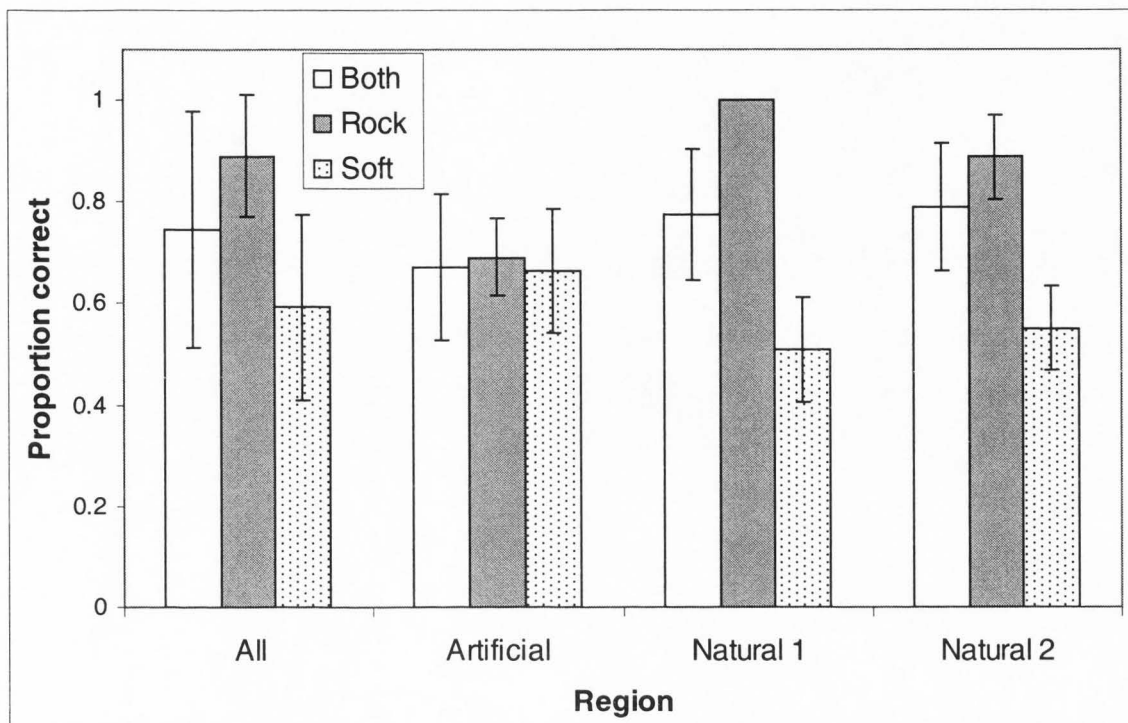


Figure 2-9: Proportion of correct VBT classifications for survey regions. Error bars are plus and minus two standard deviation for a binomial distribution of counts. *All* combines all regions and *Both* combines substrates.

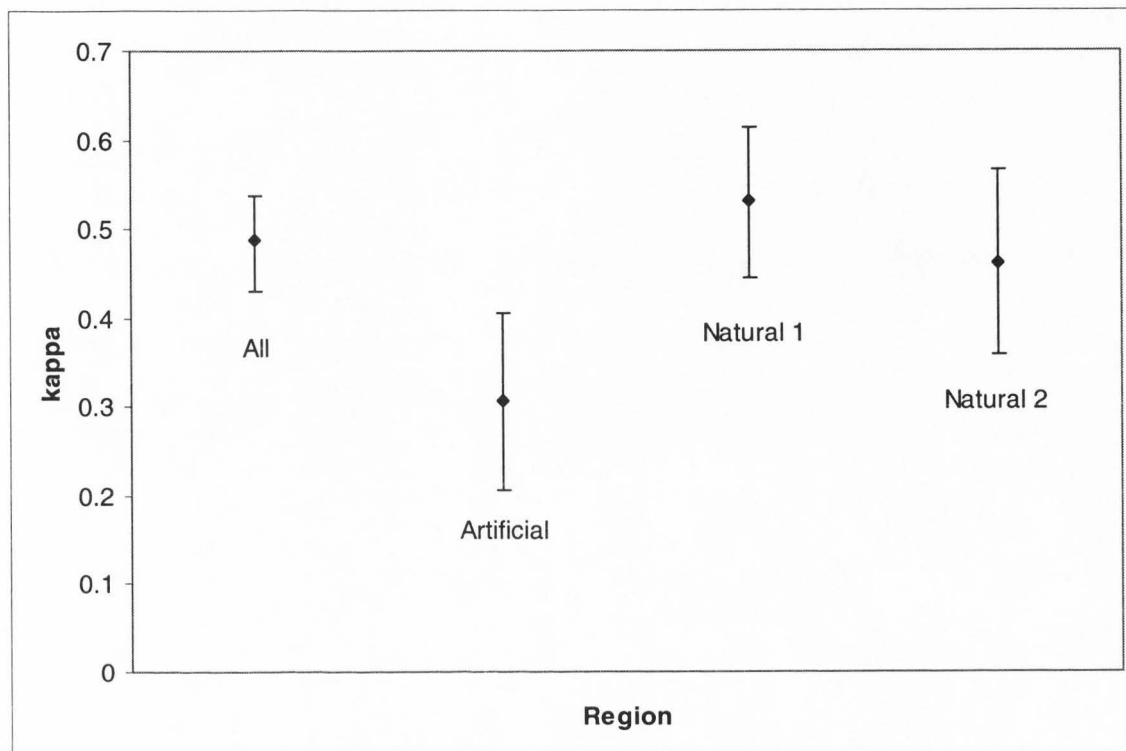


Figure 2-10: The kappa statistics on videography and VBT agreement for survey regions. Error bars are 90% confidence intervals. *All* combines all regions.

CHAPTER 3

BENTHIC INVERTEBRATE ABUNDANCES ON ARTIFICIAL AND NATURAL REEFS IN RELATION TO ENDEMIC FISH DIET, BEAR LAKE, UTAH/IDAHO¹

Abstract.—We assessed the potential of artificial reefs to function as foraging habitat for endemic fishes within Bear Lake, Utah/Idaho. We compared benthic invertebrate taxa abundances and diversities between one region of artificial reefs, and two natural reefs in spring and summer. We discussed results in relation to diets of endemic fishes, habitat complexity, and benthic invertebrate substrate preference and dispersal. Generally, artificial reefs contained benthic invertebrate abundances similar to one or both natural reefs, although reef differences were detected for some taxa. The artificial reef benthic invertebrate assemblages were predominantly composed of mobile taxa, or taxa also found in high densities on soft substrate. The artificial reefs hosted prey consumed by endemic Bonneville whitefish and Bear Lake sculpin, and thus provided additional foraging habitat.

Introduction

Determination of benthic invertebrate community variation between artificial and natural structures is necessary to evaluate the utility of artificial reefs to function as foraging habitat to the fish community. Due to cost and logistical constraints, artificial reefs may be composed of essentially homogenous material and may be much smaller in

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size when compared to local natural substrate (Grove et al. 1991). As the complexity of habitat decreases, so should species richness (Hart and Horwitz 1991). Artificial reef habitat depauperation may render them ineffective as a natural habitat surrogate to the indigenous food web. We compare benthic invertebrate abundances and diversity on artificial and natural reefs in Bear Lake, located on the Utah (UT) and Idaho (ID) border. We discuss these two parameters in relation to the diet of Bear Lake endemic fishes, benthic invertebrate substrate preference and dispersal, and habitat complexity.

Previous investigations have associated reef complexity variation to faunal parameters. Edwards and Smith (2005) found diversities of demersal fishes and benthic invertebrates were lower on artificial reefs less complex than nearby natural reefs. Differences between artificial and natural structures' intertidal communities were found on the coast of Italy, with a smaller number of species found on the less complex artificial structures (Bulleri and Chapman 2004). Bulleri and Chapman (2004) concluded the man-made structures did not function as additional natural habitat for indigenous intertidal assemblages. Perkol-Finkel and Beneyahu (2004, 2005, and 2007) produced a series of papers exploring community variation between artificial and natural reefs in the Red Sea. They found coral communities on artificial reefs that did not mimic natural habitat differed from natural habitat communities (Perkol-Finkel and Beneyahu 2004). This difference in communities possibly resulted from artificial reefs increasing habitat heterogeneity and thereby increasing local benthic production and species diversity. Perkol-Finkel and Beneyahu (2005) found the artificial reef community shifted from soft coral to one dominated by a sponge over a 10 year period. They determined recruitment for benthic assemblages differed for artificial and natural reefs leading to the conclusion

that if conservation of current biota is desired, artificial reef structure should mimic natural structure (Perkol-Finkel and Beneyahu 2007).

Utah Division of Wildlife Resources (UDWR) built four artificial reefs in Bear Lake to provide foraging habitat to endemic fishes. Bear Lake is rock and macrophyte limited and located in an arid region prone to drought. During years of drought, rock along the eastern shore is dewatered, reducing rock habitat within the lake. The artificial reefs are located in an area not historically subjected to dewatering, thus they will provide rock habitat in years of drought. Bear Lake contains four endemic fish species: Bear Lake and Bonneville whitefish (*Prosopium abyssicola* and *P. spilonotus*), Bonneville cisco (*P. gemmifer*), and Bear Lake sculpin (*Cottus extensus*). Although benthic invertebrate biomass within Bear Lake is low for a midlatitude lake, benthic invertebrates represent a large portion of the diet for some size classes of endemic fish in Bear Lake (Wurtsbaugh and Hawkins 1990). In addition, many of the benthic invertebrate taxa are predominantly found on rock (Wurtsbaugh and Hawkins 1990).

Our objective for this study was to assess the potential of artificial reefs to function as foraging habitat for endemic fishes within Bear Lake, UT/ID. We compared benthic invertebrate taxa abundances and diversities between the artificial reefs, and two natural reefs. We predicted similar densities on the artificial and natural reefs. We discussed results in relation to diets of endemic fishes, habitat complexity, and benthic invertebrate substrate preference and dispersal.

Methods

Study area.—Bear Lake is an oligotrophic lake, approximately 282 km² in area, containing 7.86km³ of water and 1805m in elevation at full pool. It is located in northeast Utah and southwest Idaho at latitude 42° 00' North and longitude 111° 20' West (Figure 3-1). Bear Lake is oval shaped, with the longer axis laying north to south and bisected by the Utah/Idaho boarder. The western shore slopes gradually to its maximum depth of approximately 63m; the mean depth of the lack is 28m at full pool. The eastern shore drops abruptly and the lake displays classic tilt-block morphology.

Four artificial reefs were built in Bear Lake in October 2005 at approximately 10m depth in October 2005. Artificial reefs were located 200-1000m north of Bear Lake marina. A total of 720m³ of rock was used in construction, and each reef contained 180m³ of rock. Artificial reef rock was transported by a dump truck on a barge. Intermediate length measurements were taken on 100 artificial rocks. Mean intermediate length for the rock used was 0.119m with a standard deviation of 0.030m.

Data were collected on three reef regions within Bear Lake (Figure 3-1). The *Artificial* region contained the four artificial reefs. The two natural reef regions were along the eastern shore (*Natural 1*), and the rockpile reef (*Natural 2*) on the western shore. Bear Lake's artificial reefs differed from natural reefs within the lake in spatial placement and area. *Artificial* had isolated-homogenous rock habitats. The natural reefs had continuous-heterogeneous rock habitats. The natural reef rock varied by size (gravel to large stones), and *Natural 2* contained large amounts of an intricate, perforated rock. *Natural 1* had an estimated 32.5 times (135314.07m²) the total rock area of *Artificial*,

while *Natural 2* had an estimated 16 times (67108.95m^2) the area of *Artificial* (Chapter 2).

Four sample sites were located within each reef region (Figure 3-1). Each artificial reef was a sample site. Sites within *Artificial* and *Natural 1* were located approximately 200m apart, on a north-south transect, and approximately 10m deep in October 2005. Because of the topography and location of *Natural 2*, sites were scattered 50 to 100m meters apart, and depths ranged from 11 to 13.5m in October 2005.

Benthic invertebrate collection.—Gangs of four plastic crates ($0.27 \times 0.306 \times 0.306\text{m}$) were deployed on each of the 12 reef sites. Crates were similar to traditional milk crates with a crisscrossed framework of plastic forming the sides and bottom, and an open top. The lattice structure allowed movement of benthic invertebrates into and out of the crates. The crates were filled with equivalent amounts of the same rock used in artificial reef construction. Twelve crates filled with rock were selected for volumetric displacement. The mean volumetric displacement of rock within a crate was 15.763 liters with a standard deviation of 1.02 liters.

Gangs were set on April 23, 2006, pulled June 26-29, 2006, reset June 26-29, 2006, and pulled August 21-22, 2006. The April to June set represented spring samples, while the June to August set represented summer samples. Benthic invertebrates were scrubbed from each crate's rock into a container with surface lake water. The removed benthic invertebrates and lake water were rinsed through 254 micrometer Nitex netting to collect invertebrates. Benthic invertebrates were preserved in ethanol and transported to the Utah State University Limnology lab.

Benthic invertebrates were sorted into major taxonomical groups. During sorting, taxa likely to pass through the Nitex netting, or introduced through rinsing with lake water were ignored. These omitted taxa included zooplankton, Ostracoda, and terrestrial invertebrates. Chironomidae pupae were classified with Diptera. Benthic invertebrates were categorized as whole (complete) and partial (fragment of individual). Whole and partial individuals were measured with a dissecting scope for up to 10 individuals per crate. Benthic invertebrate scope measurements were converted into millimeters.

Average whole taxa millimeters for each region and taxa were determined to account for partial individuals. Total partial lengths for each taxa and crate were divided by the mean whole lengths for the corresponding taxa and reef. This calculation provided an estimate of the number of whole individuals the partial samples represented. The estimated number was added to the whole number to provide the total number of individuals of each taxon in each crate. Because of the difficulty in determining whole Oligocheata, and a problem of Oligocheata breaking into parts during sorting, all Oligocheata were categorized as partial and all parts were measured. The summations of Oligocheata lengths (mm) were determined for each crate, and crate total lengths were analyzed identical to abundances.

Benthic invertebrate statistical analyses.—Benthic invertebrate mean abundances were determined for each gang and taxa by dividing the number of individuals within a gang by the number of crates retrieved from the gang. The standardization of abundance to sample units (crates) allowed comparisons of the densities of the taxa. Mean gang abundance was used to determine mean abundance and standard errors for each reef.

Mean abundances for each season, taxa, and region were plotted with plus and minus one standard error bars to graphically represent trends.

Taxa diversity for each crate were measured by Simpson diversity index (D):

$$D = 1 - \sum \left(\frac{n}{N} \right)^2,$$

where N was the total abundance of organisms of all taxa for a crate and n was the total abundance of a particular taxon in the crate. The value of the Simpson's Diversity Index was interpreted as ranging from 0 (no diversity) to 1 (infinite diversity). Average diversity was determined for gangs and reef regions as for abundance.

ANOVAs were performed separately for each predominant taxon to determine differences in taxa abundances by reef region. To elucidate differences between artificial and natural reef regions, separate ANOVAs were run for spring and summer collections due to the variability in species abundances between seasons. The model was

$$Abundance = Region,$$

where *Abundance* was the response and *Region* was the factor in the ANOVA. There were three levels for *Region*: *Artificial*, *Natural 1*, and *Natural 2*. A p-value of 0.10 indicated a significant *Region* factor. Bartlett's test for equal variance between regions was run on each response. Fitted versus residual plots were checked to determine if the assumptions of equal variance was met. Transformations were performed when necessary. A Bonferroni adjustment was used for pairwise comparison of significant ANOVA results. A p-value of 0.10 indicated significant differences between reefs. All statistical analyses were run in R 2.4.0.

Results

Table 3-1 lists descriptions of the abbreviations and symbols used for the benthic invertebrate results. Appendix III (Tables AIII-1 to AIII-4) contains tables of crate sample taxa numbers, mean site abundances and diversities, and Bartlett's tests for equal reef variance. Appendix III (Figures AIII-1 and AIII-2) contains figures of non-predominant taxa. Table 3-2 lists mean region abundances for each season and taxa. One crate was lost on site RR2 in the June collection.

Benthic invertebrate taxa abundance.—Spring results suggested total abundances of benthic invertebrates were not dissimilar between reefs, although abundance on *Natural 2* was lower than the other reefs (Table 3-2 and Figure 3-2). The p-value for total benthic invertebrate abundance was not significant (Table 3-3). Spring predominant taxa were Amphipoda, Chironomidae, Gastropoda, Oligocheata, and Trombidiform. Non-predominant taxa included Diptera, Hirudinea, Plectoptera, and Trichoptera (Table 3-2 and Figure AIII-1). Reef differences in abundances were detected in three predominant taxa, while no difference was found in two predominant taxa.

Spring Gastropoda abundances were different between natural and artificial reefs (Table 3-2 and Figure 3-3). *Natural 1* and *Natural 2* had approximately the same mean abundance of Gastropoda in spring, while *Artificial* Gastropoda mean abundance was low (0.1 individuals). *Region* was significant with the two natural reefs having a significantly higher abundance of Gastropoda compared to the artificial reefs (Tables 3-3 and 3-4).

Although reef differences were found in spring Amphipoda and Oligocheata abundances, the patterns did not relate to artificial and natural reefs (Table 3-2 and Figure

3-3). Spring Amphipoda abundance on *Artificial* was significantly higher than *Natural 1* (Tables 3-3 and 3-4). The mean summation of Oligocheata lengths for each site were approximately the same for *Artificial* and *Natural 1* in spring, both of which were significantly higher than *Natural 2* (Tables 3-3 and 3-4, and Figure 3-3).

No significant region differences in spring Chironomidae and Trombidiform abundances were found indicating the densities of these two taxa were not dissimilar on artificial and natural reefs (Table 3-3). Trombidiform had the highest abundance of all taxa in the spring collection for all regions (Table 3-2 and Figure 3-3). Trombidiform crate abundances were variable due to the large number of recently hatched individuals found.

Region was not significant for summer mean total abundances indicating total benthic invertebrate abundances on artificial and natural regions were not dissimilar (Table 3-3). *Natural 2* had the highest abundance, followed by *Natural 1*, then *Artificial* (Figure 3-2). Summer predominant and non-predominant taxa were the same as in spring (Figures 3-4 and AIII-2). Significant region differences were found in two predominant taxa, while no differences were detected in three predominant taxa.

As in spring, summer Gastropoda abundances differed between natural and artificial regions. Gastropoda abundances increased in the summer collection compared to the spring collection (Table 3-2). Summer Gastropoda abundance was highest on *Natural 2*, followed by *Natural 1*, then *Artificial* (Figure 3-5). Gastropoda abundance on in the artificial reef region was significantly lower than both of the natural reef regions (Tables 3-3 and 3-4).

All regions were significantly different from one another for summer mean Chironomidae abundances, but abundance on *Artificial* was intermediate to the two natural regions (Tables 3-3 and 3-4). Overall, Chironomidae abundances increased in summer, but this was largely due the increase in *Natural 1* (Table 3-2). *Natural 1* had the highest summer Chironomidae abundance, followed by *Artificial*, then *Natural 2* (Figure 3-4).

No significant differences were found between regions for summer Amphipoda and Trombidiform abundances, and Oligocheata lengths (Table 3-3). Despite the non-significant results, *Artificial* hosted the highest densities of all three of these taxa (Table 3-2). Amphipoda abundance increased in the summer (Table 3-2). Although error bars did not overlap for summer mean Amphipoda abundance between regions, ANOVA results were not significant for transformed Amphipoda abundances (Figure 3-4 and Table 3-3). Summer Trombidiform numbers were similar to spring for *Artificial* and *Natural 1*, but decreased on *Natural 2* (Table 3-2 and Figures 3-2 and 3-4). Mean site total length of Oligocheata decreased in the summer (Table 3-2 and Figures 3-2 and 3-4).

Benthic invertebrate diversity.—Although a significant difference in diversity was found between regions for spring and summer, the differences appeared independent of artificial and natural reef regions (Table 3-5, Figure 3-5). *Artificial* diversity was significantly lower than *Natural 2* in spring, and diversity on *Natural 1* was significantly higher than diversity on the other reefs in summer (Table 3-4).

Discussion

Our results suggested artificial reefs hosted benthic invertebrate densities similar to one of both natural reefs, although differences were detected for some taxa. Spring and summer differences between artificial and one or both natural reefs in Amphipoda, Chironomidae, Oligocheata, and Trombidiform abundances were either non-significant, or the artificial reef abundance was intermediate that of the two natural reefs. Gastropoda abundance was significantly higher on natural reefs compared to the artificial reefs.

To assess the potential of artificial reefs as foraging habitat it is necessary to associate the results of our study to previous knowledge. We discuss our results in relation to fish diet data and benthic invertebrate substrate densities from a previous study. We offer possible explanations for benthic invertebrate patterns between reefs based on colonization and habitat complexity.

Wurtsbaugh and Hawkins (1990) determined the diets of endemic fish in Bear Lake for spring and summer 1987. We related our results to diet data for the whitefish complex (Bear Lake and Bonneville whitefish) and Bear Lake sculpin, and to rock and soft benthic invertebrate densities. Bonneville ciscoes were not considered since their diets excluded the predominant benthic invertebrates found in our study (Appendix 27 in Wurtsbaugh and Hawkins 1990).

The sampled depth ranges for Wurtsbaugh and Hawkins (1990) differed from our study. Our study collected benthic invertebrate samples from 10 to 13m deep.

Wurtsbaugh and Hawkins weighted diet data collect from fish in the epilimnion, metalimnion, and hypolimnion. In determining substrate preference, Wurtsbaugh and

Hawkins, compared benthic invertebrate from soft substrate samples collected at intervals from 1 to 55m to rock samples collected at less than 1m in April and July 1987.

Fish diet.—The potential of artificial reefs to function as additional foraging habitat for endemic fishes was suggested by benthic invertebrate substrate preference and fish diet. Trombidiform and Chironomidae densities were 178.6 and 184.85 times, respectively, higher on rock substrate than soft substrate (Wurtsbaugh and Hawkins 1990). Higher Trombidiforms and Chironomidae densities on rock substrate suggested the artificial reefs could function as additional habitat for these two taxa. The predominant taxa found in whitefish and Bear Lake sculpin diets were Chironomidae and Trombidiform. Gastropoda and Oligocheata were not found in June and August diets for the endemic fishes. Amphipoda occasionally contributed to endemic fish diet, but Crustaceans, such as Amphipoda, had a density 8.63 higher on soft substrate, suggesting foraging for Amphipoda occurred on soft substrate.

Diet data for whitefish suggested the artificial reefs may function as additional foraging habitat for whitefish (Wurtsbaugh and Hawkins 1990, Appendix 22). Chironomidae were found in the diet for all size classes of whitefish in spring, and all but large whitefish in summer. In spring, Chironomidae made up approximately 30% of the dry biomass of the diet of whitefish sized 0-74mm, approximately 75% of the diet for size 75-249mm, and approximately 85% of the diet for whitefish greater than 250mm. In summer Chironomidae made up approximately 22, 81, and 5.5% for the small, medium, and large size classes whitefish diets, respectively. Since artificial reef Chironomidae abundance was intermediate that of the natural reefs in both seasons, the artificial reefs were a potential foraging habitat for whitefish. Although some coregonids may prey

exclusively on Trombidiforms (Thorp and Covich 2001), the contribution of Trombidiform to the whitefish diets in Bear Lake was minimal except for small (0-74mm) summer whitefish. Small summer whitefish obtained approximately 69% of their diet from Trombidiforms. Since Trombidiform abundances were not dissimilar in summer, the artificial reefs provided additional foraging habitat to small whitefish.

Bonneville whitefish were more likely to receive a benefit from the additional foraging habitat provided by artificial reefs than Bear Lake whitefish. The whitefish complex (Bonneville and Bear Lake) diet data were combined in Wurtsbaugh and Hawkins. A recent study determined ecological differences between Bonneville and Bear Lake whitefish, including diets (Kennedy et al. 2006). Kennedy et al. (2006) found little contribution of the predominant taxa in our study to Bear Lake whitefish diet. Furthermore, Bear Lake whitefish were normally found between 45-55m in spring and summer, while Bonneville were found shallower (Kennedy 2005). Kennedy et al. (2006) did not classify Trombidiforms, but their study found Chironomidae made up a higher proportion of Bonneville whitefish diet, compared to Bear Lake whitefish, when all depths were considered. Kennedy et al. (2006) found a majority of the percent of dry weight was composed of Chironomidae for spring and summer Bonneville whitefish at 10m, but no Bear Lake whitefish were caught at this depth.

Diet data for Bear Lake sculpin suggested the artificial reefs may also function as additional foraging habitat for sculpin (Wurtsbaugh and Hawkins 1990, Appendix 21). Chironomidae were found in the diets for medium and large size classes of Bear Lake sculpin in spring, and medium size sculpin in the summer. The contribution of Chironomidae to small sculpin (0-39mm) in spring was slight (approximately 3% dry

biomass), while medium (40-79mm) and large (>80mm) spring sculpin diets obtained approximately 42 and 64% of their diet from Chironomidae. The contribution of Chironomidae to large sculpin diet in the summer was slight (0.02%), but approximately 52% for small, and 7.5% for medium sculpin. Since artificial reef Chironomidae abundance was intermediate that of the natural reef regions in both seasons, the artificial reefs were a potential foraging habitat for sculpin.

Sculpin diet contained Trombidiforms and Amphipoda, but these results did not relate the potential of artificial reefs to function as foraging habitat. Trombidiform contribution to sculpin diet was slight and usually zero. Amphipoda contributed 18% in spring for medium sculpin. In summer Amphipoda contributed approximately 4% of the diet for small and 3% for large sculpin. Since Amphipoda were predominantly found on soft substrate, their contribution to sculpin diet does not elucidate the potential of artificial reefs to function as additional foraging habitat.

Colonization and habitat complexity.—Patterns of predominant benthic invertebrate taxa on the artificial reefs can be explained by invertebrate mobility and substrate preference. Colonization of the new habitat offered by artificial reefs occurred by mobile taxa or taxa also found in high densities on soft substrate. The rapid colonization of Chironomidae on the artificial reefs may be due to the planktonic dispersal of the first instar for many species of Chironomidae (Coffman and Ferrington 1983). Trombidiform dispersal is tied to Bear Lake aquatic insect dispersal. Most species of Trombidiform are parasitic on imaginal insects and are dispersed through them (Thorp and Covich 2001). Trombidiforms are also good swimmers (Thorp and Covich 2001), and quick colonization of the artificial reefs by Trombidiforms could also occur

from populations located near by on the rip rap of the Bear Lake marina, or in macrophytes approximately 200m west of the reefs. Amphipoda and Oligocheata may have colonized the artificial reefs from surrounding soft substrate. Amphipoda are found in higher densities on soft substrate (Wurtsbaugh and Hawkins 1990). Although higher on rock, Oligocheata densities (by individuals) were $412/\text{m}^2$ on soft substrate (Wurtsbaugh and Hawkins 1990). The significantly lower abundance of Gastropoda on artificial reefs compared to natural reefs may have resulted from colonization time. Gastropoda may migrate throughout a body of water within environmental toleration, but migration is slow (Pennak 1953). Euclidean distances between artificial and natural reefs were 6.5 to 9.5km. Besides slow migration, differences in rock complexity may have contributed to the differences in Gastropoda abundances.

The complexity of rock habitat may have contributed to similar abundances of Gastropoda on the natural reefs and significantly lower abundance on the artificial reefs for both seasons. Relative to the natural reefs, the artificial reef rock complexity was depauperate. The greatest Gastropoda abundance was on *Natural 2*, which also contains Gastropoda shells fused within an intricate arrangement of perforated rock (personal observation). The abundance of Gastropoda was also significantly higher on *Natural 1* compared to *Artificial*. *Natural 1* contains rock habitat ranging from gravel to large boulders, fulfilling the needs of greater number of rock habitat requirements. Thus, the artificial reef rock may lack the complexity necessary for Gastropoda shelter.

Diversity patterns may also have been influenced by colonization and habitat complexity. When compared to the natural reef regions, the low diversity on the artificial reefs in spring may have resulted from a large proportion of Trombidiforms in the

composition of *Artificial*, and the reduced complexity of the artificial reefs. The higher summer diversity on *Natural 1* may have resulted from the greater rock complexity within that region. The shift of *Natural 2* from highest diversity in spring to the lowest in summer was likely the result of the large increase of Gastropoda on *Natural 2* for the summer collection. The summer increase in *Natural 2* Gastropoda suggested the intricate rock complexity of *Natural 2* might be ideal for Gastropoda.

Conclusions.—Generally, artificial reefs hosted benthic invertebrate densities similar to one or both natural reefs, although differences were detected for some taxa. Rapid dispersal of Chironomidae and Trombidiforms, coupled with their affinity for rock, produced similar abundances between artificial and natural reefs. The artificial reefs hosted prey consumed by endemic fishes within the lake, and thus provided additional foraging habitat.

Since colonization time and habitat complexity influence benthic invertebrate taxa presence and abundances, additional studies are warranted. Effects of colonization and habitat complexity parameters could be detected by sampling crates varying in soak time and rock complexity. To isolate colonization and habitat effects, samples varying in soak time and rock complexity should be collected in the same geographic region of the lake.

Greater clarity in the use of artificial reefs for foraging would be obtained by diet analyses of fish collected during benthic invertebrate sampling over artificial and natural reefs, and adjacent soft substrate. To elucidate fish foraging, it may be necessary to isolate habitat to limit fish migration. Repelling equipment, such as electronic barriers, could be used to limit movement of fish during the study. A similar study, conducted

solely on natural reefs that varied in large scale spatial arrangement, would elucidate the effect of large scale habitat complexity on fish foraging.

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Table 3-1: Abbreviations and symbol used for benthic invertebrate tables and plots.

Code	Represents	Common name
#	Crate number	
ABND	Abundance	
AMP	Amphipoda (Order)	Scuds
BI	Benthic invertebrate(s)	
CHR	Chironomidae (Family)	Midges
D	Simpson's diversity	
DPT	Diptera (Order)	Flies
GST	Gastropoda (Class)	Snails
HRD	Hirudinea (Class)	Leeches
N	Total	
OLG	Oligocheata (Class)	Worms
PCT	Plecoptera (Order)	Stoneflies
TCP	Trichoptera (Order)	Caddisflies
TMB	Trombidiform (Order)	Water mites

Table 3-2: 2006 spring and summer benthic invertebrate mean abundance and standard deviations (SD) for each region, taxa group, and total, and mean Simpson's diversity for reefs. Codes defined in Table 3-1.

Month	Region	Stat	AMP	CHR	DPT	GST	HRD	OLG	PCT	TCP	TMB	N	D
Spring	Artificial	Mean	15.3	19.5	0.4	0.1	0.0	9.2	0.1	0.1	95.1	139.9	0.546
	Natural 1	Mean	4.2	45.2	1.1	7.7	0.3	8.2	0.0	0.0	55.9	122.6	0.612
	Natural 2	Mean	13.8	6.8	0.1	9.0	0.3	2.9	0.0	0.0	25.2	58.0	0.678
	Artificial	SD	7.3	1.9	0.2	0.1	0.0	3.6	0.1	0.1	67.9	69.5	0.085
	Natural 1	SD	6.4	19.8	0.1	4.3	0.4	3.0	0.0	0.0	44.5	71.6	0.042
	Natural 2	SD	5.0	4.2	0.1	4.4	0.5	2.1	0.0	0.0	16.4	25.5	0.045
Summer	Artificial	Mean	46.5	20.5	2.5	5.3	0.1	4.3	1.7	1.3	176.6	258.7	0.533
	Natural 1	Mean	6.5	129.9	10.0	70.9	0.6	0.9	0.3	1.9	116.0	336.9	0.63
	Natural 2	Mean	26.3	3.6	2.4	151.5	2.8	2.6	0.0	0.0	165.7	354.9	0.491
	Artificial	SD	6.029	7.639	1.245	5.062	0.25	2.894	0.999	1.31	71.4	79.23	0.032
	Natural 1	SD	4.24	41.7	5.277	30.29	0.826	0.829	0.289	1.109	20.71	45.62	0.014
	Natural 2	SD	18.93	1.972	2.515	85.22	2.865	3.602	0	0	243.5	314.5	0.076

Table 3-3: 2006 spring and summer benthic invertebrate ANOVA results for predominant taxa mean site abundance, mean site total abundance (N), and site mean Simpson's diversity (D). Codes defined in Table 3-1.

Season	Response	Transformation	Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Spring	N	ABND^0.2	Region	2	0.39	0.195	2.642	0.125
			Error	9	0.664	0.074		
	Amphipoda	None	Region	2	291.65	145.82	3.667	0.068
			Error	9	357.87	39.76		
	Chironomidae	sin(ABND)^2	Region	2	0.078	0.039	0.54	0.6
			Error	9	0.648	0.072		
	Gastropoda	ABND^0.3	Region	2	6.079	3.04	24.299	<0.001
			Error	9	1.126	0.125		
	Oligocheata	ABND^0.5	Region	2	4.649	2.325	7.139	0.014
			Error	9	2.931	0.326		
	Trombidiform	Ln(ABND)	Region	2	2.663	1.332	1.712	0.235
			Error	9	7.002	0.778		
Summer	D	ABND^3	Region	2	0.041	0.021	5.12	0.033
			Error	9	0.036	0.004		
	N	sin(Total / 100)	Region	2	1.423	0.712	2.781	0.115
			Error	9	2.303	0.256		
	Amphipoda	sin(ABND)	Region	2	0.233	0.116	0.332	0.726
			Error	9	3.157	0.351		
	Chironomidae	ABND^0.2	Region	2	3.761	1.88	73.243	<0.001
			Error	9	0.231	0.026		
	Gastropoda	ABND^0.2	Region	2	4.15	2.075	22.258	<0.001
			Error	9	0.839	0.093		
	Oligocheata	ABND^0.4	Region	2	1.458	0.729	1.655	0.244
			Error	9	3.964	0.441		
	Trombidiform	sin(ABND)	Region	2	0.562	0.281	0.67	0.536
			Error	9	3.776	0.42		
	D	ABND^10	Region	2	0	0	22.729	<0.001
			Error	9	0	0		

Table 3-4: 2006 spring and summer benthic invertebrate p-values for pairwise comparisons for significant ANOVA results. Bonferroni adjustment used. Codes defined in Table 3-1.

Season	Response	Region	Artificial	Natural 1
Spring	Amphipoda	Natural 1	0.100	
		Natural 2	1.000	0.180
	Gastropoda	Natural 1	0.001	
		Natural 2	<0.001	1.000
	Oligocheata	Natural 1	1.000	
		Natural 2	0.022	0.041
	D	Natural 1	0.648	
		Natural 2	0.033	0.290
Summer	Chironomidae	Natural 1	<0.001	
		Natural 2	0.003	<0.001
	Gastropoda	Natural 1	0.003	
		Natural 2	<0.001	0.436
	D	Natural 1	0.001	
		Natural 2	1.000	0.001

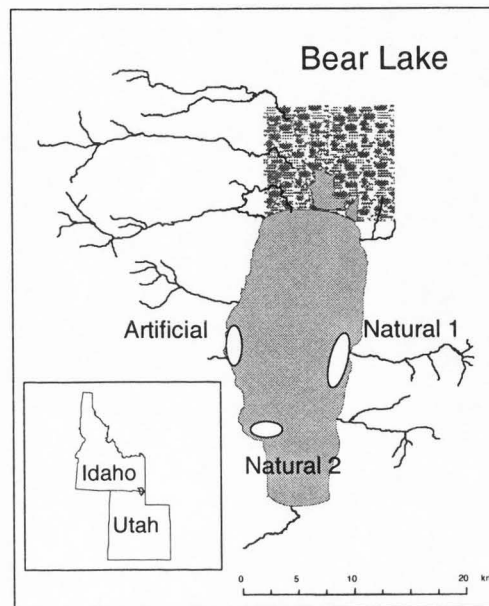


Figure 3-1: Artificial and natural reef sampling sites, Bear Lake, Utah/Idaho. White ellipsoids represent approximate location of reef regions.

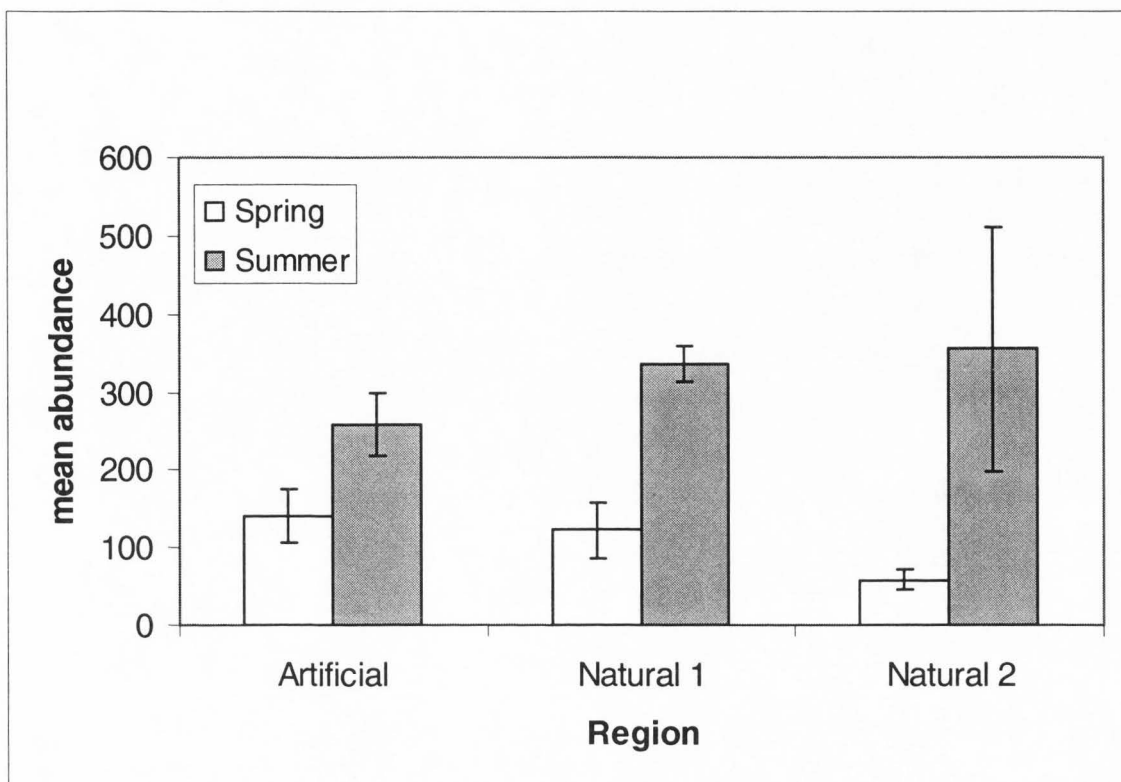


Figure 3-2: 2006 spring and summer benthic invertebrate mean region abundances. Error bars represent \pm one standard error.

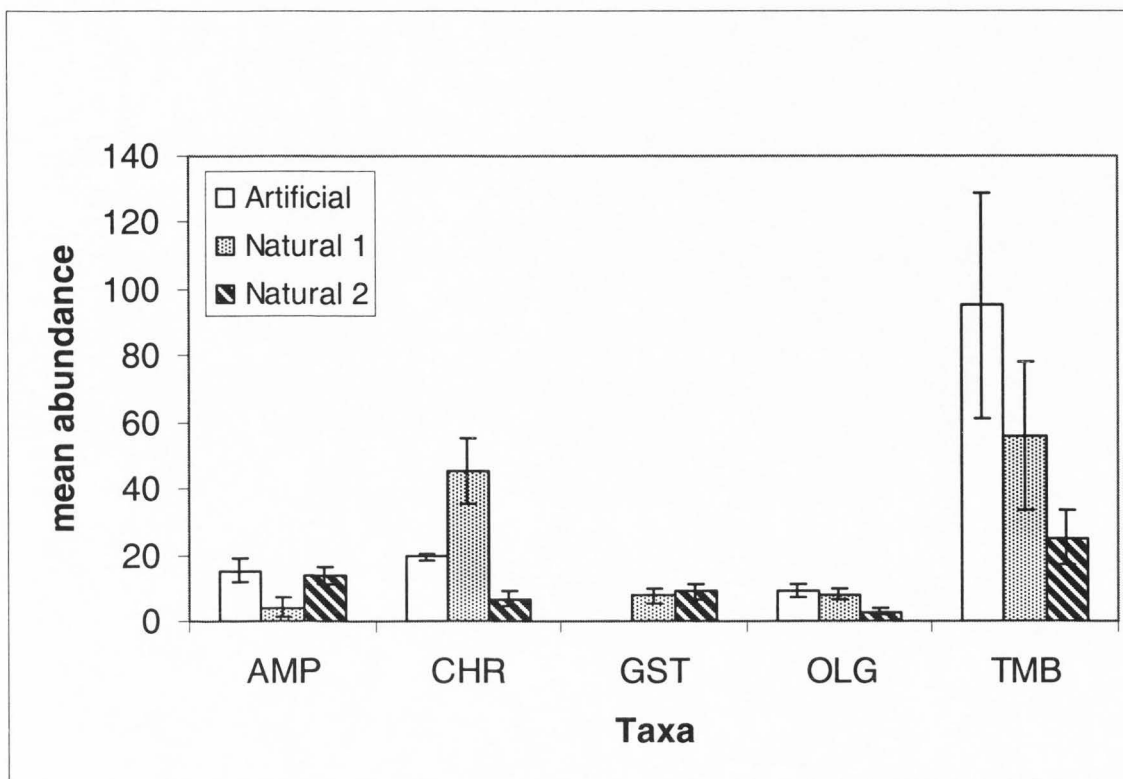


Figure 3-3: Spring 2006 predominant benthic invertebrate abundance for each reef region. Error bars represent \pm one standard error.

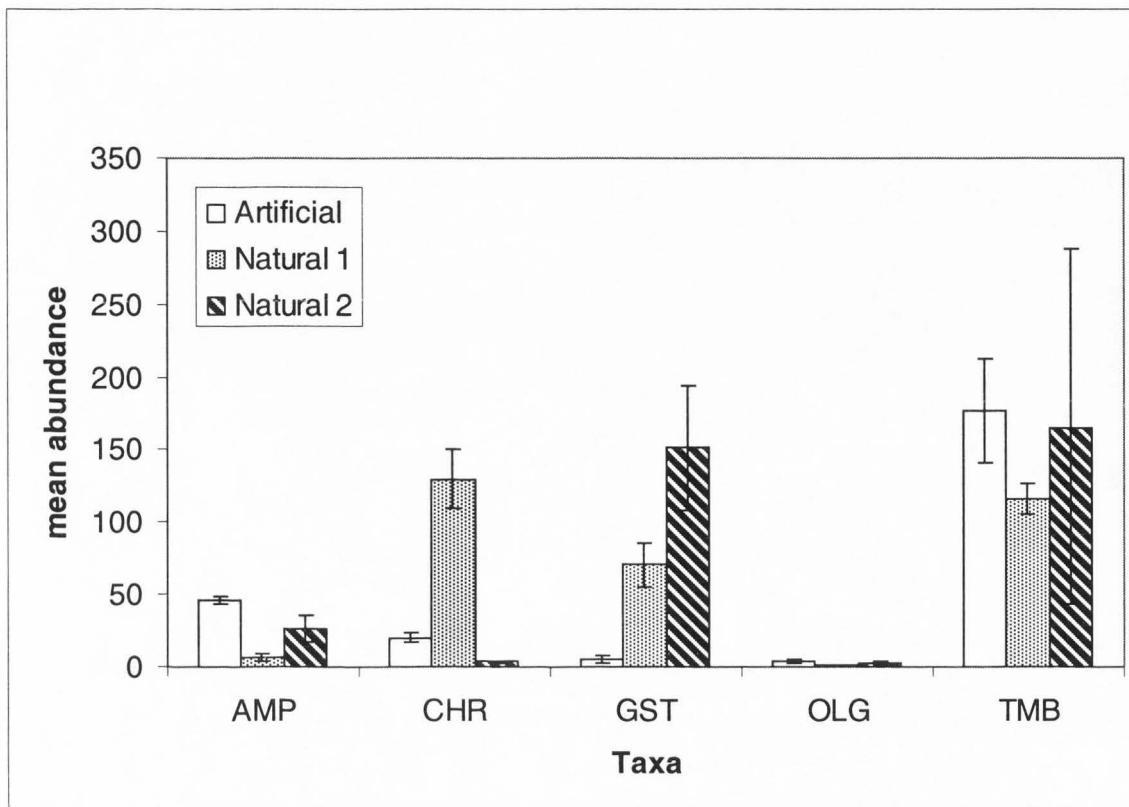


Figure 3-4: Summer 2006 predominant benthic invertebrate abundance for each reef region. Error bars represent +/- one standard error.

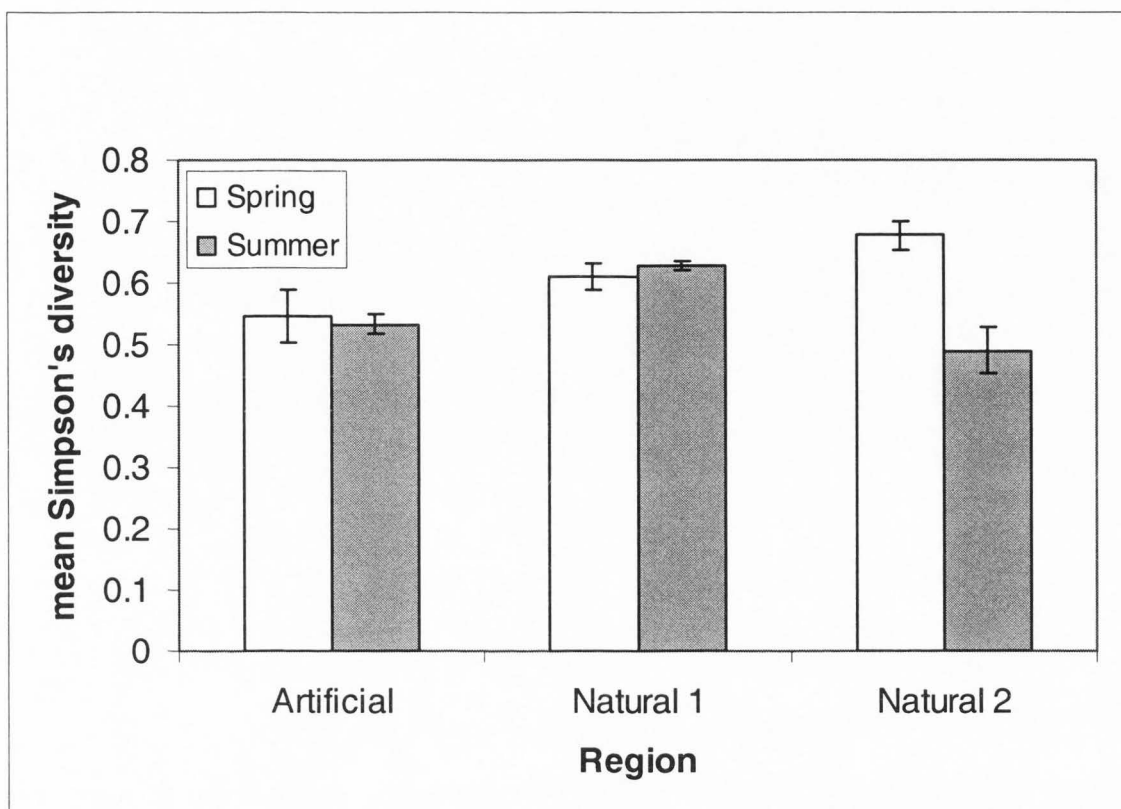


Figure 3-5: 2006 spring and summer benthic invertebrate mean region Simpson's diversity for each reef region. Error bars represent +/- one standard error.

CHAPTER 4

COMPARISON OF FISH ABUNDANCE AND DIVERSITY IN NATURAL AND
ARTIFICIAL REEF REGIONS, BEAR LAKE, UTAH/IDAHO¹

Abstract: Artificial reefs were built to increase the catchability of sport fishes and provide habitat for endemic fishes, which spawn on reefs in Bear Lake Utah/Idaho. Bear Lake is located in an arid region subject to drought. Drought dewatered natural reef habitat fringing the eastern shore of Bear Lake. Our objectives were to assess the potential of artificial reefs to function in attraction of sport fishes, and conservation of endemic fishes. Differences in fish catch per unit effort (CPUE) and diversity on rock and soft substrate between one artificial and two natural reef regions were compared. We hypothesized that fish catches and diversity within the artificial reef region will show similar patterns on rock and soft substrate, as to substrate catch pattern within two natural reef regions. Results demonstrated spawning lake trout were attracted to natural reefs, otherwise attraction to reefs was not found for the sport fishes. Winter cisco and whitefish CPUE on rock and soft substrate supported the hypothesis that Bear Lake fish species use the artificial reefs similar to natural reefs, but fall lake trout, crayfish, and yellow perch use of artificial and natural reefs were dissimilar. Results suggest artificial reefs may aid in conservation by functioning as additional habitat for spawning cisco and foraging Bonneville whitefish. Detected patterns that could alter the Bear Lake fish community are discussed.

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Introduction

Artificial reefs are believed to counteract anthropogenic effects by increasing foraging, spawning, and shelter habitat for multiple fish life stages (Grossman et al. 1997). This belief assumes fish recruitment is limited by a lack of structure, whereby the addition of artificial reefs leads to an increase in fish biomass (Bohnsack 1989; Bohnsack et al. 1991). In this chapter we discuss artificial reef theory. We discuss fish parameters in relation to artificial and natural reefs, and mechanisms leading to increased recruitment. We compare catch per unit efforts and diversity of fish between regions with artificial and natural reefs, and adjacent areas of soft substrate within Bear Lake, Utah/Idaho. Based on results, we assess the utility of artificial reefs as fishing gear and conservation agents.

The use of artificial reefs is controversial since the degree they act to attract fish to angling sites versus the degree they increase recruitment is unresolved. This debate is known as the attraction versus production issue. The attraction versus production issue has been difficult to answer due to the complexity and variability of aquatic systems, the scale necessary for sampling, and the accuracy of the measurements required (Lindberg 1997).

The attraction versus production issue is described by two hypothetical responses to artificial reefs, production and attraction, which are detailed by Bohnsack (1989). The production hypothesis predicts the additional foraging, spawning, and shelter offered by artificial reefs will increase fish biomass. The increase in biomass may result from the greater access to foraging habitat increasing fish size, and/or from the greater access to

spawning habitat increasing recruitment, which yields higher densities. The increase in production is represented by an increase in total annual catch in Figure 4-1. Catch response in the production hypothesis may be either linear or saturated. A linear response predicts habitat is always limited, thus biomass increases as the number of artificial reefs increase. In the saturation response there is an initial increase in catch as the number of artificial reefs increase, but eventually habitat is no longer limited and catch stabilizes.

The attraction hypothesis predicts an eventual decrease in catchability of fish from the installation of artificial reefs (Bohnsack 1989). The attraction of fish to artificial reef structure concentrates populations and increases catchability. As fish are caught and pulled from the artificial reef system, fish occupying less preferred habitat migrate to the artificial reefs to occupy the open preferred habitat. These fish are pulled from the system and eventually there are little numbers of fish available to fill the artificial reef habitat. In an open system, with mobile populations, catch may be sustained from migration in the attraction hypothesis. It should be emphasized that attraction and production aren't absolutes but a matter of degree. The coupling of increased removal from attraction and increased fecundity from production determine the effect on fish populations (Bohnsack 1989).

Artificial reef complexity influences fish abundance (Nanami and Nishihira 2003a and 2003b; Creque et al. 2006), diversity (Freitas and Petrere 2001; Nanami and Nishihira 2003a and 2003b; Gratwicke and Speight 2005), native and non-native fish biomass (Jan et al. 2003), and trophic dynamics (Hixon and Beets 1989). Due to cost and logistical constraints, artificial reefs may be composed of essentially homogenous

material and structures may be much smaller in size when compared to local natural substrate (Grove et al. 1991). Thus, artificial reefs may not function as surrogate habitat, but lead to deviations from indigenous communities (Bulleri and Chapman 2004; Edwards and Smith 2005; Perkol-Finkel and Beneyahu 2004, 2005, 2007).

Artificial reefs may facilitate recruitment through increased egg survival. Rock habitat benefits fish eggs by providing interstitial spaces, where the water circulation prevents sediment accumulation and provides oxygen (Chapman 1988). Interstitial spaces are also critical in the protection of eggs from predation (Marsden et al. 1995b). Depauperate rock habitat within Bear Lake is believed to limit reproduction for demersal spawners (Ruzycki et al. 2001; Albrecht 2004). By acting as a surrogate for natural rock, artificial reef can provide the necessary shelter for eggs.

Four artificial reefs were built in Bear Lake to function as surrogate habitat for endemic fishes, and increase sport fishes catchability. Bear Lake contains four endemic fish species (Table 4-1): Bear Lake and Bonneville whitefish (*Prosopium abyssicola* and *P. spilonotus*), Bonneville cisco (*P. gemmifer*), and Bear Lake sculpin (*Cottus extensus*). Studies have shown a preference for spawning on rock habitat for Bear Lake and Bonneville whitefish (Albercht 2004), Bonneville cisco (Bouwes and Luecke 1997), and Bear Lake sculpin (Ruzycki et al. 1998). During years of drought, rock along Bear Lake's eastern shore is dewatered, reducing rock habitat within the lake. The artificial reefs were built in an area not historically subjected to dewatering, mitigating the loss of rock habitat during drought. The top sport fishes within the lake include the native Bonneville cutthroat trout (*Oncorhynchus clarki utah*) and non-native lake trout (*Salvelinus namaycush*), both of which are primarily maintained by stocking.

Quantitative comparisons of use of artificial and natural reefs by fish are problematic (Lindberg 1997). Fish community responses to artificial reefs are obfuscated by unknown degrees of fish attraction and production on artificial reefs. Some requirements to clarify attraction and production include assessment of angling effort, migration, spawning use, and fecundity. Thus, predictions of fish response to artificial reefs are based on other predictions, often from measurements difficult or impossible to obtain. To circumvent the accumulation of statistical noise from compounding predictions, we compared fishes' catch per unit efforts (CPUE) between artificial and natural reef regions and formulate predictions based on species use in relation to their life history.

The objectives of this study were to determine the potential of artificial reefs to function as conservation agents by providing surrogate rock habitat to fish fauna of Bear Lake, and to attract sport fishes. We hypothesized that fish catch will show a similar pattern in relation to rock and soft substrate within an artificial reef region, as to substrate catch pattern within two natural reef regions. Specifically we tested for differences in fish catch per unit effort (CPUE) and diversity between artificial and natural regions, and rock and soft substrates. Measurements of parameters were compared on different substrates within each region to assess the utility of artificial reefs. Results were discussed in relation of the potential sport fish attraction and increased production. Specific consideration was given to the spawning season of a common sport fish and endemic fishes.

Methods

A description of codes and symbols used in plots and tables are in Table 4-1.

Study site.—Bear Lake is an oligotrophic lake, approximately 282 km² in area, containing 7.86 km³ of water and is 1805 meters in elevation at full pool. It is located in northeast Utah and southwest Idaho at latitude 42° 00' North and longitude 111° 20' West (Figure 4-2). Bear Lake is somewhat oval shaped, with the longer axis laying north to south and bisected by the Utah/Idaho boarder. The western shore slopes gradually to its maximum depth of approximately 63m; the mean depth of the lake is 28m at full pool. The eastern shore drops abruptly and the lake displays classic tilt-block morphology.

Data were collected on rock and soft substrate within three regions of Bear Lake. Videography was used to verify substrate. *Artificial* contains the artificial reefs, and *Natural 1* and *Natural 2* contain natural reefs. Within each region were four rock and four soft sample sites (Figure 4-1). Sites within *Artificial* and *Natural 1* were located approximately 200m apart, on a north/south transect, and were approximately 10m deep in October 2005. Because of the topography and reef shape of the *Natural 2*, rock sites were scattered 50 to 100m meters apart, and depths ranged from 11 to 13.5m in October 2005, while soft sites ranged from south to north and were approximately 10m deep in October 2005. All soft sites within each region were located within 1km of at least one rock site.

Bear Lake's artificial reefs differed from natural reefs within the lake in spatial placement and area (Chapter 2). The artificial reefs were built in October 2005 at sites located 200-1000m north of Bear Lake marina, and approximately 10m deep. A total of

720m³ of rock was used in construction. Each site received 180m³ of rock per site, transported by dump truck and barge. Mean intermediate length for the rock used was 0.119m with a standard deviation of 0.030m (N=100). *Artificial* has isolated-homogenous rock habitats. The natural regions have a continuous-heterogeneous rock habitat. *Natural 1* and *Natural 2* rock vary by size (gravel to large stones), and *Natural 2* also contains large amounts of an intricate, perforated rock.

Fish collection.—Fish were collected with experimental gillnets set on the lake bottom. The experimental gillnets had nine panels with mesh sizes 19.05, 25.40, 31.75, 38.10, 50.80, 63.50, 76.20, 88.90, and 101.60mm. Short gillnets were used on reefs to minimize net off rock over the artificial reefs, and minimize depth difference along the steep *Natural 1* rock substrate. Each of the nine short gillnet panels were 2.13m in length. Long gillnets were used on soft substrate and panel lengths were 4.57m, except for mesh sizes of 38.10 and 50.80mm which were 6.86m.

Long gillnet catch for each species was standardized for panel length by multiplying the number of fish caught by the fraction 19.202 / 47.720 for all species. The numerator used was the length of short gillnet in meters, while the denominator was the length of long gillnet in meters. Catch per unit effort for each species was calculated by:

$$CPUE_i = F_{ij} / t_j,$$

where F_i was the (adjusted) number of fish species i caught in gillnet set j , and t was the soak time in hours for gillnet set j .

Minnowtraps were used in all seasons except winter. Traps were baited with dog food and power bait. A minnowtrap was attached to both anchors of each gillnets, except

for spring 2006, where only one minnowtrap was set on soft sites. Minnowtrap data for spring 2006 soft sites was doubled to standardized minnowtrap effort.

Gillnet and minnowtrap sampling occurred in all four seasons. Three of the four possible sites for each substrate in each region were randomly chosen to gillnet for each sampling period. Gillnets were set overnight except in the winter when they were set an average of four hours during daylight to prevent flooding of nets from spawning fish. Winter gillnet sampling occurred February 03, 2006 for *Artificial* and *Natural 1*, and February 04, 2006 for *Artificial* and *Natural 2*. Thus, *Artificial* contained 6 winter gillnet sets on rock and 6 on soft, while the natural regions contained 3 on rock and 3 on soft. Spring gillnet sampling occurred May 04, 2006 and May 01, 2007 for *Natural 1* and *Natural 2*, and May 05, 2006 and May 02, 2007 for *Artificial*. Summer gillnet sampling occurred July 17, 2006 and July 16, 2007 for *Natural 1* and *Natural 2*, and July 18, 2006 and July 17, 2007 for *Artificial*. Each region had 6 rock and 6 soft gillnet sets when years were combined for spring and summer data. Fall gillnet sampling occurred in October 14, 2006 for *Natural 1* and *Natural 2*, and October 15, 2006 for *Artificial*. Each region had 3 rock and 3 soft gillnet sets for fall data. Gillnetting was conducted during cisco and lake trout spawning seasons.

Statistical analyses.—Gillnet and minnowtrap data were combined for each set for ANOVA analyses and comparison of CPUE in relation to region and substrate. The mean CPUE for each region/substrate were plotted for each species and season with plus and minus one standard error bars. Separate ANOVAs were performed for each season because of the variability in species abundances over seasons, and to focus on differences

in substrate use between artificial and natural regions. An ANOVA was run on species predominate in the catch. The model was:

$$CPUE = Region + Substrate + Region*Substrate,$$

where *CPUE* was the response, and *Region*, *Substrate* (rock, soft), and the *Region*Substrate* interaction were the factors. A Bonferroni adjustment was used for pairwise comparisons when *Region* was significant. Significant differences in *CPUE* between substrates and regions were determined by a p-value less than or equal to 0.10. Rainbow trout data were combined with Bonneville cutthroat trout data, and Bear Lake whitefish were combined with Bonneville whitefish for analyses. When necessary, fish response was transformed to obtain homogeneity of variance between groups.

Taxa diversities at sites and regions were measured by Simpson diversity index (D):

$$D = 1 - \sum \left(\frac{n}{N} \right)^2,$$

where *N* was the total *CPUE* of all species in a gillnet set and *n* was the *CPUE* of each species in the gillnet set. Separate ANOVAs on diversity were run for each season.

Diversity was the response, and *Region*, *Substrate* (rock, soft), and the *Region*Substrate* interaction were the factors. A Bonferroni adjustment was used for pairwise comparisons when *Region* was significant. Significant differences in diversity between substrates and regions were determined by a p-value less than or equal to 0.10.

Results

Interpretation of results often required simultaneous evaluation of the ANOVA and the plots of CPUE and diversity means. Interpretable results occurred when substrate was significant and natural regions displayed the same CPUE pattern on substrate, which suggested a substrate preference by fish. Results in which region was significant may have represented fish selection by regional characteristics (i.e., slope, access to deep water, and/or site fidelity) and not substrate differences. Nevertheless, a regional preference did not necessarily prevent comparisons of artificial and natural regions. Significant interactions may have masked significant factors but consideration of figures allowed distinction of patterns. When no significant differences were found, results were uninformative since there was no distinction between substrates. Dissimilar substrate CPUE patterns within natural regions also were uninformative, since determination of the species relationship to natural substrate was impossible. The number of individuals of each species, soak time, CPUE, and diversity for each gillnet set is in Appendix IV (Tables AIV-1 and AIV-2).

Figures for results that did not elucidate the utility of artificial reefs were placed in Appendix IV. These results included carp (CARP, Figure AIV-1), chub (CHUB, Figure AIV-2), redbside shiner (RSR, Figure AIV-3), Bear Lake sculpin (SCULP, Figure AIV-4), Utah sucker (US, Figure AIV-5). These results were uninformative due to lack of substrate difference, lack of agreement in substrate pattern between the natural reefs, and/or a higher CPUE on soft substrate, which is not limited in Bear Lake.

Results that elucidated the potential of artificial reefs for sport fishes attraction, and fish conservation, for at least one season, included total catch (N, Figure 4-3), (BCT_RB, Figure 4-4), crayfish (CF, Figure 4-5), cisco (CISCO, Figure 4-6), lake trout (LT, Figure 4-7), Bonneville and Bear Lake whitefish (WF, Figure 4-8), and yellow perch (YP, Figure 4-9).

CPUE.—Total catch rates varied between seasons (Figure 4-3). A clear pattern of substrate use was not present for spring, summer, and fall total catch rates. *Substrate* was not significant for these three seasons (Tables 4-5 to 4-7), and *Region* was not significant in summer and fall. No significant regional differences were found in the pairwise comparisons of total CPUE in spring (Table 4-4).

Winter total fish catch results suggested similar substrate use in regions of artificial and natural reefs, but regional differences in fish densities were present. CPUE was higher on rock substrate for every region, although it was not as pronounced in *Artificial*. Nevertheless, error bars did not overlap within regions, which indicated similarity in substrate CPUE pattern between the natural and artificial reefs. CPUE was significantly higher in *Natural 1* compared to *Artificial* and *Natural 2*, which suggested a fish preference for *Natural 1* in winter (Tables 4-3 and 4-4). Total CPUE was significantly higher on rock substrate.

Results for Bonneville cutthroat and rainbow trout did not suggest a difference in CPUE between substrates or regions (Figure 4-4). Catch patterns on substrate were dissimilar in the natural regions. Cutthroat and rainbow trout were caught in sufficient numbers for analyses in winter, spring, and summer. No significant results were found (Tables 4-3, 4-5, and 4-6).

Results for crayfish suggested dissimilar use of artificial and natural reefs (Figure 4-5). Crayfish were only caught in sufficient numbers for analyses in fall. Crayfish were only caught in *Artificial* and on soft substrate in *Natural 2*. CPUE on the artificial reefs was approximately 18 times greater than that of adjacent soft substrate, and approximately 5 times greater than soft substrate combined, although *Substrate* was not significant (Table 4-7). A significant interaction resulted from Crayfish catch being limited to soft substrate in *Natural 2*. Artificial CPUE was significantly higher than *Natural 2* CPUE (Tables 4-3 and 4-7).

CPUE for cisco varied between seasons (Figure 4-6). Cisco catch in the spring was too low for analyses (Table 4-2). Fall cisco were only caught on soft substrate in *Artificial* and *Natural 2*, and on *Natural 1* rock substrate, and no significant differences were found (Table 2-7). Summer cisco suggested differences between natural and artificial reefs. Cisco CPUE was higher on soft substrate in *Natural 1* and *Natural 2*. *Substrate* was the only significant factor in summer, with CPUE on soft substrate significantly higher than on rock substrate (Table 4-6). Winter cisco catch varied between regions and substrates.

Cisco was the predominant species caught in winter and displayed the same catch pattern as total CPUE. Winter cisco CPUE was higher on rock substrate for all regions. The natural regions displayed a greater difference in CPUE between substrates than *Artificial*, but error bars did not overlap within any region. *Natural 1* cisco CPUE was significantly higher than *Artificial* and *Natural 2* (Table 4-4). Cisco CPUE was significantly higher on rock (Table 4-3).

Lake trout were only caught in sufficient numbers for analyses in fall. Fall lake trout results suggested dissimilar use of the artificial and natural reefs. Although higher catches of lake trout were found on rock within each region, the difference was slight in *Artificial* (Figure 4-7). Lake trout CPUE was significantly higher on rock substrate (Table 4-7). *Natural 2* lake trout was significantly higher than *Artificial* and *Natural 1* (Table 4-4).

Whitefish CPUE in regions and on substrate varied between seasons (Figure 4-8). Substrate CPUE did not agree between natural regions in the fall. *Region* and *Substrate* were not significant for whitefish CPUE in the fall (Table 2-7). Results for whitefish suggested similarity between artificial and natural reef regions for spring. Spring whitefish were entirely Bonneville whitefish (Table 4-2). Spring whitefish CPUE was higher on soft substrate for every region. *Substrate* was significant higher on soft substrate (Table 4-5 and Figure 4-13). Summer whitefish results suggested differences between natural and artificial reef regions. There were 164 Bonneville whitefish and 13 Bear Lake whitefish in caught in summer (Table AIV-2). CPUE was higher on soft substrate for each region in summer, but error bars overlapped in *Artificial*. Error bars did not overlap in the natural regions. CPUE was significantly higher on soft substrate (Table 4-6). No other factors were significant.

Winter whitefish results indicated similar use of substrate in artificial and natural reef regions. Winter whitefish catch displayed a similar pattern to total and cisco CPUE. Winter whitefish was entirely Bonneville whitefish (Table 4-2). All regions had a higher CPUE on rock substrate, and error bars did not overlap within regions. All factors were significant (Table 4-3). The interaction resulted from *Natural 2* rock CPUE higher than

Artificial, but soft lower than *Artificial*. The interaction effect on *Region* was irrelevant since pairwise comparisons found no significant differences between regions (Table 4-4). Winter whitefish CPUE was significantly higher on rock.

Yellow perch were only caught in sufficient numbers for analyses in spring and fall (Table 4-2). Spring yellow perch were only caught on rock substrate in *Artificial* and *Natural 1*, but CPUE was similar on both substrates for *Natural 2* (Figure 4-9). The substrate CPUE pattern between natural regions did not agree for spring yellow perch. No factors were significant (Table 4-5). Fall analyses of yellow perch CPUE suggested dissimilarity between artificial and natural reefs. Yellow perch CPUE was higher on rock substrate for every regions, but substrate error bars overlapped within the natural regions. Yellow perch were not caught on soft substrate in *Artificial*. Yellow perch catch was highest on the artificial reefs, but no significant difference was found between regions (Table 4-7). There was a significantly higher yellow perch CPUE on rock, but this appeared to result from the catch pattern in *Artificial*.

Simpson's diversity.—Results for winter mean Simpson's diversity did not elucidate similarities and differences in fish use of artificial and natural reef regions. Both *Artificial* and *Natural 2* showed higher diversity on rock, but the difference between substrates was slight for *Artificial*, where error bars overlapped (Figure 4-10). *Natural 1* had a higher diversity on soft substrate, but error bars overlap. ANOVA results showed a significant interaction between *Region* and *Substrate*, but no other factors were significant.

Results for spring Simpson's diversity were uninformative due to a lack of agreement in rock and soft diversity pattern between the natural regions (Figure 4-10).

All regions had a higher diversity on soft, although the difference was slight for region E where error bars overlapped. *Region* and *Substrate* were significant factors (Table 4-5). Region E diversity was significantly higher than region A (Table 4-3). Diversity on soft substrate was significantly higher than on rock.

Summer Simpson's diversity results suggested similar use of artificial and natural reefs. All regions had a higher diversity on soft substrate and error bars did not overlap (Figure 4-10). *Natural 2* soft substrate had a higher diversity than *Artificial* soft substrate, but *Natural 2* rock substrate had lower diversity than *Artificial* rock substrate. This pattern produced a significant interaction in the ANOVA (Table 4-6). *Region* and *Substrate* were significant. No significant difference was found between regions from the pairwise test (Table 4-3). Diversity was significantly higher on soft substrate.

Fall Simpson's diversity results were uninformative due to differences in the pattern of substrate diversity within the natural regions. Fall diversity was higher on rock for *Natural 1* and *Artificial*, but diversity was similar for both substrates within *Natural 2* (Figure 4-15). Diversity was significantly higher on rock substrate, but the interaction was also significant (Table 4-6).

Discussion

To evaluate and predict the influence of artificial reefs on the Bear Lake fauna, it was necessary to consider the ecological context of the results. Results supporting similar fish use of artificial and natural reefs were found in winter and spring, but dissimilar use was found in summer and fall (Table 4-8). Results that could affect the conservation of endemic fishes included winter cisco and Bonneville whitefish, and fall

crayfish, lake trout, and yellow perch. For clarity, the discussion is divided into *Sport fish attraction*, *Ecologically important results*, and *Ecologically unimportant results*.

Ecologically important and unimportant results refer to results that suggest potential positive or negative effects in the conservation of endemic fishes.

Sport fish attraction.—Increased catchability of sport fish via attraction to artificial reefs was not supported. The CPUE pattern for sport fish did not fit Bohnsack's attraction hypothesis. The artificial reefs did not increase the catchability of Bonneville cutthroat, rainbow and lake trout. Although the artificial reefs aggregated prey species such as cisco and Bonneville whitefish in winter, the CPUE of the sport fishes appeared unrelated to the presence of prey fish.

Ecologically important results.—Artificial reef conservation potential was demonstrated by the similar use of rock and soft substrate for winter sampling of cisco and Bonneville whitefish in natural and artificial reef regions. Total CPUE suggested the utility of artificial reefs for conservation, but the total CPUE was largely made up of cisco and Bonneville whitefish, and reflected the catch pattern of these two species. Although the number of winter cisco and Bonneville whitefish caught on the artificial reefs was less than the natural reefs, differences may be due the smaller area of rock habitat available in *Artificial* compared to the large area of the natural reef regions (Chapter 2). The winter Bonneville whitefish and cisco CPUE patterns suggested artificial reefs aid in conservation of endemic Bear Lake fish in two ways.

The first way artificial reefs appear to aid in conservation is by functioning as additional habitat for the endemic cisco during their spawning. Lack of rock habitat in Bear Lake may limit reproduction for demersal spawners, such as cisco and whitefish

(Ruzycki et al. 2001). Rock substrate protects eggs from predation (Horns and Magunson 1981; Chotkowski and Marsden 1999). Although predation of cisco eggs broadcast over cobble was high at shallow depth (2m), cobble refugia at greater depth may provide greater protection for cisco eggs and contribute greatly to cisco recruitment (Bouwes and Luecke 1997). If cisco presence equates to cisco spawning, the artificial reefs will provide additional spawning habitat at depths greater than 2m.

Whitefish may also receive a benefit from the artificial reefs. Whitefish have an affinity for spawning on rock substrate, when compared to other substrates at 10m (Albrecht 2004). Thus, the artificial reefs may function as additional spawning habitat for the whitefish. Although the spawning habitat preferred by the endemic Bear Lake sculpin is also rock (Ruzycki et al. 1998), sculpin prefer spawning at shallow depth (Luecke, personal communication).

The second way artificial reefs may function in conservation is by providing additional foraging habitat for winter Bonneville whitefish. Although Bonneville whitefish complete their spawning in December, their CPUE in relation to region and substrate indicates similarity in substrate use between artificial and natural reefs and displays trends similar to ciscoes. The Bonneville whitefish may be located in regions of cisco spawning to forage on cisco eggs. Bouwes and Luecke (1997) found stomachs averaged greater than 2000 cisco eggs for 12 whitefish. Examination of Bonneville whitefish stomachs from our winter gillnet sets revealed Bonneville whitefish diet was dominated by eggs for all regions within Bear Lake (personal observation).

Fall sampling results did not demonstrate the artificial reefs function as additional rock habitat during the lake trout spawning season. Although no substrate preference was

found for lake trout in the artificial reef region during their spawning, the natural regions showed a trend for lake trout on rock. The lake trout CPUE pattern suggested use of the natural reefs by lake trout for spawning.

Lake trout are non-native to Bear Lake, thus artificial reef spawning by lake trout is not desirable. Lake trout are native to the Great Lakes where their spawning success may be limited by habitat availability (Marsden et al. 1995a). Lake trout preferred clean, recently constructed artificial habitat, over natural reefs, for spawning in the Great Lakes (Marsden et al. 1995b, Fitzsimons 1996; Claramunt et al. 2005). Great lake lake trout egg survival on artificial reefs is comparable to natural reefs (Marsden et al. 1995b).

Despite concerns of lake trout affinity for artificial reef spawning, our results do not demonstrate a use of artificial reefs by spawning lake trout. Introduced lake trout can impact native fauna as in Yellowstone Lake, Wyoming, where lake trout prey on the native cutthroat trout (Ruzycki et al. 2003). Lake trout have been stocked in Bear Lake since 1911, but only triploid lake trout have been stocked since 2002 (Scott Tolentino, personal communication). Since Bear Lake still contains fertile lake trout resulting from stocking prior to 2002, and sterilization may not be 100% effective (Garcia-Abiado et al. 2002, and Abiado et al. 2007), future sampling of the artificial reefs during lake trout spawning season is warranted.

Fall results demonstrate crayfish use the artificial reefs and not the natural reefs. Based on current knowledge, there is a native and non-native species of crayfish in Bear Lake (Scott Tolentino, Utah Division of Wildlife Resources (UDWR), personal communication). Fall crayfish collected in sample were recorded but were not identified

to species. The impact of crayfish use of artificial reefs to the fish community is unknown, although crayfish prey on fish eggs (Fitzsimons et al. 2007).

Fall results suggested Bear Lake's artificial reefs may function as habitat for exotic yellow perch. Although the interaction and *Region* were not significant, results suggests a yellow perch were only attracted to the rock in the artificial reef region. The total lengths of eleven of the 13 yellow perch caught on the artificial reefs, were less than 100mm (Table 4-9). The yellow perch may obtain a shelter benefit from the artificial reefs. Studies have demonstrated the use of refuge habitats, such as rock and macrophytes, of prey species for shelter from predation (Werner et al. 1983; Tabor and Wurtsbaugh 1991; Fraser et al. 1996; Halvorsen et al. 1997; Landry et al. 1999; Biro et al. 2003). The impact of yellow perch use of artificial reefs to the fish community is unknown, although yellow perch prey on eggs (Roseman et al. 2006).

A potential impact on cisco could result from fall crayfish and yellow perch, and winter whitefish. The suggested spawning benefit afforded to cisco by artificial reefs is incongruous to the foraging potential offered by artificial reefs to whitefish, crayfish, and yellow perch. If drought does not reduce rock habitat, the additional spawning habitat provided by the artificial reefs could lead to increased cisco recruitment, leading to an increase in the cisco population. Since a proportion of demersal spawning eggs do not fall within interstitial spaces, a greater number of eggs could be available to foragers, such as the Bonneville whitefish, crayfish, and yellow perch. The additional source of energy provided by the increase in cisco eggs could increase fecundities for these egg predators. The increased fecundities could lead to increased recruitment for whitefish, crayfish, and yellow perch, and thus increased predation on cisco eggs.

Ecologically unimportant results.—A benefit from artificial reefs is not suggested for species showing a preference for soft substrate. Construction of additional rock habitat does not provide additional habitat to fishes that use soft substrate greater than rock. It is unlikely that the amount of soft habitat available has become limiting due to the construction of the artificial reefs (Chapter 2). Species showing a preference for soft substrate include whitefish for spring sampling, and cisco, sculpin, whitefish, and diversity for summer sampling.

Given the high catch rate of Utah sucker in our study, it is unlikely conservation measures need to be taken for Utah sucker. Utah sucker results in the fall demonstrated greater use of rock habitat in the natural regions. There was no clear trend of substrate use in the artificial region. The lack of a clear trend may have resulted from the small area and isolation of the artificial reefs, compared to the natural reef regions (Chapter 2).

Conclusions

Although winter cisco and whitefish supports similar use of artificial and natural reefs by some of the Bear Lake fish species, fall crayfish, lake trout, and yellow perch found dissimilar use. Result suggests artificial reef may aid in conservation by functioning as addition habitat by spawning cisco and foraging Bonneville whitefish. Yellow perch and crayfish affinities to the artificial reefs may be undesirable responses that could lead to an increase in non-native competition and endemic fish egg predation.

Sport fish attraction to the artificial reefs was not found. Lake trout were attracted to natural rock substrate during their spawning period, but the CPUE on the artificial

reefs was similar to adjacent soft substrate. Bonneville cutthroat trout did not show a preference for a substrate or a region for any season.

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Table 4-1: Codes used in Chapter 4. * denotes endemic species.

Code	Represents	Scientific name
A	Artificial region	
AR	Artificial region rock	
AS	Artificial region soft	
BCT	Bonneville cutthroat trout	<i>Onchorhynchus clarki utah</i>
BCT_RB	BCT and RB	
BLW	Bear Lake whitefish*	<i>Prosopium abyssicola</i>
BONN	Bonneville whitefish*	<i>Prosopium spilonotus</i>
CARP	Common carp	<i>Cyprinus carpio</i>
CF	Crayfish	
CHUB	Chub	<i>Githela atraria</i>
CISCO	Bonneville cisco*	<i>Prosopium gemmifer</i>
CPUE	Catch Per Unit Effort	
D	Simpson's diversity index	
FI	fall	
LN	Natural log	
LT	Lake trout	<i>Salvelinus namaycush</i>
N	Total	
N1	Eastern region	
N1R	Eastern region rock	
N1S	Eastern region soft	
N2	Rockpile region	
N2R	Rockpile region rock	
N2S	Rockpile region soft	
NS	Non-significant	
R	Rock substrate	
RB	Rainbow trout	<i>Oncorhynchus mykiss</i>
Reg:Sub	Region Substrate Interaction	
RSR	Redside shiner	<i>Richardsonius balteatus</i>
S	Soft substrate	
SCULP	Bear Lake sculpin*	<i>Cottus extensus</i>
smr	Summer	
spr	Spring	
US	Utah sucker	<i>Catostomus ardens</i>
WF	BLW and BONN	
wnt	Winter	
YP	Yellow perch	<i>Perca flavescens</i>

Table 4-2: Season mean region and substrate CPUE, mean total (N) and mean Simpson's diversity (D). BCT_RB is BCT and RB combined. WF is BLW and BONN combined. Codes defined in Table 4-1.

Season	Area	BCT	RB	BCT_RB	BLW	BONN	WF	CF	CARP	CHUB	CISCO	LT	RSR	SCULP	US	YP	N	D
wnt	AR	0.118	0	0.118	0	0.903	0.903	0	0	0	2.219	0.029	0	0	0.209	0	3.477	0.434
wnt	AS	0.084	0	0.084	0	0.315	0.315	0	0	0	0.56	0	0	0	0.129	0	1.088	0.354
wnt	N1R	0.135	0	0.135	0	1.976	1.976	0	0	0	21.635	0	0	0	0	0	23.746	0.173
wnt	N1S	0.173	0	0.173	0	1.054	1.054	0	0.025	0	9.257	0	0	0	0.025	0	10.532	0.256
wnt	N2R	0.548	0	0.548	0	1.913	1.913	0	0	0	5.067	0	0	0	0.327	0	7.855	0.506
wnt	N2S	0	0	0	0	0	0	0	0	0	0	0	0	0	0.056	0	0.056	0.000
spr	AR	0	0	0	0	0.013	0.013	0	0	0	0	0	0	0.026	0.199	0.027	0.265	0.252
spr	AS	0.016	0	0.016	0	0.053	0.053	0	0	0	0	0.005	0	0.025	0.205	0	0.304	0.419
spr	N1R	0.013	0	0.013	0	0	0	0	0	0.16	0	0	0	0.353	0.121	0.04	0.687	0.562
spr	N1S	0.006	0	0.006	0	0.052	0.052	0	0	0.079	0	0.005	0	0.069	0.144	0	0.355	0.590
spr	N2R	0	0	0	0	0	0	0	0.012	0.087	0	0	0	0.011	0.132	0.012	0.254	0.270
spr	N2S	0.013	0	0.013	0	0.107	0.107	0	0	0.061	0	0	0	0	0.166	0.005	0.351	0.559
smr	AR	0.025	0	0.025	0	0.168	0.168	0.013	0.014	0.014	0.013	0	0	0.013	0.528	0	0.787	0.410
smr	AS	0	0.011	0.011	0.037	0.212	0.25	0	0.021	0.122	0.016	0	0	0.024	0.374	0	0.816	0.599
smr	N1R	0.013	0	0.013	0	0.105	0.105	0	0.055	0.039	0	0	0.04	0.013	0.354	0	0.619	0.530
smr	N1S	0.022	0.01	0.032	0.004	0.324	0.327	0	0.013	0.083	0.217	0	0	0.159	0.269	0	1.100	0.674
smr	N2R	0.021	0	0.021	0	0.044	0.044	0	0	0	0	0	0	0.011	0.57	0	0.646	0.155
smr	N2S	0.004	0	0.004	0.017	0.123	0.14	0	0.032	0.072	0.013	0	0	0.063	0.313	0	0.635	0.648
fl	AR	0	0	0	0	0.138	0.138	0.161	0	0.07	0	0.023	0	0.046	0.069	0.254	0.761	0.752
fl	AS	0.009	0	0.009	0.019	0.386	0.405	0.009	0.009	0.129	0.128	0.009	0	0.022	0.056	0	0.777	0.672
fl	N1R	0	0	0	0	0.123	0.123	0	0	0.103	0.061	0.082	0	0	0.226	0.123	0.718	0.756
fl	N1S	0.041	0	0.041	0	0.033	0.033	0	0	0.411	0	0.025	0.008	0	0.075	0.02	0.613	0.435
fl	N2R	0	0	0	0	0.151	0.151	0	0	0.206	0	0.318	0	0	0.112	0.076	0.863	0.642
fl	N2S	0	0	0	0	0.415	0.415	0.022	0.007	0.117	0.037	0.109	0	0.018	0.051	0.035	0.811	0.665

Table 4-3: Winter 2006 CPUE ANOVA results. Codes defined in Table 4-1.

Species	Transformation	Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N	CPUE ^{0.6}	Region	2	65.485	32.743	31.1674	<0.001
		Substrate	1	23.877	23.877	22.7278	<0.001
		Reg:Sub	2	5.47	2.735	2.6036	0.102
		Residuals	18	18.91	1.051		
BCT_RB	CPUE ^{0.3}	Region	2	0.28466	0.14233	1.1894	0.327
		Substrate	1	0.1053	0.1053	0.8799	0.361
		Reg:Sub	2	0.52708	0.26354	2.2023	0.139
		Residuals	18	2.15397	0.11966		
CISCO	LN(CPUE + 1)	Region	2	17.3343	8.6672	24.6129	<0.001
		Substrate	1	5.0369	5.0369	14.3036	0.001
		Reg:Sub	2	1.1948	0.5974	1.6965	0.211
		Residuals	18	6.3385	0.3521		
US	CPUE ^{0.1}	Region	2	0.607	0.3035	1.5111	0.247
		Substrate	1	0.0604	0.0604	0.3007	0.590
		Reg:Sub	2	0.2876	0.1438	0.7159	0.502
		Residuals	18	3.6151	0.2008		
WF	CPUE ^{0.7}	Region	2	1.9256	0.9628	5.6318	0.013
		Substrate	1	3.5524	3.5524	20.7799	<0.001
		Reg:Sub	2	1.2009	0.6005	3.5125	0.052
		Residuals	18	3.0772	0.171		
D	CPUE ^{0.9}	Region	2	0.15911	0.07955	1.4062	0.271
		Substrate	1	0.1455	0.1455	2.5719	0.126
		Reg:Sub	2	0.31709	0.15854	2.8024	0.087
		Residuals	18	1.01835	0.05657		

Table 4-4: Pairwise comparisons of significant CPUE and diversity in Region factor. Codes defined in Table 4-1.

Season	Species	Transformation	Region	Artificial	Natural 1
Winter 2006	N	CPUE ^{0.6}	Natural 1	<0.001	
			Natural 2	1.000	0.002
	CISCO	LN(CPUE + 1)	Natural 1	<0.001	
			Natural 2	1.000	0.002
	WF	CPUE ^{0.7}	Natural 1	0.110	
			Natural 2	1.000	0.410
Spring 2006-07	N	sin(CPUE) ^{0.5}	Natural 1	0.290	
			Natural 2	1.000	0.140
	CHUB	CPUE ^{0.5}	Natural 1	0.001	
			Natural 2	0.043	0.531
	SCULP	CPUE ^{0.5}	Natural 1	0.010	
			Natural 2	0.971	0.001
	D	CPUE ³	Natural 1	0.003	
			Natural 2	0.190	0.299
Summer 2006-07	US	CPUE ^{0.2}	Natural 1	0.068	
			Natural 2	1.000	0.188
	D	CPUE ^{1.5}	Natural 1	0.670	
			Natural 2	1.000	0.150
Fall 2006	CF	CPUE ^{0.4}	Natural 1	0.041	
			Natural 2	0.133	1.000
	LT	CPUE ^{0.5}	Natural 1	0.367	
			Natural 2	0.001	0.015
	WF	CPUE ^{0.5}	Natural 1	0.150	
			Natural 2	1.000	0.190

Table 4-5: Spring 2006-2007 CPUE ANOVA results. Codes defined in Table 4-1.

Species	Transformation	Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N	sin(CPUE)^0.5	Region	2	0.14383	0.07192	2.5729	0.093
		Substrate	1	0.00582	0.00582	0.2083	0.651
		Reg:Sub	2	0.13136	0.06568	2.3497	0.113
		Residuals	30	0.83854	0.02795		
BCT_RB	None	Region	2	0.0000421	0.000021	0.0639	0.938
		Substrate	1	0.0004636	0.000464	1.4091	0.245
		Reg:Sub	2	0.0009723	0.000486	1.4776	0.244
		Residuals	30	0.0098701	0.000329		
CHUB	CPUE^0.5	Region	2	0.48263	0.24131	8.5873	0.001
		Substrate	1	0.02448	0.02448	0.8711	0.358
		Reg:Sub	2	0.11631	0.05815	2.0695	0.144
		Residuals	30	0.84304	0.0281		
SCULP	CPUE^0.5	Region	2	2.0502	1.0251	9.1308	<0.001
		Substrate	1	0.2035	0.2035	1.8129	0.188
		Reg:Sub	2	0.0127	0.0063	0.0565	0.945
		Residuals	30	3.368	0.1123		
US	None	Region	2	0.031415	0.015708	1.7259	0.195
		Substrate	1	0.004045	0.004045	0.4444	0.510
		Reg:Sub	2	0.001216	0.000608	0.0668	0.936
		Residuals	30	0.273026	0.009101		
WF	CPUE^0.5	Region	2	0.02052	0.01026	0.722	0.494
		Substrate	1	0.36863	0.36863	25.9359	<0.001
		Reg:Sub	2	0.04075	0.02037	1.4335	0.254
		Residuals	30	0.42639	0.01421		
YP	CPUE^0.5	Region	2	0.00071	0.00035	0.0268	0.974
		Substrate	1	0.03733	0.03733	2.8399	0.102
		Reg:Sub	2	0.01064	0.00532	0.4049	0.671
		Residuals	30	0.39433	0.01314		
D	CPUE^3	Region	2	0.109702	0.054851	7.2487	0.003
		Substrate	1	0.037287	0.037287	4.9275	0.034
		Reg:Sub	2	0.012029	0.006014	0.7948	0.461
		Residuals	30	0.227011	0.007567		

Table 4-6: Summer 2006-2007 CPUE ANOVA results. Codes defined in Table 4-1.

Species	Transformation	Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N	CPUE ^{0.1}	Region	2	0.00362	0.00181	0.7924	0.462
		Substrate	1	0.002808	0.002808	1.2297	0.276
		Reg:Sub	2	0.003592	0.001796	0.7863	0.465
		Residuals	30	0.068519	0.002284		
BCT_RB	CPUE ^{0.5}	Region	2	0.00926	0.00463	0.3632	0.698
		Substrate	1	0.00005	0.00005	0.0042	0.949
		Reg:Sub	2	0.04107	0.02053	1.6103	0.217
		Residuals	30	0.38256	0.01275		
CARP	CPUE ^{0.5}	Region	2	0.01891	0.00945	0.6826	0.513
		Substrate	1	0.01164	0.01164	0.8407	0.367
		Reg:Sub	2	0.0763	0.03815	2.7542	0.080
		Residuals	30	0.41552	0.01385		
CHUB	CPUE ^{0.5}	Region	2	0.04956	0.02478	1.4755	0.245
		Substrate	1	0.38583	0.38583	22.9718	<0.001
		Reg:Sub	2	0.04372	0.02186	1.3015	0.287
		Residuals	30	0.50387	0.0168		
CISCO	CPUE ^{0.5}	Region	2	0.15072	0.07536	0.787	0.464
		Substrate	1	0.82361	0.82361	8.6013	0.006
		Reg:Sub	2	0.30865	0.15432	1.6117	0.216
		Residuals	30	2.87263	0.09575		
SCULP	CPUE ^{0.1}	Region	2	0.2765	0.1382	1.1278	0.337
		Substrate	1	1.1569	1.1569	9.439	0.004
		Reg:Sub	2	0.2786	0.1393	1.1365	0.334
		Residuals	30	3.6768	0.1226		
US	CPUE ^{0.2}	Region	2	0.033091	0.016545	3.8356	0.033
		Substrate	1	0.033204	0.033204	7.6976	0.009
		Reg:Sub	2	0.006964	0.003482	0.8072	0.456
		Residuals	30	0.129408	0.004314		
WF	CPUE ^{0.3}	Region	2	0.18528	0.09264	1.4899	0.242
		Substrate	1	0.41266	0.41266	6.6364	0.015
		Reg:Sub	2	0.01548	0.00774	0.1245	0.883
		Residuals	30	1.86542	0.06218		
D	CPUE ^{1.5}	Region	2	0.16779	0.08389	4.5656	0.019
		Substrate	1	0.62534	0.62534	34.0321	<0.001
		Reg:Sub	2	0.12622	0.06311	3.4345	0.045
		Residuals	30	0.55125	0.01837		

Table 4-7: Fall 2006 CPUE ANOVA results. Codes defined in Table 4-1.

Species	Transformation	Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N	CPUE ^{^3}	Region	2	0.0256	0.0128	0.0392	0.962
		Substrate	1	0.0371	0.0371	0.1139	0.742
		Reg:Sub	2	0.0187	0.0093	0.0286	0.972
		Residuals	12	3.9128	0.3261		
CF	CPUE ^{^0.4}	Region	2	0.229583	0.114791	7.7922	0.007
		Substrate	1	0.032575	0.032575	2.2112	0.163
		Reg:Sub	2	0.189006	0.094503	6.415	0.013
		Residuals	12	0.17678	0.014732		
CHUB	CPUE ^{^0.5}	Region	2	0.13429	0.06715	1.7107	0.222
		Substrate	1	0.11811	0.11811	3.0092	0.108
		Reg:Sub	2	0.08222	0.04111	1.0474	0.381
		Residuals	12	0.471	0.03925		
CISCO	CPUE ^{^0.5}	Region	2	0.017619	0.008809	0.4174	0.668
		Substrate	1	0.057306	0.057306	2.7151	0.1253
		Region:Substrate	2	0.155162	0.077581	3.6757	0.0569
		Residuals	12	0.253277	0.021106		
LT	CPUE ^{^0.5}	Region	2	0.4314	0.2157	15.373	<0.001
		Substrate	1	0.05754	0.05754	4.1006	0.066
		Reg:Sub	2	0.03144	0.01572	1.1205	0.358
		Residuals	12	0.16837	0.01403		
US	CPUE ^{^0.5}	Region	2	0.02662	0.01331	0.4676	0.637
		Substrate	1	0.0956	0.0956	3.3585	0.092
		Reg:Sub	2	0.0752	0.0376	1.321	0.303
		Residuals	12	0.34157	0.02846		
WF	CPUE ^{^0.5}	Region	2	0.236246	0.118123	4.8772	0.0282
		Substrate	1	0.074708	0.074708	3.0847	0.1045
		Reg:Sub	2	0.246776	0.123388	5.0946	0.025
		Residuals	12	0.290633	0.024219		
YP	CPUE ^{^0.3}	Region	2	0.01468	0.00734	0.1127	0.894
		Substrate	1	0.53817	0.53817	8.2598	0.014
		Reg:Sub	2	0.19069	0.09534	1.4633	0.270
		Residuals	12	0.78187	0.06516		
D	CPUE ^{^3}	Region	2	0.030717	0.015358	1.4729	0.268
		Substrate	1	0.094493	0.094493	9.0623	0.011
		Reg:Sub	2	0.0962	0.0481	4.613	0.033
		Residuals	12	0.125126	0.010427		

Table 4-8: Summary of evidence for similarity and dissimilarity between artificial and natural reefs, natural reefs' CPUE pattern on substrate. *Denotes results that indicate potential influence of artificial reefs based on region and substrate CPUE patterns. Codes defined in Table 4-1.

Season	Similarity	Dissimilarity	Natural regions pattern
Winter	Bonneville Cisco*		Rock > Soft
	Bonneville Whitefish*		Rock > Soft
Spring	Bonneville Whitefish		Soft > Rock
Summer	Diversity	Bonneville Cisco	Soft > Rock
		Bear Lake Sculpin	Soft > Rock
		Bonneville whitefish	Soft > Rock
Fall		Crayfish*	Rock ~ Soft
		Lake Trout*	Rock > Soft
		Utah Sucker	Rock > Soft
		Yellow Perch*	Rock ~ Soft

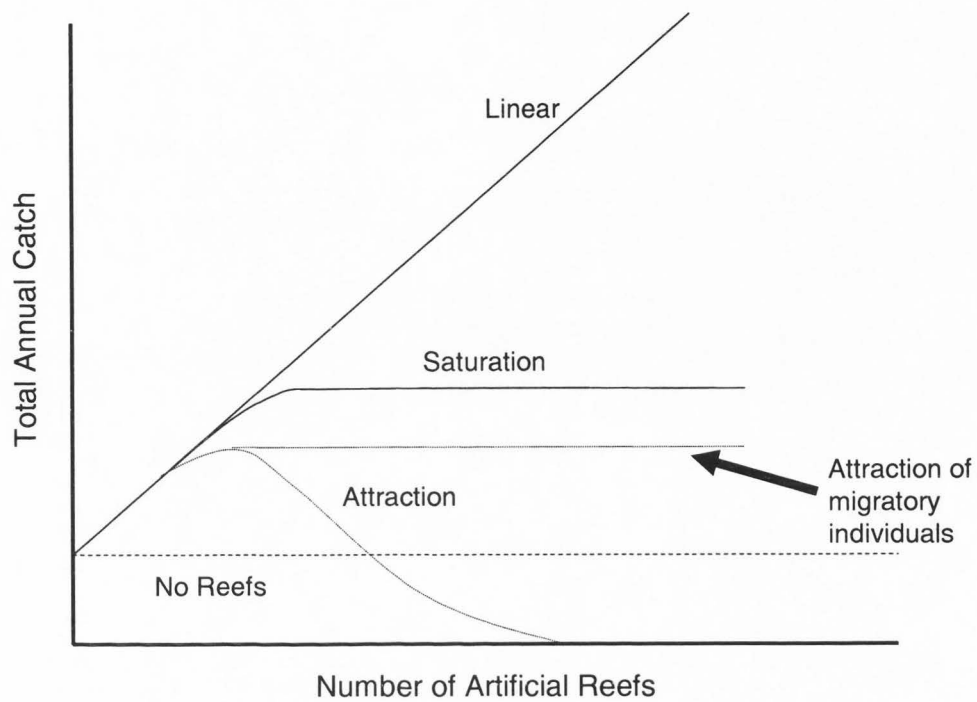


Figure 4-1: Hypothetical annual catch responses to artificial reefs. Production hypothesis (Linear and Saturation), and attraction hypothesis (Attraction). Reproduced from Bohnsack (1989).

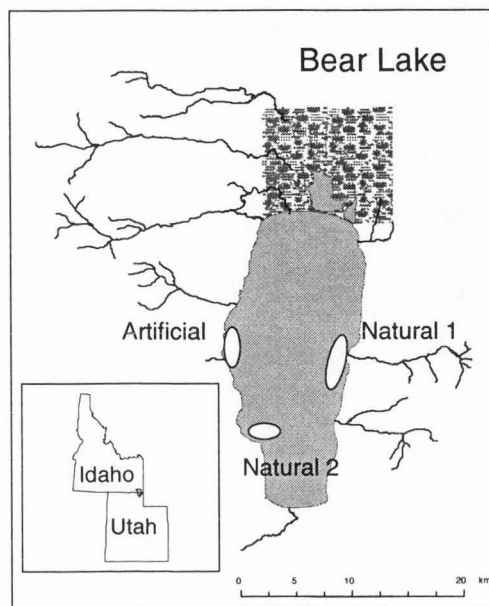


Figure 4-2: Bear Lake Utah/Idaho. Approximate location of gillnet samples are represented by white ellipsoids. Codes defined in Table 4-1.

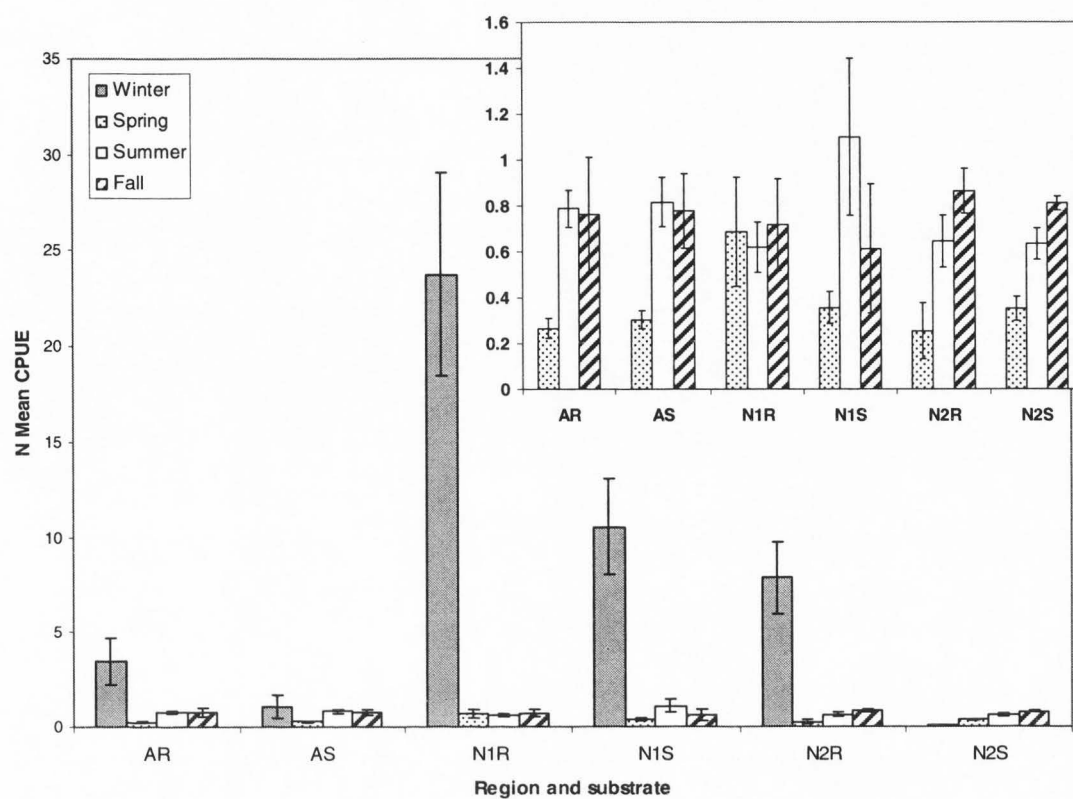


Figure 4-3: Season mean total CPUE for region and substrate. Inset shows same figure without winter data. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

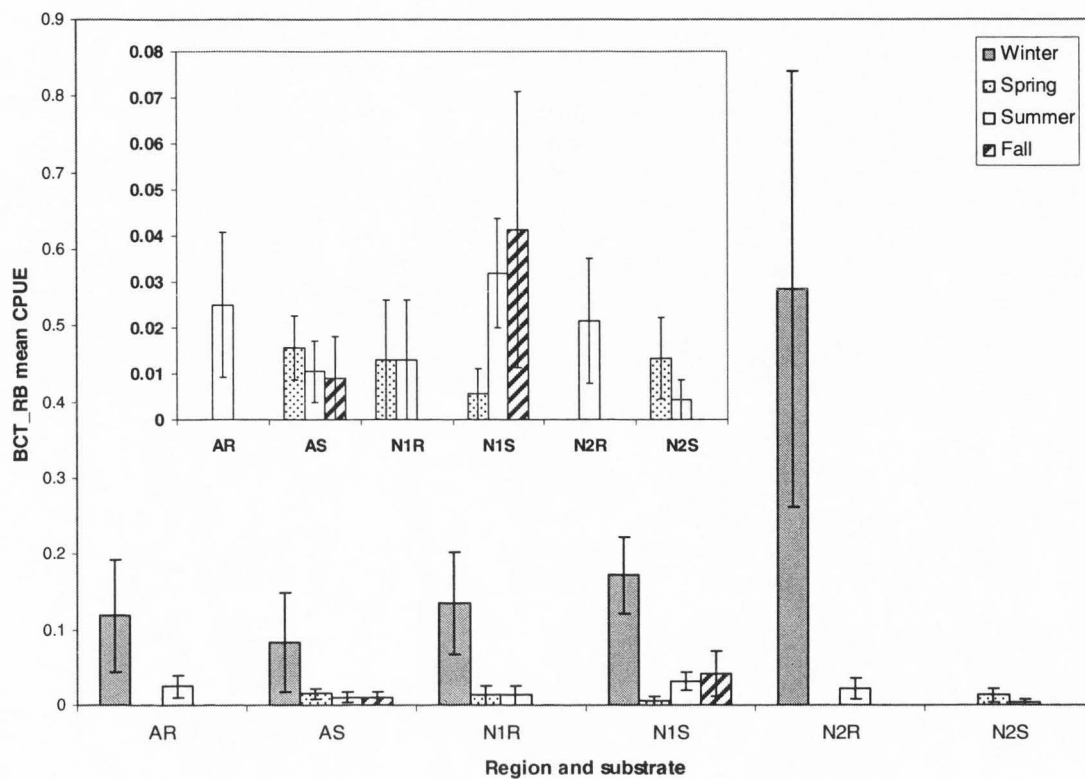


Figure 4-4: Season mean BCT_RB CPUE for region and substrate. Inset shows same figure without winter data. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

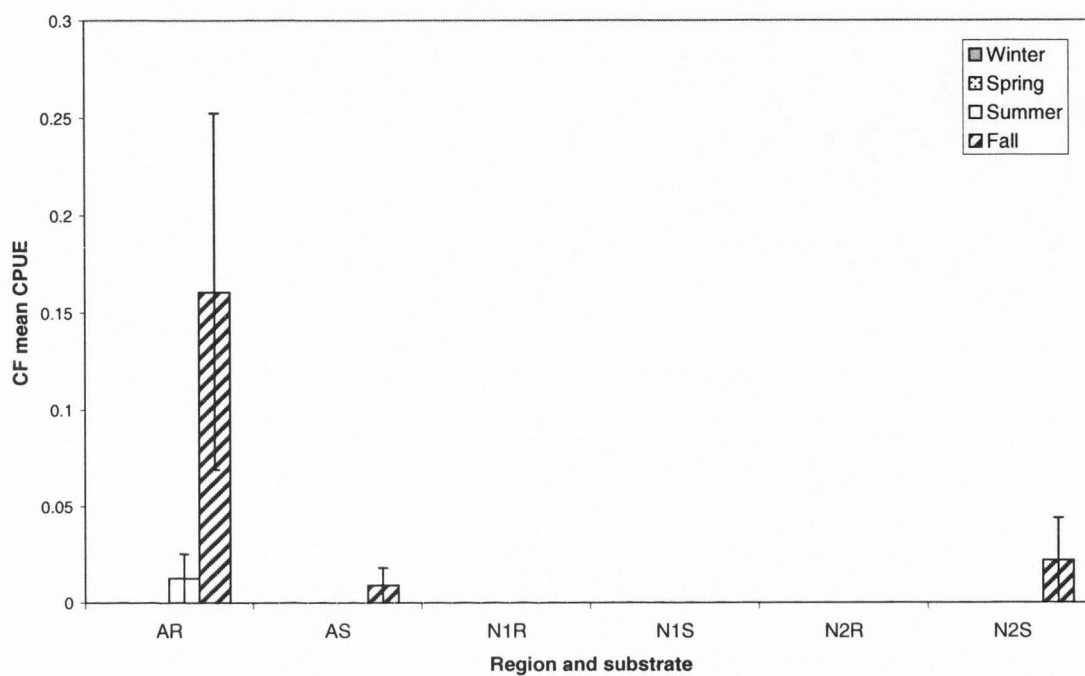


Figure 4-5: Season mean CF CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

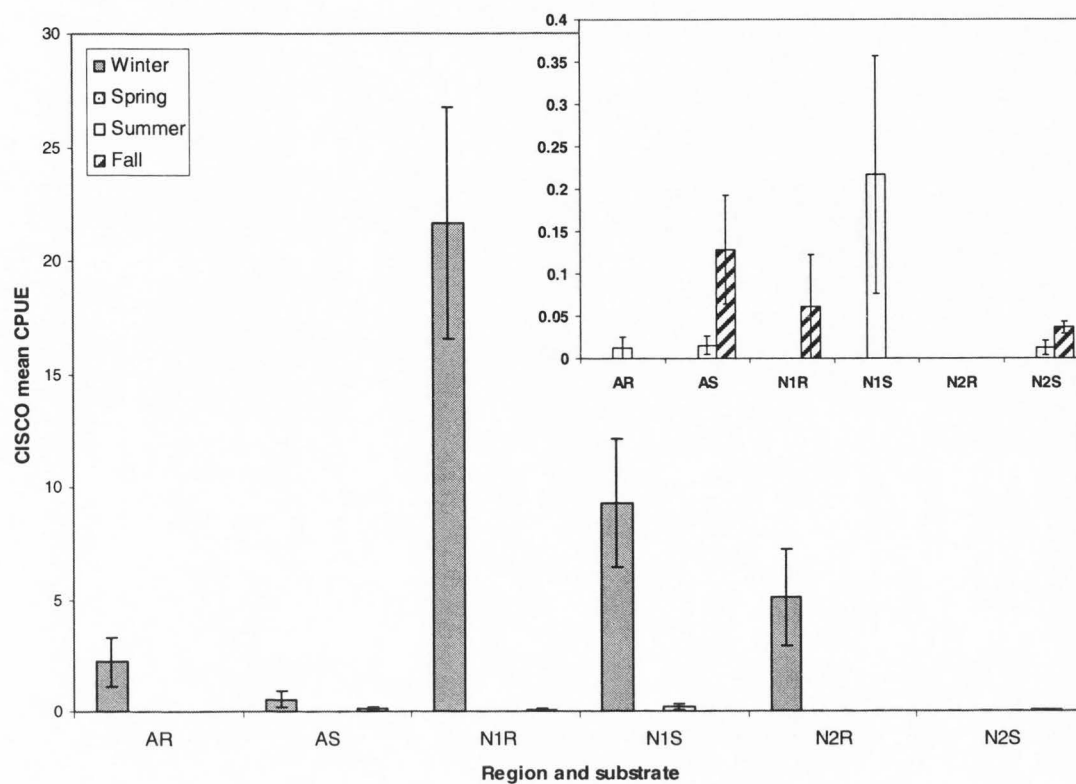


Figure 4-6: Season mean CISCO CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Inset is same chart without winter data. Codes defined in Table 4-1.

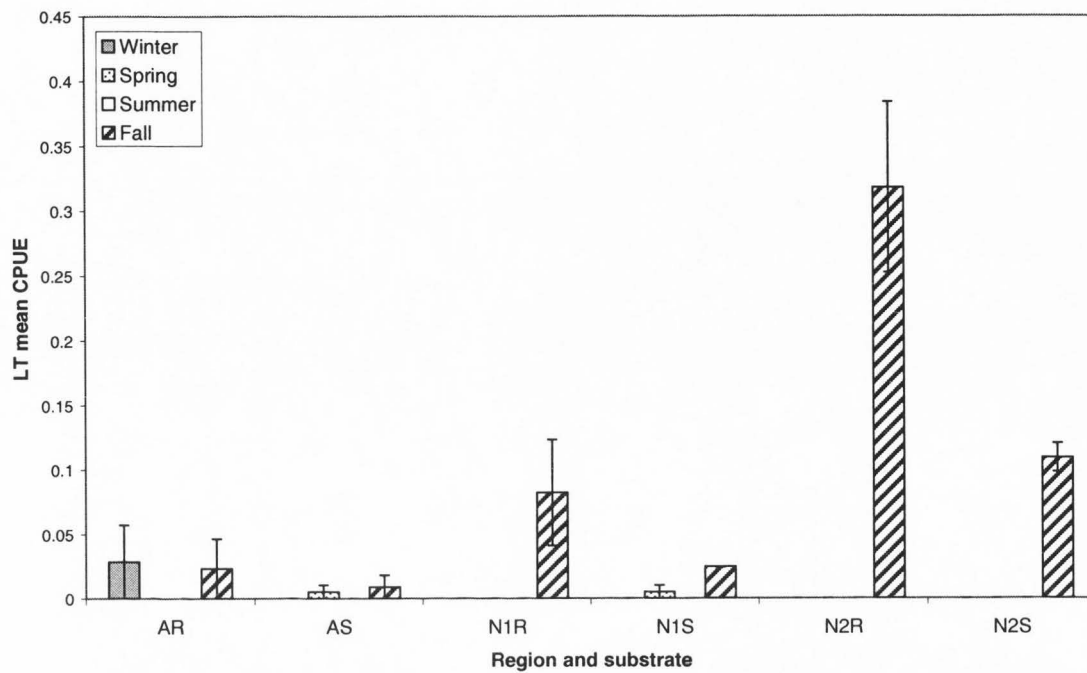


Figure 4-7: Season mean LT CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

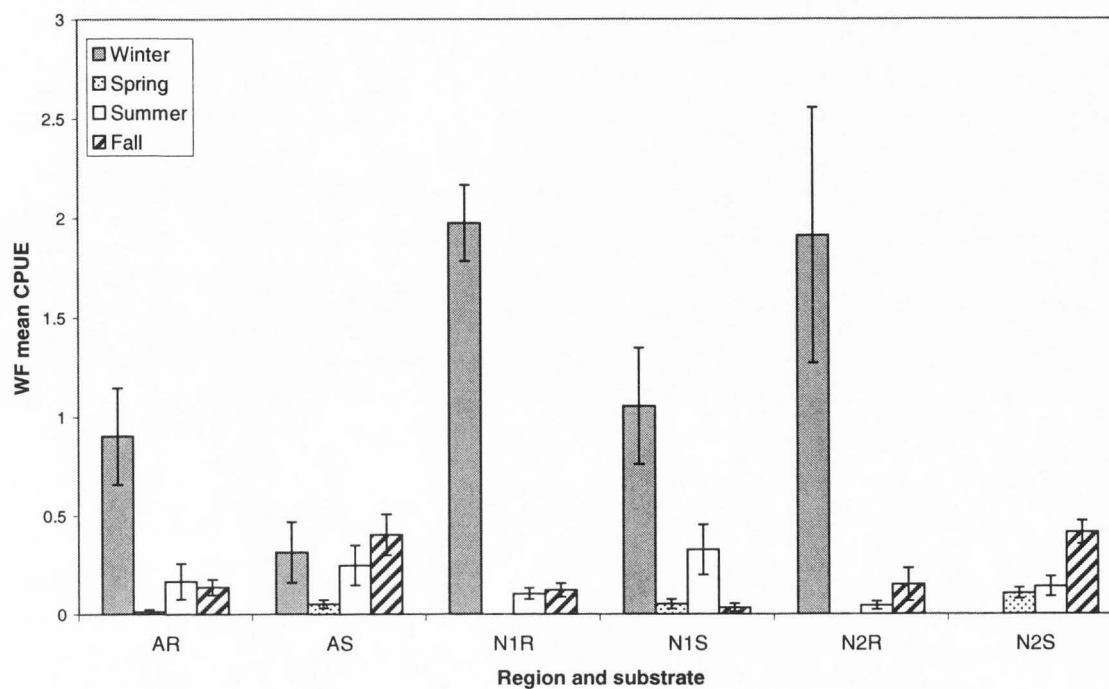


Figure 4-8: Season mean WF CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

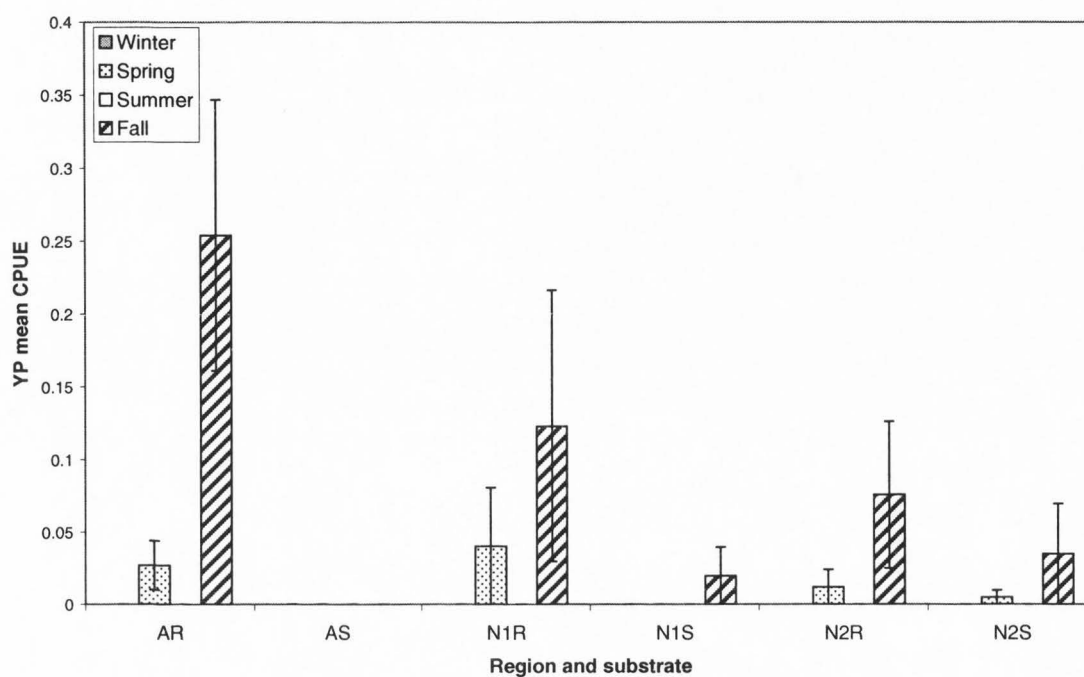


Figure 4-9: Season mean YP CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

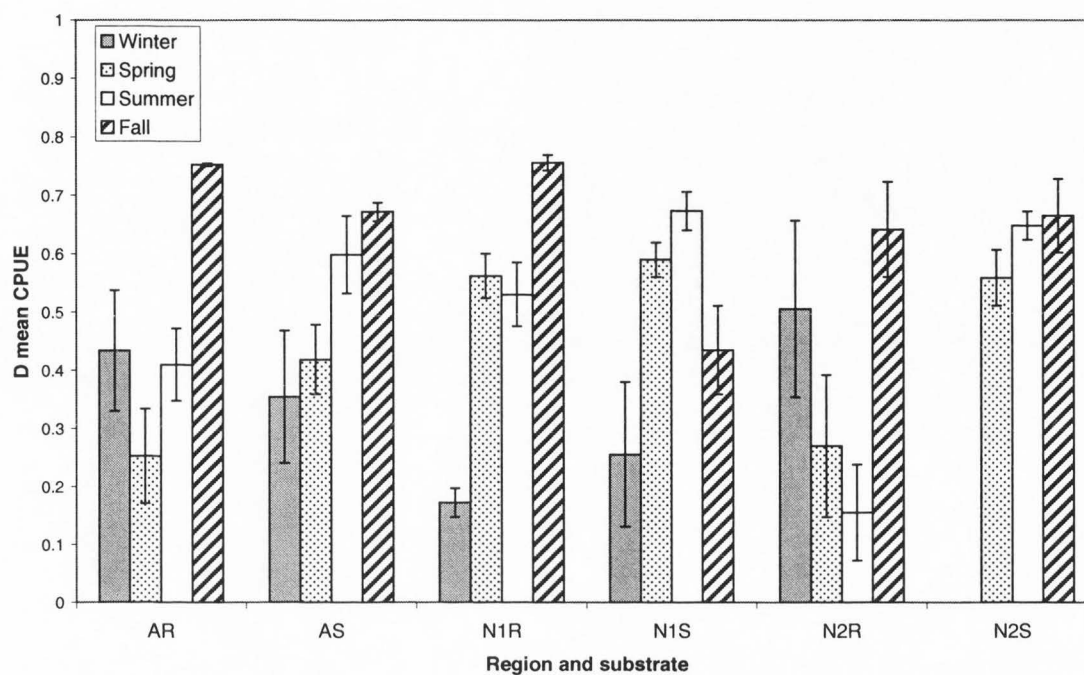


Figure 4-10: Season mean Simpson's diversity for region and substrate. Error bars in the figure represent + and - one standard error. Codes defined in Table 4-1.

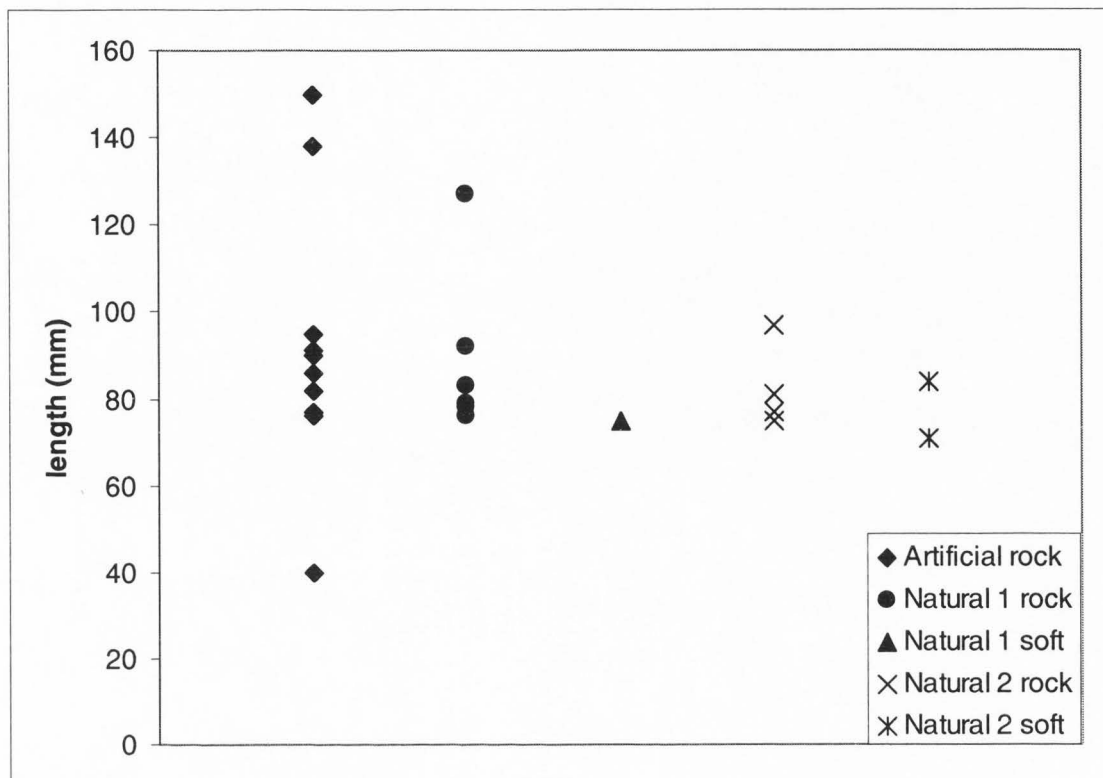


Figure 4-11: Yellow perch total length (mm) for all gillnet and minnowtrap data.

CHAPTER 5

CONCLUSIONS

Our results support the use of hydroacoustics substrate classification, and suggest the Bear Lake artificial reefs function as surrogate natural habitat for some species. First, hydroacoustics demonstrated an ability to distinguish soft versus rocky bottom types in relation to rock complexity and slope, which allowed collection of information important in fisheries management. Second, the artificial reefs functioned as surrogate habitat for benthic invertebrates consumed by endemic Bonneville whitefish and Bear Lake sculpin. Third, similar substrate use in artificial and natural regions were found for Bonneville cisco and whitefish in winter. However, despite the general accuracy of hydroacoustic classification, hydroacoustic inaccuracies were found. Additionally, artificial reef use by two non-endemic egg predators suggests a negative influence of the artificial reefs for the conservation of endemic fishes.

Hydroacoustics substrate classification captured differences in substrate complexity in three regions of Bear Lake, although inaccuracies and a bias were present. Our results indicated rock area influences hydroacoustic classification accuracy. We found VBT biased substrate classification towards the predominant substrate, leading to greater accuracy on predominant substrate, and decreased accuracy on non-predominant substrate. Our results did not support rejecting the slope null hypothesis, that increased slope results in decreased hydroacoustic classification accuracy, nor did they provide unequivocal data to the contrary. Although results found higher rock classification

accuracy on a steep slope compared to a gentle slope, differences may have been masked by the predominant substrate bias.

Our results suggest the artificial reefs function as rock foraging habitat for some endemic fishes in Bear Lake. Generally, artificial and natural reef benthic invertebrate abundances were not significantly different in spring and summer, but Gastropoda abundances were significantly higher on the natural reefs. Gastropoda did not contribute to endemic fishes diets. The two taxa found in our study, which contributed to endemic fish diets in spring and summer, were Chironomidae and Trombidiforms. Rapid dispersal of Chironomidae and Trombidiforms, coupled with their affinity for rock, produced similar abundances between artificial and natural reefs. Bonneville whitefish may receive a foraging benefit from Chironomidae on artificial reefs in spring and summer. Small Bonneville whitefish may receive a benefit from Trombidiform in the summer. Medium and large Bear Lake sculpin may receive a foraging benefit from Chironomidae on the artificial reefs in the spring, while small sculpin would receive a benefit in the summer. Trombidiform did not contribute to sculpin diet.

Fish use of substrate within artificial and natural regions suggests sport fish attraction to artificial reefs was minimal, two endemic fishes benefit from the artificial reefs, and yellow perch and crayfish may also benefit from the installation of the artificial reefs. Lake trout were attracted to natural rock substrate during their spawning period, but rock and soft substrate CPUE in the artificial reef region were similar. Bonneville cutthroat trout did not show a preference for a substrate or a region for any season. Artificial reefs may aid in conservation by functioning as additional habitat for spawning cisco and foraging Bonneville whitefish in winter. Fall yellow perch and crayfish

affinities to the artificial reefs may be undesirable responses that could lead to an increase in non-native competition and endemic fish egg predation.

Assessment of the potential of artificial reefs to function in conserving endemic fish may be influenced by the bias towards predominant substrate in hydroacoustic classification. The soft substrate is predominant in the artificial reefs region, while rock substrate is predominant in the natural reef regions. The VBT bias of classification towards predominant substrate will lead to a lower estimation of the area of surrogate rock provided by the artificial reefs, and an overestimation of the area of natural rock available. Analysis of hydroacoustic data in GIS will also overestimate the eastern shore rock habitat loss during drought. Bonneville cisco and whitefish benefit from rock habitat, and appeared to use the artificial reefs similar to the natural reefs. Thus, the overestimation of rock habitat for the natural reefs will lead to predictions of higher fecundity and recruitment for Bonneville whitefish and cisco, which benefit from rock substrate. Conversely, overestimation of soft substrate for the artificial reefs will lead to lower predictions. The bias towards predominant substrate will also reduce habitat complexity, since small scale heterogeneity in the substrate would likely be classified as the predominant substrate. Inaccuracies in habitat delineation will produce erroneous patterns of fish and habitat association.

Since colonization time and habitat complexity influence benthic invertebrate taxa presence and abundances, additional studies are warranted. Effects of colonization and habitat complexity parameters could be detected by sampling crates varying in soak time and rock complexity. To isolate colonization and habitat effects, samples varying in soak time and rock complexity should be collected in the same geographic region of the lake.

Greater clarity in the use of artificial reefs for foraging would be obtained by diet analyses of fish collected during benthic invertebrate sampling over artificial and natural reefs, and adjacent soft substrate. To elucidate fish foraging, it may be necessary to isolate habitat to limit fish migration. Repelling equipment, such as electronic barriers, could be used to limit movement of fish during the study. A similar study, conducted solely on natural reefs that varied in large scale spatial arrangement, would elucidate the effect of large scale habitat complexity on fish foraging. Electivity indices on the fish diet in relation to artificial and natural reefs, and reef complexity would further elucidate the ability of surrogate rock to function as fish foraging habitat.

Continued studies on the association of fish to reef complexity (area and spatial arrangement) would aid in producing the desired fish assemblage for future installation of artificial reefs in Bear Lake. Substrate data collected in our study can be used to locate natural rock areas of varying complexity. Videography can be used to verify the rock complexity of the area. Gillnet sampling in these regions can determine the association of Bear Lake fish assemblages to reef complexity. The association would aid in tailoring artificial reefs to fish species of interests. Previous attempts at egg collection during spawning in Bear Lake were problematic (personal observation), but continued effort could elucidate the potential of the artificial reefs to benefit fish recruitment and egg foraging.

APPENDICES

Appendix I:

HYDROACOUSTIC MECHANICS AND MEASUREMENT VARIATION

Hydroacoustics is used to measure aquatic parameters by generating and receiving pressure waves. Hydroacoustic transducers are comprised of elements that are used to convert electrical energy into acoustic pulses to generate a pressure wave. The elements transmit identical acoustic pulses at a certain frequency (kHz) for a specified pulse duration (milliseconds). The signal, or beam, shape is conical with the apex angle of cone called the beam angle. Beam shape can be altered by controlling the energy to certain elements. Characteristics of a body of water and its basin alter the transmitted pressure waves, which are reflected back to the transducer elements, converted back into electrical energy, amplified and recorded. A signal threshold is set to eliminate reflected noise from small objects of no interests (MacLennan and Simmonds 1992).

The transducer beam pattern determines the way the elements receive the echo and allows for measurements on reflective targets. The beam of the transducer relates the change in sensitivity of the transducer to a received signal based on direction. Acoustic waves are returned in different phases, which vary by the angle of return. The difference in phases can be used to determine angle and direction of the reflected target in some transducers. A single-beam transducer transmits and receives energy in the same area of the transducer, producing a single echo signal. Target distance can be determined from travel time of the incident transmission to return of the echo. A disadvantage of the single-beam is a lack of ability to directly ascertain direction of the reflected signal. Dual and split-beam transducers receive the echo signal as different beams allowing estimation

of the angular location of a reflected target. A dual-beam transducer receives the echo signals as broad and narrow beams. A dual-beam produces an approximation of the location of the reflected target. A split-beam transducer receives the echo signal in four quadrants, allowing phase differences in the echo to be determined. The phase differences relate the angular location of the reflected target. Dual and split-beam transducers also remove the beam pattern, allowing a measure of the signal returning from the reflected object, referred to as backscattering. Target strength can be determined from backscatter. Target strength can be indirectly estimated for single-beam transducers with deconvolution preformed by a software algorithm (MacLennan and Simmonds 1992).

Patterns within the hydroacoustic echoes are used to derive information including fish, macrophyte, and substrate characteristics. Modern acoustic and global positioning equipment allows visualization, storage, and association to spatial location of the received signal. Data are then analyzed to acquire information. Target strengths are used to determine fish parameters such as density and biomass. The acoustic reflectivity of submerged aquatic vegetation (SAV) is used to derive macrophyte measurements from acoustic echoes (Sabol et al. 2002). Substrate characteristics are determined from echo shapes and energies and comparing them to known substrate patterns (Hamilton 2001, Burczynski et al. 2005).

The accuracy of information between hydroacoustic systems, and compared to ground-truth observations are of concern in research. Variations in hydroacoustic systems include beam pattern, beam shape, and frequency, which may influence the precision of measurements. Generally, studies evaluating hardware variation have found

equivalent measurements to observations and between gear types, although some disagreement is present. Fish biomass estimates obtained from two 120 kHz split-beam elliptical transducers, ran approximately five minutes apart, found good precision in the temporal repeatability of measurements (Wanzenbock et al. 2003). In addition, Wanzenbock et al. found similar fish biomass for concurrent sampling with split-beam transducers varying in frequency, beam width, beam shape, pulse duration, and software. Other studies found similar agreement in measured parameters from different hardware. Thirty-eight kHz split and dual-beam sonar comparisons found no significant difference in Northwest Atlantic redfish target strengths (Gauthier and Rose 2002). Comparison of a 129 kHz dual-beam, and 120 and 70 kHz split-beam transducers ran simultaneously found similar young of year perch (*Perca fluviatilis*) mean target strengths and significantly similar volume scatter (Guillard et al. 2004). Good agreement between hydroacoustic and trawl fish density and age estimates have been found, although distinguishing age with hydroacoustics was problematic (Parkinson et al. 1994). Although most studies found good agreement in measurement to hardware variation, some inaccuracies were noted. A study in marine and freshwater systems found a single-beam bias towards smaller targets, although corrected algorithms eliminated the bias in all but the freshwater hypolimnion (Rudstam et al. 1999). Another study found significantly poorer submerged aquatic vegetation (SAV) boundary spatial placement with a 70 kHz single-beam transducer compared to a 420 kHz split-beam transducer (Hoffman et al. 2002). Hoffman et al. attributed the poor results to lower frequency.

Concerns in SAV measurements included measurement variation from different hydroacoustic gear and software analyzed differences from observed measurements.

Only one software, specifically designed for SAV measurements, is currently available. Generally, research has found good agreement in software measurements between gear and compared to observed observations, although some discrepancies were observed. Comparison of hydroacoustic software measurements of SAV parameters to diver and video collected samples found good agreement between depth, canopy height and canopy cover (Sabot et al. 2002). Although a separate study found no significant difference in individual plant heights compared to diver measurements, software measurement of plant occupied water column were lower than observed (Valley and Drake 2005). Sabot et al. (2002), and Valley and Drake (2005) used a 420 kHz transducer for most measured parameters. Comparisons of a 70 kHz echo sounder to a 420 kHz echo sounder found the lower frequency produced significantly poorer results in SAV boundary placement (Hoffman et al. 2002), but comparisons of videography determined SAV to a 200 kHz split-beam transducer found non-significant differences in coverage and good qualitative agreement for macrophyte height (Winfield et al. 2007).

Methods of delineating aquatic substrate vary since different software analyze hydroacoustic data differently. Single echo analyzers, such as QTC-View (Quester Tangent Corporation, Sidney, B.C., Canada), consider the shape of the first echo (Hamilton 2001). Multiple echo software, such as RoxAnn (Marine Micro Systems Ltd., Aberdeen, Scotland), considers the energy from the first and second echoes (Hamilton 2001). One multi-echo analyzer, BioSonics Visual Bottom Typer (VBT), considers the energy from the sediment echo, the energy of the second echo, and distinguishes the energy from the first and second part of the first echo (Burczynski et al. 2005). Consideration of the second echo provides more information about the bottom. The

second echo is reflected from the bottom, up to the surface, back to the bottom, and finally to the transducer making it strongly influenced from the bottom. A drawback to the multi-echo technique is the additional noise (Hamilton 2001).

Evaluations of substrate software primarily focus on QTC-View and RoxAnn. Studies on the accuracy of VBT are rare. QTC-View and RoxAnn may provide equivalent classifications, although differences in the systems and inaccuracies have been found. QTC-View classification provides consistent grain size and texture within substrate classified, but RoxAnn does not (Hamilton et al. 1999). The consistency of grain size with QTC-View is likely the result of QTC-View considering only the shape of the first echo, which is strongly influenced by grain size and sediment density (Tsemahman et al. 1997).

The ability of software substrate classification accuracy in relation to sampling parameters and topography are of concern in research. A study found QTC-View and the first echo in RoxAnn showed no apparent dependence on ship speed change, but the second echo of RoxAnn displayed additional noise and variability with changes in ship speed (Hamilton et al. 1999). Comparisons of substrate classification to videography found no effect in the ability of QTC-View to classify substrate for speeds between 3 and 12 knots but classification was affected by even modest slopes (von Szalay and McConnaughey 2002). The ability of VBT to map non-flat slopes is also a concern since past and current versions of VBT do not use depth normalization (Dommissie and Urban 2005). BioSonics is releasing a new version of VBT in Fall 2007 that corrects this problem (BioSonics, Mike Burger, personal communication).

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Appendix II: CHAPTER 2 HYDROACOUSTIC TABLE

Table AII-1: The number of VBT classifications agreeing with videography for survey regions. *All* is all regions combined and *Both* are substrate combined.

Region	Both correct	Both incorrect	Rock correct	Rock incorrect	Soft correct	Soft incorrect
All	532	181	326	40	206	141
Artificial	160	78	47	21	113	57
Natural 1	184	53	129	0	55	53
Natural 2	188	50	150	19	38	31

Appendix III: Chapter 3 Benthic Invertebrate tables and figures.

Table AIII-1: Spring 2006 benthic invertebrates' numbers by crate (OLG is total mm).

Site	#	AMP	CHR	DPT	GST	HRD	OLG	PCT	TCP	TMB
AR1	1	9.0	36.0	1.0	0.0	0.0	9.7	0.0	0.0	340.0
AR1	2	7.0	3.7	0.0	0.0	0.0	0.6	0.0	0.0	30.0
AR1	3	14.0	13.2	0.0	1.0	0.0	0.7	0.0	0.0	46.0
AR1	4	13.0	35.4	0.0	0.0	0.0	21.8	0.0	0.0	32.0
AR2	1	26.5	26.0	0.0	0.0	0.0	3.8	0.0	1.0	257.0
AR2	2	9.0	5.7	0.0	0.0	0.0	8.2	0.0	0.0	11.0
AR2	3	35.4	20.9	1.0	0.0	0.0	7.5	1.0	0.0	47.0
AR2	4	21.0	19.6	0.0	0.0	0.0	4.4	0.0	0.0	3.0
AR3	1	28.0	13.6	0.0	0.0	0.0	5.2	0.0	0.0	388.0
AR3	2	8.0	11.7	0.0	0.0	0.0	8.2	0.0	0.0	9.0
AR3	3	12.0	25.4	2.0	1.0	0.0	19.1	0.0	0.0	194.0
AR3	4	32.0	22.0	0.0	0.0	0.0	0.9	0.0	1.0	113.0
AR4	1	7.0	14.0	1.0	0.0	0.0	0.9	0.0	0.0	2.0
AR4	2	2.0	35.7	0.0	0.0	0.0	39.0	0.0	0.0	10.0
AR4	3	9.5	16.0	2.0	0.0	0.0	5.2	0.0	0.0	37.0
AR4	4	12.0	13.0	0.0	0.0	0.0	12.0	0.0	0.0	3.0
ER1	1	19.0	75.9	3.9	4.0	1.0	4.3	0.0	0.0	78.0
ER1	2	4.0	32.0	0.0	5.0	0.0	1.3	0.0	0.0	53.0
ER1	3	7.1	71.9	0.0	15.5	2.0	11.8	0.0	0.0	169.0
ER1	4	24.6	100.9	0.0	9.9	0.0	7.3	0.0	0.0	174.0
ER2	1	0.0	14.4	1.0	0.0	2.0	6.8	0.0	0.0	17.0
ER2	2	0.0	52.2	2.0	21.0	0.0	16.1	0.0	0.0	41.0
ER2	3	1.0	13.5	1.0	2.0	0.0	4.0	0.0	0.0	10.0
ER2	4	1.0	18.0	1.0	6.0	0.0	2.9	0.0	0.0	43.0
ER3	1	0.0	15.8	3.0	1.0	0.0	6.5	0.0	0.0	16.0
ER3	2	0.0	17.8	0.0	3.0	0.0	1.6	0.0	0.0	32.0
ER3	3	2.0	44.4	1.0	3.0	0.0	15.6	0.0	0.0	20.0
ER3	4	0.0	63.9	0.0	2.0	0.0	2.6	0.0	0.0	16.0
ER4	1	1.0	15.5	0.0	7.0	0.0	8.5	0.0	0.0	52.0
ER4	2	1.0	24.9	0.0	10.9	0.0	18.6	0.0	0.0	19.0
ER4	3	5.1	142.8	2.0	26.0	0.0	20.6	0.0	0.0	103.0
ER4	4	1.0	19.4	2.5	7.0	0.0	2.5	0.0	0.0	51.3
RR1	1	24.8	13.8	1.0	6.0	0.0	2.4	0.0	0.0	39.0
RR1	2	10.0	14.0	0.0	2.0	0.0	7.7	0.0	0.0	86.0
RR1	3	16.6	10.8	0.0	5.0	0.0	8.0	0.0	0.0	39.0
RR1	4	13.2	11.8	0.0	2.6	0.0	2.5	0.0	0.0	26.0
RR2	1	8.0	4.0	0.0	7.0	0.0	4.3	0.0	0.0	13.0
RR2	2	39.4	7.7	0.0	23.0	3.0	6.8	0.0	0.0	35.2
RR2	3	11.6	9.7	0.0	12.0	0.0	1.3	0.0	0.0	34.0
RR2	4	No	Data							
RR3	1	11.0	5.0	0.0	11.0	0.0	0.5	0.0	0.0	7.0
RR3	2	12.6	3.8	1.0	8.0	0.0	4.2	0.0	0.0	20.0
RR3	3	2.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	5.0
RR3	4	11.0	6.7	0.0	4.0	0.0	1.0	0.0	0.0	11.0
RR4	1	7.8	1.8	0.0	5.0	0.0	1.1	0.0	0.0	20.0
RR4	2	4.6	3.0	0.0	15.0	0.0	1.8	0.0	0.0	27.0
RR4	3	15.4	5.8	0.0	6.0	0.0	0.1	0.0	0.0	8.0
RR4	4	12.6	3.0	0.0	18.0	0.0	0.2	0.0	0.0	6.0

Table AIII-2: Summer 2006 benthic invertebrates' numbers by crate (OLG is total mm).

Site	#	AMP	CHR	DPT	GST	HRD	OLG	PCT	TCP	TMB
AR1	1	51.0	32.7	5.0	6.0	1.0	1.1	0.0	4.2	415.0
AR1	2	32.4	23.0	1.0	22.0	0.0	0.0	2.0	0.0	123.0
AR1	3	63.0	28.9	2.0	4.0	0.0	0.0	5.0	0.0	236.0
AR1	4	28.0	40.4	3.0	12.0	1.0	31.1	2.4	2.0	155.0
AR2	1	34.8	14.3	2.0	0.0	0.0	0.0	2.1	2.0	159.0
AR2	2	76.0	20.0	4.0	3.0	0.0	1.0	0.0	9.0	81.0
AR2	3	56.7	24.3	0.0	0.0	0.0	2.5	5.0	1.0	691.0
AR2	4	22.2	9.0	8.9	2.0	0.0	1.1	4.0	0.0	36.0
AR3	1	54.0	34.4	6.4	14.0	0.0	0.3	3.0	0.0	49.0
AR3	2	18.7	18.1	0.0	0.0	0.0	15.8	0.0	1.0	128.0
AR3	3	70.0	19.1	4.4	10.0	0.0	1.3	0.0	0.0	313.0
AR3	4	19.2	8.4	0.0	8.0	0.0	0.9	1.0	0.0	48.0
AR4	1	54.1	8.0	2.0	0.0	0.0	0.0	0.0	1.0	107.0
AR4	2	32.0	27.0	0.0	2.0	0.0	12.5	0.0	0.0	85.0
AR4	3	57.9	10.3	1.0	0.0	0.0	0.7	1.0	0.0	64.0
AR4	4	73.9	9.4	0.0	1.0	0.0	0.0	2.0	0.0	136.0
ER1	1	5.0	12.5	2.0	97.0	0.0	0.0	1.0	1.0	75.0
ER1	2	25.0	406.8	31.8	58.0	0.0	1.1	0.0	1.0	125.0
ER1	3	3.4	41.4	0.0	22.5	0.0	5.8	0.0	3.0	86.0
ER1	4	18.0	212.9	17.8	111.0	0.0	0.0	1.0	1.0	126.0
ER2	1	4.0	91.7	8.0	213.0	0.0	0.0	1.0	6.0	126.0
ER2	2	1.0	135.8	7.0	86.0	0.0	0.0	0.0	5.0	62.0
ER2	3	1.0	118.8	18.0	24.0	0.0	0.0	0.0	0.0	22.0
ER2	4	11.0	124.3	11.4	124.0	0.0	0.4	1.0	0.0	172.0
ER3	1	9.9	198.5	8.5	77.0	0.0	0.0	0.0	6.3	248.0
ER3	2	3.0	49.3	4.0	13.0	0.0	0.9	0.0	0.0	88.0
ER3	3	0.0	144.7	17.8	32.0	1.0	0.0	0.0	3.0	65.0
ER3	4	6.0	236.1	24.6	38.0	1.0	0.4	0.0	2.0	163.0
ER4	1	8.4	60.5	3.0	62.5	6.0	1.5	0.0	1.0	171.0
ER4	2	0.2	79.3	1.0	21.0	0.0	3.8	0.0	1.0	106.0
ER4	3	3.0	73.7	3.0	59.0	0.0	0.0	0.0	0.0	76.0
ER4	4	5.0	92.8	2.0	96.0	1.0	1.0	0.0	0.0	145.0
RR1	1	19.0	6.5	5.5	381.0	0.0	0.8	0.0	0.0	201.0
RR1	2	9.0	8.6	1.0	194.0	0.0	5.4	0.0	0.0	882.0
RR1	3	30.8	3.0	12.2	257.0	0.0	0.0	0.0	0.0	691.0
RR1	4	16.0	6.1	5.0	117.0	7.0	0.0	0.0	0.0	344.0
RR2	1	67.1	3.0	3.0	79.0	1.0	0.9	0.0	0.0	51.0
RR2	2	22.5	2.0	0.0	115.0	3.0	29.0	0.0	0.0	29.0
RR2	3	14.0	4.2	6.5	165.0	6.0	0.0	0.0	0.0	35.0
RR2	4	32.8	4.0	0.0	91.0	0.0	1.6	0.0	0.0	138.0
RR3	1	6.0	2.0	2.0	67.0	0.0	0.0	0.0	0.0	15.0
RR3	2	1.6	0.0	1.0	51.0	0.0	0.0	0.0	0.0	5.0
RR3	3	8.0	1.0	1.0	38.0	0.0	0.0	0.0	0.0	16.0
RR3	4	2.0	2.0	0.0	49.0	0.0	0.0	0.0	0.0	19.0
RR4	1	29.0	4.0	1.0	186.0	0.0	0.0	0.0	0.0	41.0
RR4	2	12.3	4.0	0.0	255.0	10.0	0.7	0.0	0.0	66.0
RR4	3	47.0	5.9	0.0	223.0	0.0	1.8	0.0	0.0	51.0
RR4	4	104.4	1.7	0.0	156.0	17.0	1.0	0.0	0.0	67.0

Table AIII-3: 2006 benthic invertebrate site mean abundance and Simpson's diversity.

Month	Site	AMP	CHR	DPT	GST	HRD	OLG	PCT	TCP	TMB	N	D
Spring	AR1	10.7	22.1	0.3	0.3	0.0	8.2	0.0	0.0	112.0	153.5	0.491
	AR2	23.0	18.1	0.3	0.0	0.0	6.0	0.3	0.3	79.5	127.3	0.593
	AR3	20.0	18.2	0.5	0.3	0.0	8.4	0.0	0.3	176.0	223.5	0.460
	AR4	7.6	19.7	0.8	0.0	0.0	14.3	0.0	0.0	13.0	55.3	0.640
	ER1	13.7	70.2	1.0	8.6	0.8	6.2	0.0	0.0	118.5	218.8	0.591
	ER2	0.5	24.5	1.3	7.3	0.5	7.5	0.0	0.0	27.8	69.2	0.663
	ER3	0.5	35.5	1.0	2.3	0.0	6.6	0.0	0.0	21.0	66.8	0.566
	ER4	2.0	50.6	1.1	12.7	0.0	12.6	0.0	0.0	56.3	135.4	0.627
	RR1	16.1	12.6	0.3	3.9	0.0	5.1	0.0	0.0	47.5	85.6	0.627
	RR2	19.7	7.1	0.0	14.0	1.0	4.1	0.0	0.0	27.4	73.3	0.725
	RR3	9.1	3.9	0.3	7.0	0.0	1.4	0.0	0.0	10.8	32.4	0.706
	RR4	10.1	3.4	0.0	11.0	0.0	0.8	0.0	0.0	15.3	40.6	0.653
Summer	AR1	43.6	31.2	2.8	11.0	0.5	8.0	2.4	1.5	232.3	333.3	0.508
	AR2	47.4	16.9	3.7	1.3	0.0	1.1	2.8	3.0	241.8	318.0	0.500
	AR3	40.5	20.0	2.7	8.0	0.0	4.6	1.0	0.3	134.5	211.5	0.560
	AR4	54.5	13.7	0.8	0.8	0.0	3.3	0.8	0.3	98.0	171.9	0.562
	ER1	12.8	168.4	12.9	72.1	0.0	1.7	0.5	1.5	103.0	373.0	0.618
	ER2	4.3	117.7	11.1	111.8	0.0	0.1	0.5	2.8	95.5	343.6	0.638
	ER3	4.7	157.1	13.7	40.0	0.5	0.3	0.0	2.8	141.0	360.2	0.617
	ER4	4.2	76.6	2.3	59.6	1.8	1.6	0.0	0.5	124.5	270.9	0.644
	RR1	18.7	6.0	5.9	237.3	1.8	1.5	0.0	0.0	529.5	800.7	0.435
	RR2	34.1	3.3	2.4	112.5	2.5	7.9	0.0	0.0	63.3	225.9	0.590
	RR3	4.4	1.3	1.0	51.3	0.0	0.0	0.0	0.0	13.8	71.7	0.427
	RR4	48.2	3.9	0.3	205.0	6.8	0.9	0.0	0.0	56.3	321.2	0.511

Table AIII-4: 2006 spring and summer benthic invertebrate Barlett's test for equal reef variances for ANOVA model responses.

Season	Response	Transformation	Df	Untransformed		Transformed	
				K ²	p-value	K ²	p-value
Spring	N	ABND ^{0.2}	2	2.641	0.267	0.445	0.801
	Amphipoda	None	2	0.37	0.831		
	Chironomidae	sin(ABND) ²	2	12.182	0.002	0.055	0.6
	Gastropoda	ABND ^{0.3}	2	14.66	0.001	0.127	0.938
	Oligocheata	ABND ^{0.5}	2	0.72	0.698	0.216	0.898
	Trombidiform	Ln(ABND)	2	4.124	0.127	0.884	0.643
	D	ABND ³	2	1.654	0.437	0.578	0.749
Summer	N	sin(Total / 100)	2	9.318	0.009	0.331	0.848
	Amphipoda	sin(ABND)	2	6.294	0.043	0.185	0.912
	Chironomidae	ABND ^{0.2}	2	16.48	<0.001	0.328	0.849
	Gastropoda	ABND ^{0.2}	2	12.506	0.002	0.939	0.625
	Oligocheata	ABND ^{0.4}	2	4.363	0.113	1.967	0.374
	Trombidiform	sin(ABND)	2	11.379	0.003	0.729	0.695
	D	ABND ¹⁰	2	6.326	0.042	1.304	0.521

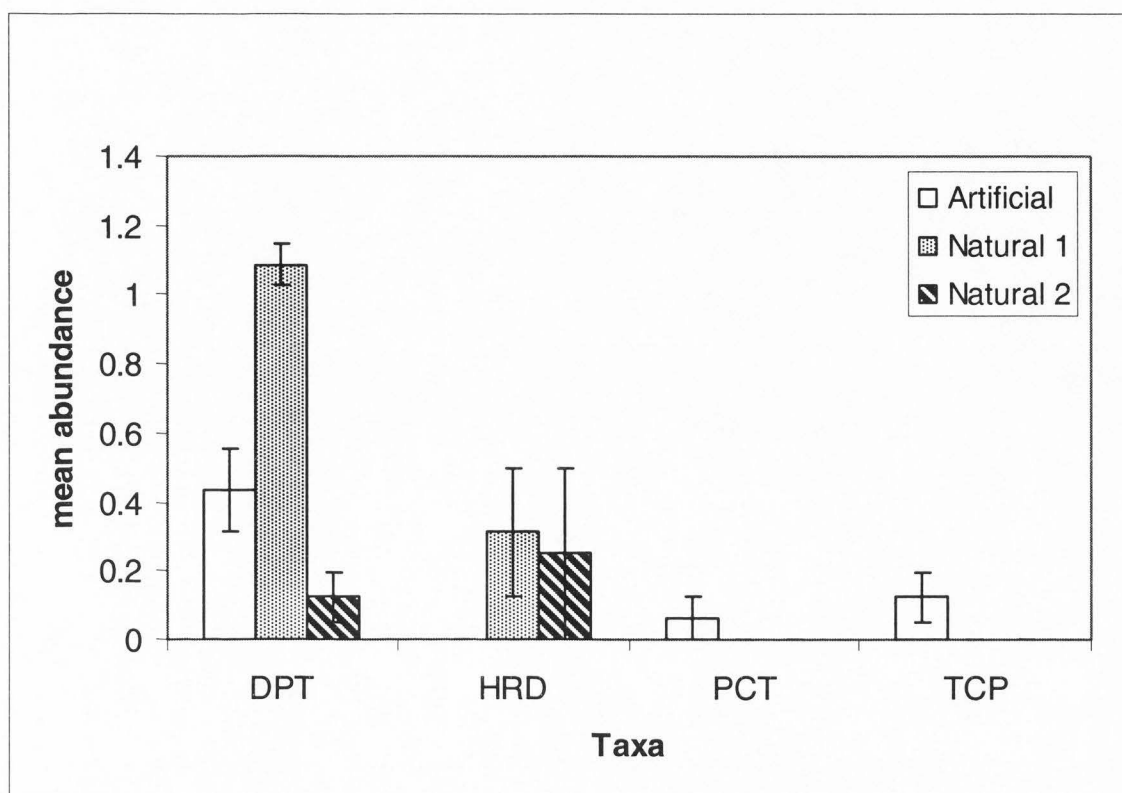


Figure AIII-1: Spring 2006 non-predominant benthic invertebrate abundance for each reef region. Error bars represent \pm one standard error.

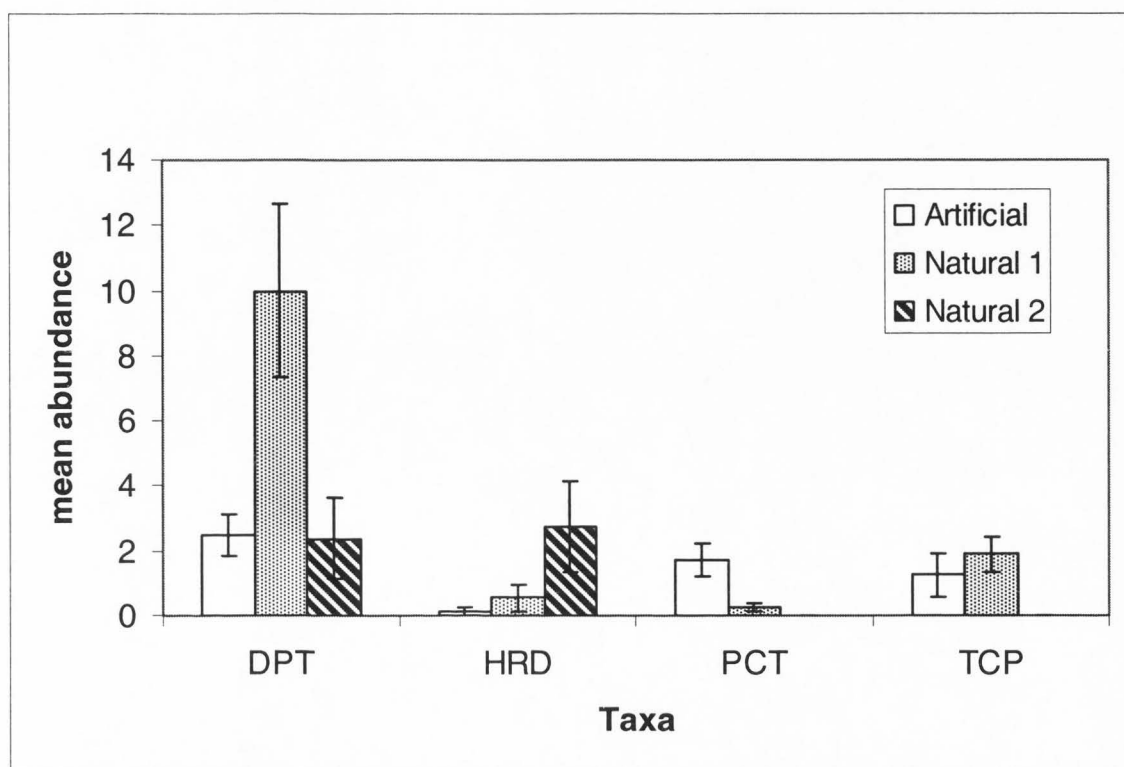


Figure AIII-2: Summer 2006 non-predominant benthic invertebrate abundance for each reef. Error bars represent +/- one standard error.

Appendix IV: Chapter 4 tables and figures

Table AIV-1: Species number caught for each sample and net soak time in hours (Hr). *Site* number follows region substrate code by "--". Number in parenthesis indicates number of gillnet sets at that site for *Year* and *Season*. Codes in Table 4-1.

Year	Season	Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	Soak (Hr)
2006	wnt	AR-1	0	0	8	0	0	0	38	1	0	0	0	0	0	5.82
2006	wnt	AR-1(2)	0	0	0	0	0	0	0	0	0	0	0	1	0	3.00
2006	wnt	AR-2	1	0	1	0	0	0	2	0	0	0	0	1	0	2.95
2006	wnt	AR-3	2	0	7	0	0	0	24	0	0	0	0	1	0	5.40
2006	wnt	AR-4	0	0	5	0	0	0	3	0	0	0	0	2	0	5.07
2006	wnt	AR-4(2)	0	0	4	0	0	0	3	0	0	0	0	0	0	2.82
2006	wnt	AS-1	4	0	5	0	0	0	24	0	0	0	0	2	0	4.20
2006	wnt	AS-1(2)	0	0	7	0	0	0	6	0	0	0	0	3	0	2.93
2006	wnt	AS-2	0	0	1	0	0	0	0	0	0	0	0	0	0	4.03
2006	wnt	AS-2(2)	0	0	1	0	0	0	0	0	0	0	0	1	0	2.93
2006	wnt	AS-3	1	0	0	0	0	0	1	0	0	0	0	0	0	4.07
2006	wnt	AS-4	0	0	1	0	0	0	0	0	0	0	0	0	0	2.95
2006	wnt	NR1-2	0	0	8	0	0	0	55	0	0	0	0	0	0	4.70
2006	wnt	NR1-3	1	0	9	0	0	0	118	0	0	0	0	0	0	4.78
2006	wnt	NR1-4	1	0	12	0	0	0	146	0	0	0	0	0	0	5.12
2006	wnt	NS1-1	1	0	9	0	0	0	175	0	0	0	0	0	0	5.92
2006	wnt	NS1-2	3	0	12	0	0	0	157	0	0	0	0	0	0	5.58
2006	wnt	NS1-3	3	0	22	1	0	0	48	0	0	0	0	1	0	5.70
2006	wnt	NR2-1	2	0	4	0	0	0	5	0	0	0	0	1	0	2.92
2006	wnt	NR2-2	0	0	3	0	0	0	23	0	0	0	0	0	0	2.55
2006	wnt	NR2-4	3	0	10	0	0	0	14	0	0	0	0	2	0	3.13
2006	wnt	NS2-1	0	0	0	0	0	0	0	0	0	0	0	1	0	2.52
2006	wnt	NS2-3	0	0	0	0	0	0	0	0	0	0	0	0	0	2.78
2006	wnt	NS2-4	0	0	0	0	0	0	0	0	0	0	0	0	0	3.15

Table AIV-1: Continued from previous page.

Year	Season	Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	Soak (Hr)
2006	Spr	AR-1	0	0	0	0	0	0	0	0	0	0	0	3	0	12.43
2006	Spr	AR-3	0	0	0	0	0	0	0	0	0	0	1	3	0	12.65
2006	Spr	AR-4	0	0	1	0	0	0	0	0	0	0	0	3	0	12.75
2006	Spr	AS-1	1	0	0	0	0	0	0	0	0	0	0	9	0	13.30
2006	spr	AS-3	1	0	1	0	0	0	0	0	0	0	1	6	0	13.12
2006	spr	AS-4	0	0	0	0	0	0	0	1	0	0	0	3	0	13.28
2006	spr	N1R-1	0	0	0	0	0	1	0	0	0	0	7	3	0	11.95
2006	spr	N1R-3	0	0	0	0	0	4	0	0	0	0	15	0	3	12.40
2006	spr	N1R-4	0	0	0	0	0	2	0	0	0	0	2	1	0	12.22
2006	spr	N1S-1	0	0	0	0	0	11	0	0	0	0	1	4	0	12.28
2006	spr	N1S-3	1	0	1	0	0	1	0	0	0	0	0	3	0	12.55
2006	spr	N1S-4	0	0	0	0	0	0	0	0	0	0	1	3	0	12.65
2006	spr	N1S-1	0	0	0	0	0	1	0	0	0	0	1	2	0	14.92
2006	spr	N2R-3	0	0	0	0	0	0	0	0	0	0	0	3	0	15.18
2006	spr	N2R-4	0	0	0	0	0	7	0	0	0	0	0	6	0	15.43
2006	spr	N2S-1	0	0	3	0	0	0	0	0	0	0	0	7	0	16.37
2006	spr	N2S-3	2	0	0	0	0	2	0	0	0	0	0	10	0	16.55
2006	spr	N2S-4	0	0	5	0	0	8	0	0	0	0	0	11	0	17.12
2006	smr	AR-1	0	0	2	1	0	1	0	0	0	0	0	6	0	11.68
2006	smr	AR-2	0	0	7	0	0	0	0	0	0	0	0	6	0	11.72
2006	smr	AR-3	0	0	2	0	0	0	0	0	0	0	1	7	0	12.48
2006	smr	AS-1	0	0	1	2	0	7	2	0	0	0	1	7	0	12.77
2006	smr	AS-2	0	0	20	0	0	2	0	0	1	0	0	15	0	13.10
2006	smr	AS-3	0	0	2	0	0	2	0	0	1	0	0	17	0	13.52

Table AIV-1: Continued from previous page.

Year	Season	Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	Soak (Hr)
2006	smr	N1R-1	0	0	2	1	0	1	0	0	0	3	0	2	0	12.57
2006	smr	N1R-2	1	0	2	0	0	1	0	0	0	0	0	7	0	12.77
2006	smr	N1R-3	0	0	1	1	0	1	0	0	0	0	1	7	0	12.85
2006	smr	N1S-1	0	0	28	1	0	7	27	0	1	0	2	13	0	13.27
2006	smr	N1S-2	1	0	9	0	0	2	0	0	0	0	1	6	0	13.70
2006	smr	N1S-3	1	0	10	0	0	2	1	0	1	0	8	8	0	14.10
2006	smr	N2R-1	0	0	1	0	0	0	0	0	0	0	0	13	0	14.20
2006	smr	N2R-2	0	0	0	0	0	0	0	0	0	0	0	10	0	14.55
2006	smr	N2R-3	0	0	0	0	0	0	0	0	0	0	0	3	0	14.80
2006	smr	N2S-1	0	0	1	3	0	3	0	0	0	0	2	6	0	15.05
2006	smr	N2S-2	0	0	2	2	0	7	0	0	0	0	0	12	0	15.42
2006	smr	N2S-3	0	0	1	1	0	4	0	0	0	0	1	11	0	15.75
2006	fl	AR-1	0	0	2	0	1	3	0	1	0	0	1	0	5	14.30
2006	fl	AR-3	0	0	3	0	5	0	0	0	0	0	1	2	5	14.53
2006	fl	AR-4	0	0	1	0	1	0	0	0	0	0	0	1	1	14.65
2006	fl	AS-1	0	0	7	1	0	4	0	0	0	0	0	4	0	14.90
2006	fl	AS-3	0	2	16	0	0	5	7	0	0	0	1	1	0	15.13
2006	fl	AS-4	1	0	19	0	1	5	7	1	0	0	0	1	0	15.42
2006	fl	N1R-2	0	0	2	0	0	2	0	2	0	0	0	3	1	15.93
2006	fl	N1R-3	0	0	3	0	0	1	0	3	0	0	0	6	5	16.33
2006	fl	N1R-4	0	0	1	0	0	2	0	2	0	0	0	2	0	16.48
2006	fl	N1S-2	4	0	1	0	0	28	0	1	0	1	0	9	1	16.85
2006	fl	N1S-3	0	0	3	0	0	15	0	1	0	0	0	0	0	17.17
2006	fl	N1S-4	1	0	0	0	0	7	0	1	0	0	0	0	0	17.38

Table AIV-1: Continued from previous page.

Year	Season	Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	Soak (Hr)
2006	fl	N2R-2	0	0	5	0	0	3	0	5	0	0	0	1	3	17.48
2006	fl	N2R-3	0	0	3	0	0	8	0	4	0	0	0	2	0	17.88
2006	fl	N2R-4	0	0	0	0	0	0	0	8	0	0	0	3	1	18.00
2006	fl	N2S-2	0	0	19	1	0	5	2	4	0	0	1	0	0	18.72
2006	fl	N2S-3	0	0	14	0	3	7	1	5	0	0	0	4	2	19.12
2006	fl	N2S-4	0	0	24	0	0	4	2	6	0	0	0	3	0	19.67
2007	spr	AR-1	0	0	0	0	0	0	0	0	0	0	0	0	1	12.28
2007	spr	AR-3	0	0	0	0	0	0	0	0	0	0	0	2	1	12.40
2007	spr	AR-4	0	0	0	0	0	0	0	0	0	0	1	4	0	12.57
2007	spr	AS-1	0	0	3	0	0	0	0	0	0	0	0	7	0	13.00
2007	spr	AS-3	0	0	4	0	0	0	0	0	0	0	0	6	0	13.38
2007	spr	AS-4	1	0	2	0	0	0	0	0	0	0	0	8	0	13.83
2007	spr	N1R-1	0	0	0	0	0	1	0	0	0	0	0	2	0	12.73
2007	spr	N1R-3	1	0	0	0	0	3	0	0	0	0	1	1	0	12.78
2007	spr	N1R-4	0	0	0	0	0	1	0	0	0	0	1	2	0	12.82
2007	spr	N1S-1	0	0	1	0	0	2	0	0	0	0	1	4	0	13.43
2007	spr	N1S-3	0	0	4	0	0	0	0	0	0	0	2	6	0	13.27
2007	spr	N1S-4	0	0	4	0	0	0	0	1	0	0	0	7	0	13.68
2007	spr	N2R-1	0	0	0	0	0	0	0	0	0	0	0	1	0	13.82
2007	spr	N2R-2	0	0	0	0	0	0	0	0	0	0	0	0	0	14.00
2007	spr	N2R-4	0	0	0	1	0	0	0	0	0	0	0	1	0	13.95
2007	spr	N2S-1	0	0	4	0	0	1	0	0	0	0	0	2	0	14.10
2007	spr	N2S-3	1	0	4	0	0	2	0	0	0	0	0	4	1	14.37
2007	spr	N2S-4	0	0	7	0	0	1	0	0	0	0	0	4	0	14.45

Table AIV-1: Continued from previous page.

Year	Season	Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	Soak (Hr)
2007	smr	AR-1	0	0	1	0	1	0	1	0	0	0	0	7	0	13.10
2007	smr	AR-2	1	0	0	0	0	0	0	0	0	0	0	6	0	13.25
2007	smr	AR-3	1	0	0	0	0	0	0	0	0	0	0	8	0	13.52
2007	smr	AS-1	0	0	1	1	0	2	0	0	0	0	0	11	0	13.97
2007	smr	AS-2	0	4	9	1	0	9	0	0	0	0	0	10	0	14.63
2007	smr	AS-3	0	4	9	0	0	2	1	0	0	0	1	14	0	15.25
2007	smr	N1R-1	0	0	1	0	0	0	0	0	0	0	0	2	0	17.10
2007	smr	N1R-2	0	0	0	3	0	0	0	0	0	0	0	9	0	17.48
2007	smr	N1R-4	0	0	3	0	0	0	0	0	0	0	0	4	0	16.72
2007	smr	N1S-2	3	0	18	0	0	3	16	0	0	0	2	12	0	18.12
2007	smr	N1S-3	0	1	2	1	0	4	0	0	0	0	0	13	0	19.58
2007	smr	N1S-4	0	0	1	1	0	0	2	0	0	0	1	10	0	18.85
2007	smr	N2R-2	0	0	0	0	0	0	0	0	0	0	0	7	0	15.32
2007	smr	N2R-3	1	0	1	0	0	0	0	0	0	0	0	9	0	15.47
2007	smr	N2R-4	1	0	2	0	0	0	0	0	0	0	1	9	0	15.62
2007	smr	N2S-2	1	3	3	0	0	1	0	0	0	0	0	12	0	16.03
2007	smr	N2S-3	0	0	12	0	0	0	2	0	0	0	2	18	0	16.58
2007	smr	N2S-4	0	1	10	1	0	1	1	0	0	0	1	13	0	17.20

Table AIV-2: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in winter 2006. *Site* number follows region substrate code by "-". Number in parenthesis indicates number of gillnet sets at that site for *Year* and *Season*. Codes in Table 4-1.

Site	BCT	BLW	BONN	CF	CARP	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	1.3754	0	0	0	6.533	0.1719	0	0	0	0	0	8.080	0.317
AR-1(2)	0	0	0	0	0	0	0	0	0	0	0	0.3333	0	0.333	0.000
AR-2(2)	0.339	0	0.339	0	0	0	0.678	0	0	0	0	0.339	0	1.695	0.720
AR-3	0.3704	0	1.2963	0	0	0	4.4444	0	0	0	0	0.1852	0	6.296	0.455
AR-4	0	0	0.9868	0	0	0	0.5921	0	0	0	0	0.3947	0	1.974	0.620
AR-4(2)	0	0	1.4201	0	0	0	1.0651	0	0	0	0	0	0	2.485	0.490
AS-1	0.4	0	0.5	0	0	0	2.4	0	0	0	0	0.2	0	3.500	0.493
AS-1(2)	0	0	1.0023	0	0	0	0.8591	0	0	0	0	0.4295	0	2.291	0.633
AS-2	0	0	0.1041	0	0	0	0	0	0	0	0	0	0	0.104	0.000
AS-2(2)	0	0	0.1432	0	0	0	0	0	0	0	0	0.1432	0	0.286	0.500
AS-3	0.1033	0	0	0	0	0	0.1033	0	0	0	0	0	0	0.207	0.500
AS-4(2)	0	0	0.1424	0	0	0	0	0	0	0	0	0	0	0.142	0.000
N1R-2	0	0	1.7021	0	0	0	11.702	0	0	0	0	0	0	13.404	0.222
N1R-3	0.2091	0	1.8815	0	0	0	24.669	0	0	0	0	0	0	26.760	0.145
N1R-4	0.1954	0	2.3453	0	0	0	28.534	0	0	0	0	0	0	31.075	0.151
N1S-1	0.071	0	0.6389	0	0	0	12.423	0	0	0	0	0	0	13.132	0.103
N1S-2	0.2257	0	0.9027	0	0	0	11.81	0	0	0	0	0	0	12.939	0.162
N1S-3	0.2211	0	1.6211	0	0.0737	0	3.5368	0	0	0	0	0.0737	0	5.526	0.502
N2R-1	0.6857	0	1.3714	0	0	0	1.7143	0	0	0	0	0.3429	0	4.114	0.681
N2R-2	0	0	1.1765	0	0	0	9.0196	0	0	0	0	0	0	10.196	0.204
N2R-4	0.9574	0	3.1915	0	0	0	4.4681	0	0	0	0	0.6383	0	9.255	0.633
N2S-1	0	0	0	0	0	0	0	0	0	0	0	0.1669	0	0.167	0.000
N2S-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000
N2S-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000

Table AIV-3: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in spring 2006. *Site* number follows region substrate code by "--". Number in parenthesis indicates number of gillnet sets at that site for *Year* and *Season*. Codes defined in Table 4-1.

Site	BCT	BLW	BONN	CF	CARP	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	0	0	0	0	0	0	0	0	0	0.2413	0	0.241	0.000
AR-3	0	0	0	0	0	0	0	0	0	0	0.0791	0.2372	0	0.316	0.375
AR-4	0	0	0.0784	0	0	0	0	0	0	0	0	0.2353	0	0.314	0.375
AS-1	0.0316	0	0	0	0	0	0	0	0	0	0	0.2842	0	0.316	0.180
AS-3	0.032	0	0.032	0	0	0	0	0	0	0	0.1525	0.1921	0	0.409	0.627
AS-4	0	0	0	0	0	0	0	0.0316	0	0	0	0.0949	0	0.126	0.375
N1R-1	0	0	0	0	0	0.0837	0	0	0	0	0.5858	0.251	0	0.921	0.512
N1R-3	0	0	0	0	0	0.3226	0	0	0	0	1.2097	0	0.2419	1.774	0.483
N1R-4	0	0	0	0	0	0.1637	0	0	0	0	0.1637	0.0819	0	0.409	0.640
N1S-1	0	0	0	0	0	0.3761	0	0	0	0	0.1628	0.1368	0	0.676	0.591
N1S-3	0.0335	0	0.0335	0	0	0.0335	0	0	0	0	0	0.1004	0	0.201	0.667
N1S-4	0	0	0	0	0	0	0	0	0	0	0.1581	0.0996	0	0.258	0.474
N2R-1	0	0	0	0	0	0.067	0	0	0	0	0.067	0.1341	0	0.268	0.625
N2R-3	0	0	0	0	0	0	0	0	0	0	0	0.1976	0	0.198	0.000
N2R-4	0	0	0	0	0	0.4536	0	0	0	0	0	0.3888	0	0.842	0.497
N2S-1	0	0	0.077	0	0	0	0	0	0	0	0	0.1796	0	0.257	0.420
N2S-3	0.0508	0	0	0	0	0.0508	0	0	0	0	0	0.2538	0	0.355	0.449
N2S-4	0	0	0.1227	0	0	0.1963	0	0	0	0	0	0.2699	0	0.589	0.635

Table AIV-4: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in summer 2006. *Site* number follows region substrate code by "--". Codes defined in Table 4-1.

Site	BCT	BLW	BONN	CF	CARP	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	0.1712	0	0.0856	0.0856	0	0	0	0	0	0.5136	0	0.856	0.580
AR-2	0	0	0.5974	0	0	0	0	0	0	0	0	0.5121	0	1.110	0.497
AR-3	0	0	0.1602	0	0	0	0	0	0	0	0.0801	0.5607	0	0.801	0.460
AS-1	0	0	0.0329	0	0.0658	0.2303	0.0658	0	0	0	0.0783	0.2303	0	0.703	0.754
AS-2	0	0	0.6412	0	0	0.0641	0	0	0.0321	0	0	0.4809	0	1.218	0.564
AS-3	0	0	0.0621	0	0	0.0621	0	0	0.0311	0	0	0.5282	0	0.684	0.384
N1R-1	0	0	0.1592	0	0.0796	0.0796	0	0	0	0.2387	0	0.1592	0	0.716	0.765
N1R-2	0.0783	0	0.1567	0	0	0.0783	0	0	0	0	0	0.5483	0	0.862	0.545
N1R-3	0	0	0.0778	0	0.0778	0.0778	0	0	0	0	0.0778	0.5447	0	0.856	0.562
N1S-1	0	0	0.8864	0	0.0317	0.2216	0.8548	0	0.0317	0	0.1508	0.4116	0	2.588	0.737
N1S-2	0.0307	0	0.2759	0	0	0.0613	0	0	0	0	0.073	0.1839	0	0.625	0.693
N1S-3	0.0298	0	0.2979	0	0	0.0596	0.0298	0	0.0298	0	0.5674	0.2383	0	1.252	0.698
N2R-1	0	0	0.0704	0	0	0	0	0	0	0	0	0.9155	0	0.986	0.133
N2R-2	0	0	0	0	0	0	0	0	0	0	0	0.6873	0	0.687	0.000
N2R-3	0	0	0	0	0	0	0	0	0	0	0	0.2027	0	0.203	0.000
N2S-1	0	0	0.0279	0	0.0837	0.0837	0	0	0	0	0.1329	0.1674	0	0.496	0.754
N2S-2	0	0	0.0545	0	0.0545	0.1907	0	0	0	0	0	0.3269	0	0.627	0.620
N2S-3	0	0	0.0267	0	0.0267	0.1067	0	0	0	0	0.0635	0.2933	0	0.517	0.615

Table AIV-5: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in fall 2006. *Site* number follows region substrate code by "-". Codes defined in Table 4-1.

Site	BCT	BLW	BONN	CF	CARP	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	0.1399	0.0699	0	0.2098	0	0.0699	0	0	0.0699	0	0.3497	0.909	0.757
AR-3	0	0	0.2064	0.344	0	0	0	0	0	0	0.0688	0.1376	0.344	1.101	0.750
AR-4	0	0	0.0683	0.0683	0	0	0	0	0	0	0	0.0683	0.0683	0.273	0.750
AS-1	0	0	0.1973	0	0.0282	0.1128	0	0	0	0	0	0.1128	0	0.451	0.680
AS-3	0	0.0555	0.4441	0	0	0.1388	0.1943	0	0	0	0.0661	0.0278	0	0.926	0.694
AS-4	0.0272	0	0.5176	0.0272	0	0.1362	0.1907	0.0272	0	0	0	0.0272	0	0.954	0.642
N1R-2	0	0	0.1255	0	0	0.1255	0	0.1255	0	0	0	0.1883	0.0628	0.628	0.780
N1R-3	0	0	0.1837	0	0	0.0612	0.1837	0	0	0	0	0.3673	0.3061	1.102	0.753
N1R-4	0	0	0.0607	0	0	0.1213	0	0.1213	0	0	0	0.1213	0	0.425	0.735
N1S-2	0.0997	0	0.0249	0	0	0.6979	0	0.0249	0	0.0249	0	0.2243	0.0593	1.156	0.586
N1S-3	0	0	0.0734	0	0	0.367	0	0.0245	0	0	0	0	0	0.465	0.349
N1S-4	0.0242	0	0	0	0	0.1691	0	0.0242	0	0	0	0	0	0.217	0.370
N2R-2	0	0	0.286	0	0	0.1716	0	0.286	0	0	0	0.0572	0.1716	0.972	0.761
N2R-3	0	0	0.1678	0	0	0.4473	0	0.2237	0	0	0	0.1118	0	0.951	0.678
N2R-4	0	0	0	0	0	0	0	0.4444	0	0	0	0.1667	0.0556	0.667	0.486
N2S-2	0	0	0.4264	0	0.0224	0.1122	0.0449	0.0898	0	0	0.0534	0	0	0.749	0.630
N2S-3	0	0	0.3076	0.0659	0	0.1538	0.022	0.1099	0	0	0	0.0879	0.1046	0.852	0.788
N2S-4	0	0	0.5125	0	0	0.0854	0.0427	0.1281	0	0	0	0.0641	0	0.833	0.579

Table AIV-6: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in spring 2007. *Site* number follows region substrate code by "-". Codes defined in Table 4-1.

Site	BCT	BLW	BONN	CF	CARP	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	0	0	0	0	0	0	0	0	0	0	0.0814	0.081	0.000
AR-3	0	0	0	0	0	0	0	0	0	0	0	0.1613	0.0806	0.242	0.444
AR-4	0	0	0	0	0	0	0	0	0	0	0.0796	0.3183	0	0.398	0.320
AS-1	0	0	0.0969	0	0	0	0	0	0	0	0	0.2262	0	0.323	0.420
AS-3	0	0	0.1255	0	0	0	0	0	0	0	0	0.1883	0	0.314	0.480
AS-4	0.0304	0	0.0607	0	0	0	0	0	0	0	0	0.2429	0	0.334	0.430
N1R-1	0	0	0	0	0	0.0785	0	0	0	0	0	0.1571	0	0.236	0.444
N1R-3	0.0782	0	0	0	0	0.2347	0	0	0	0	0.0782	0.0782	0	0.469	0.667
N1R-4	0	0	0	0	0	0.078	0	0	0	0	0.078	0.156	0	0.312	0.625
N1S-1	0	0	0.0313	0	0	0.0625	0	0	0	0	0.0313	0.1251	0	0.250	0.656
N1S-3	0	0	0.1266	0	0	0	0	0	0	0	0.0633	0.1899	0	0.380	0.611
N1S-4	0	0	0.1228	0	0	0	0	0.0307	0	0	0	0.2149	0	0.368	0.542
N2R-1	0	0	0	0	0	0	0	0	0	0	0	0	0.0724	0.072	0.000
N2R-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000	0.000
N2R-4	0	0	0	0	0.0717	0	0	0	0	0	0	0.0717	0	0.143	0.500
N2S-1	0	0	0.1191	0	0	0.0298	0	0	0	0	0	0.0596	0	0.209	0.571
N2S-3	0.0292	0	0.1169	0	0	0.0585	0	0	0	0	0	0.1169	0.0292	0.351	0.736
N2S-4	0	0	0.2035	0	0	0.0291	0	0	0	0	0	0.1163	0	0.349	0.542

Table AIV-7: CPUE and Simpson's diversity index for each gillnet-minnowtrap sample in summer 2007. *Site* number follows region substrate code by "--". Codes defined in Table 4-1.

Site	BCT	BLW	BONN	CARP	CF	CHUB	CISCO	LT	RB	RSR	SCULP	US	YP	N	D
AR-1	0	0	0.076	0	0.08	0	0.076	0	0	0	0.534351	0	0	0.763	0.480
AR-2	0.0755	0	0	0	0	0	0	0	0	0	0.45283	0	0	0.528	0.245
AR-3	0.074	0	0	0	0	0	0	0	0	0	0.591862	0	0	0.666	0.198
AS-1	0	0	0.03	0.03007	0	0.06	0	0	0	0	0.330788	0	0	0.451	0.436
AS-2	0	0.1148	0.258	0.0287	0	0.258	0	0	0	0	0.287016	0	0	0.947	0.744
AS-3	0	0.1102	0.248	0	0	0.055	0.028	0	0	0	0.385574	0.065574	0	0.892	0.710
N1R-1	0	0	0.058	0	0	0	0	0	0	0	0.116959	0	0	0.175	0.444
N1R-2	0	0	0	0.17159	0	0	0	0	0	0	0.514776	0	0	0.686	0.375
N1R-4	0	0	0.179	0	0	0	0	0	0	0	0.239282	0	0	0.419	0.490
N1S-2	0.0695	0	0.417	0	0	0.07	0.371	0	0	0	0.278197	0.110396	0	1.316	0.763
N1S-3	0	0.0214	0.043	0.02145	0	0.086	0	0	0	0	0.278809	0	0	0.450	0.567
N1S-4	0	0	0.022	0.02228	0	0	0.045	0	0	0	0.222812	0.05305	0	0.365	0.584
N2R-2	0	0	0	0	0	0	0	0	0	0	0.457018	0	0	0.457	0.000
N2R-3	0.0647	0	0.065	0	0	0	0	0	0	0	0.581897	0	0	0.711	0.314
N2R-4	0.064	0	0.128	0	0	0	0	0	0	0	0.576307	0.064034	0	0.832	0.485
N2S-2	0.0262	0.0786	0.079	0	0	0.026	0	0	0	0	0.314345	0	0	0.524	0.590
N2S-3	0	0	0.304	0	0	0	0.051	0	0	0	0.455879	0.120603	0	0.931	0.634
N2S-4	0	0.0244	0.244	0.02442	0	0.024	0.024	0	0	0	0.317442	0.05814	0	0.717	0.677

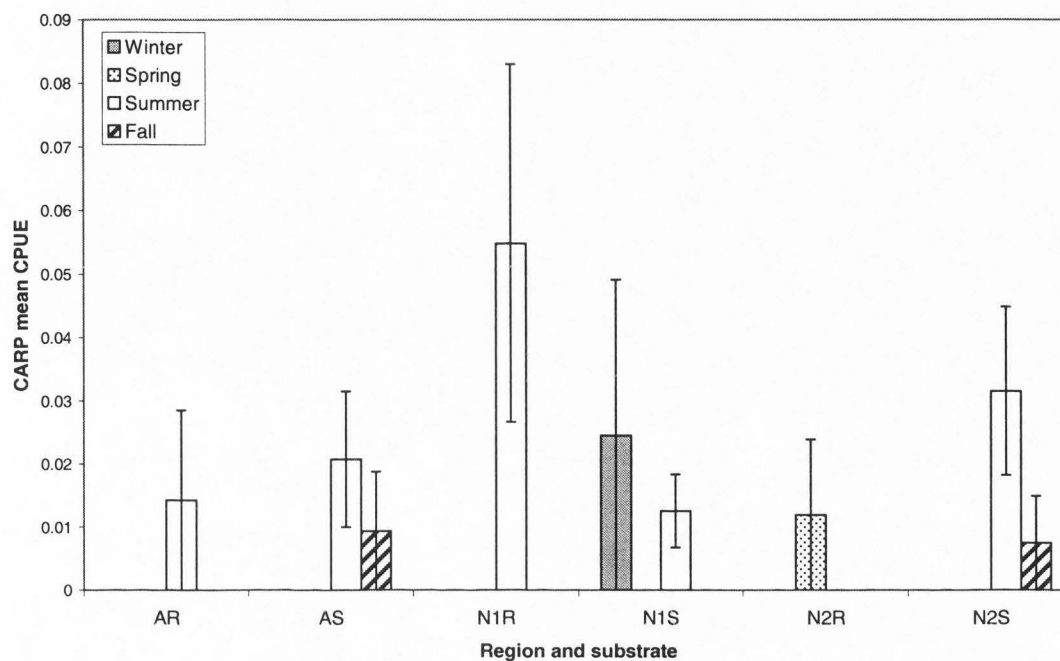


Figure AIV-1: Season mean CARP CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Symbols defined in Table 4-1.

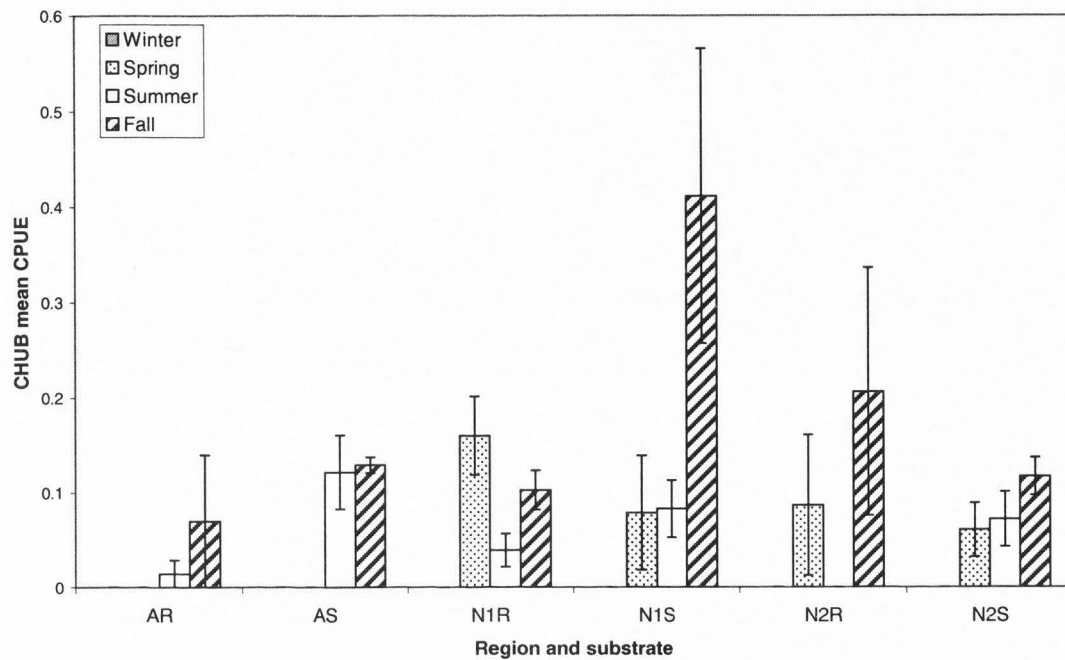


Figure AIV-2: Season mean CHUB CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Symbols defined in Table 4-1.

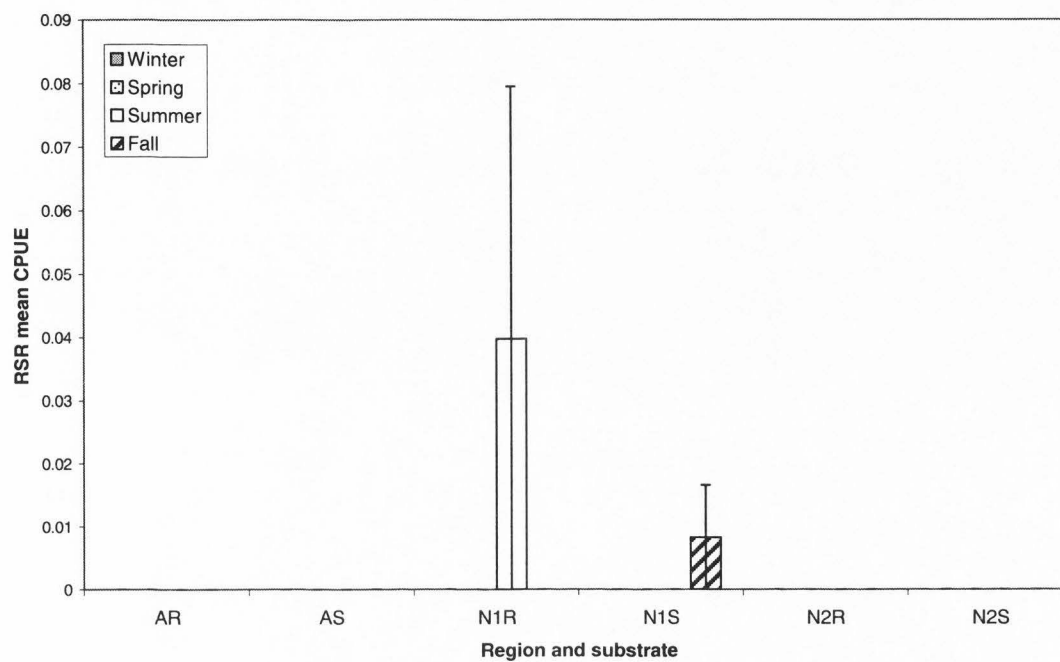


Figure AIV-3: Season mean RSR CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Symbols defined in Table 4-1.

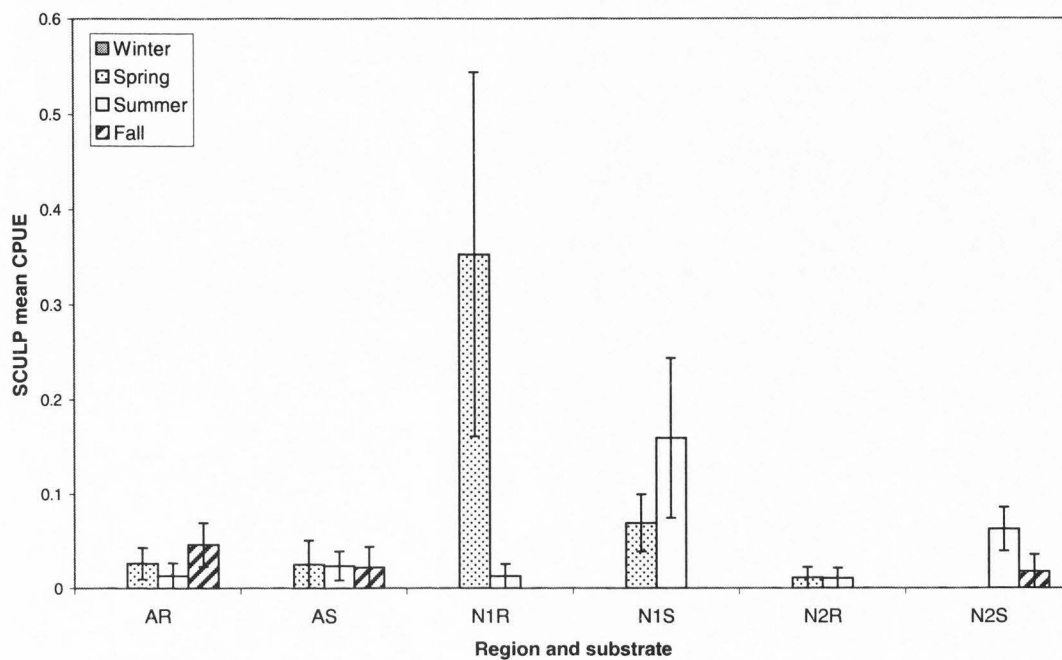


Figure AIV-4: Season mean SCULP CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Symbols defined in Table 4-1.

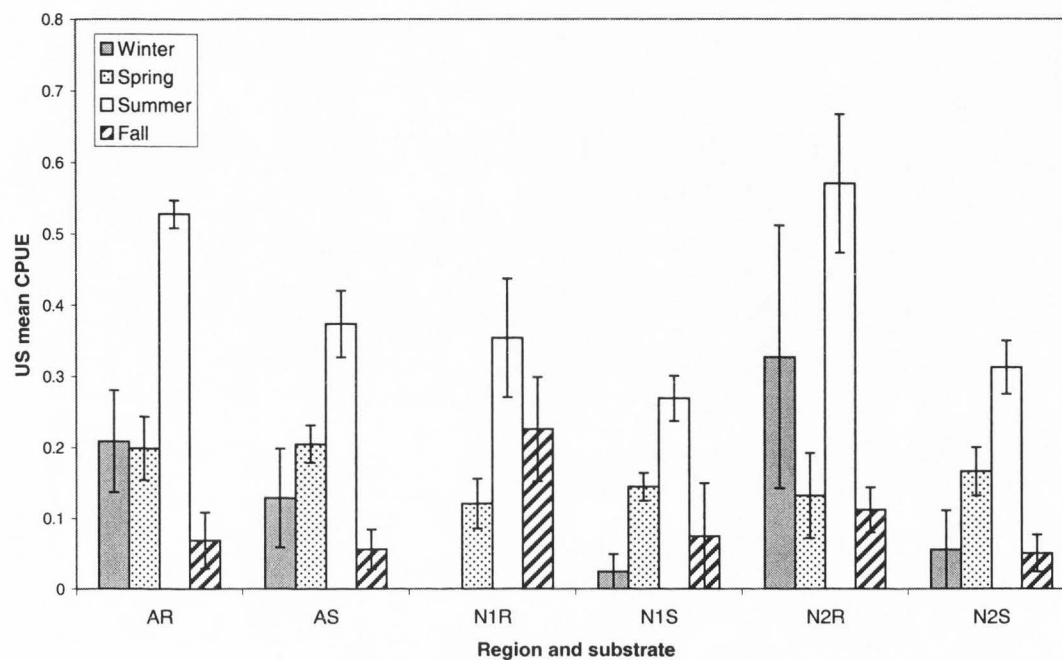


Figure AIV-5: Season mean US CPUE for region and substrate. Error bars in the figure represent + and - one standard error. Symbols defined in Table 4-1.