Temporal Persistence of Red Grouper (*Epinephelus morio*) Holes in the Steamboat Lumps MPA and the Analysis of Associated Fish Assemblages from Towed Camera Data

By

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<A> Introduction

The discourse around fisheries management in the Gulf of Mexico often centers on the large and complex Red Snapper *Lutjanus campechanus* stocks found within its waters (Morrison 2016). However, historic grouper landings in the Gulf of Mexico, composed mainly of Red Grouper *Epinephelus morio,* have far surpassed those of Red Snapper (Simmons et al. 2015). This trend holds when considering just the eastern Gulf of Mexico where landings revenue has and continues to be dominated by Red Grouper over the other reef fish fisheries in the region (NOAA Fisheries 2016). In 2004, Red Grouper were classified as a 'near-threatened' species by the International Union for the Conservation of Nature (IUCN). This designation was updated in late-2018 to 'vulnerable' meaning that this species' global mature population is continuing to decline (Brule et al. 2018). The outlook is better for the Red Grouper population in the Gulf of Mexico as the most recent stock assessment has found the population is rebuilding (SEDAR 2015). Knowing more about this species' population dynamics and habitat use is therefore imperative to evaluate their population status and develop effective management strategies for one of the most important fisheries in the Gulf of Mexico.

Red Grouper are a long-lived species (Beaumariage and Bullock 1976; Burgos et al. 2007) that are also known ecological engineers (Coleman and Williams 2002; Coleman et al. 2010). In certain areas, juvenile to adult life stage individuals have been found to actively clear and maintain large holes on the seafloor for several years (Scanlon et al. 2005; Coleman et al. 2010). This behavior creates habitat for themselves as well as small reef fishes in areas that are otherwise very low in species diversity and structural complexity (Ellis 2015). In the Steamboat Lumps Marine Protected Area (SL-MPA; Fig. 1), the creation and continued excavation of these holes by Red Grouper is a notable example of this behavior. Aside from these holes, the surrounding seafloor within the SL-

MPA is largely comprised of flat, sandy expanses with some low-relief features (Gardner et al. 2005). The grouper holes in this area were extensively analyzed by Wall et al. (2011) and a large portion of this study was devoted to determining if the holes in the SL-MPA were being maintained, abandoned, or newly excavated between 2006 and 2009. The purpose of the present study is to continue analyzing these trends with an additional multibeam bathymetry dataset collected in 2017. This purpose of this new analysis was to further elucidate the long-term persistence of these bio-engineered features.

[Figure 1]

Past assessments of Steamboat Lumps' grouper hole species assemblages have been carried out using stationary cameras, submersibles, and ROV's (Gledhill and David 2004; Coleman et al. 2010). In this study, the second objective was to collect video data using a towed camera system in an attempt to observe Red Grouper presence and species diversity of larger reef fishes within the holes.

<B> Methods

The new bathymetric dataset used in this study was collected in April 2017 by the Continental Shelf Characterization, Assessment, and Mapping Project (C-SCAMP) using a Reson Seabat 7125. This system is a high-resolution, dual-frequency multibeam swath sonar with 512 overlapping beams. It was operated at 400 kHz with a 140° swath which provides an across-track receive beam width of 0.5° and an along-track transmit beam width of 1°. Navigation and motion compensation data were collected with an Applanix POS MV OceanMaster system with Fugro Marinestar (Fugro 2016). The POS MV OceanMaster with Marinestar enabled has a horizontal accuracy of 10 cm with 95% certainty and a vertical accuracy of 15 cm with 95% certainty (Applanix 2017). The roll and pitch have a 0.01° accuracy. An AML Oceanographic Minos•X with an SV•Xchange sound velocity sensor was used for sound velocity profile correction.

The previously collected data as well as the full data analysis from the Wall et al. (2011) publication were obtained directly from Dr. Carrie Wall. This included the bathymetry surfaces used for analysis as well as all of the georeferenced, individual grouper hole data (i.e. latitude/longitude, depth, etc.). In order to do a comparison analysis, the bathymetric data from April 2017 were processed in Caris HIPS & SIPS 10 to exceed International Hydrographic Organization (IHO) standards 1B (IHO 2008). The resulting bathymetry surface using the 2017 data could be processed to a 0.5 m x 0.5 m grid size. However, for direct comparison, the 2017 multibeam data were processed to 3 m x 3 m grid size to match the 2006 and 2009 surfaces.

The 3 m x 3 m grid multibeam bathymetry surface for 2017 was then imported into ArcMap 10.4.1 (ESRI 2016) along with the Wall et al. (2011) bathymetric surfaces from 2006 and 2009. The same 1.64 km^2 comparison extent from Wall et al. (2011) was then identified for the 2017 bathymetric surface in order to begin analysis (white bounding box; Fig. 1). Grouper holes present in 2017 within this boundary were identified and counted using the slope surface derived from the 2017 bathymetric surface, as slope more clearly delineates the hole depressions within the area (Fig. 1). The density of grouper holes for all three years within the overlapping area was then calculated for comparison. Holes that were present in one dataset but not the other within the comparison extent were noted separately as 'Newly Formed' or 'Filled In'. The amount of multibeam data collected in 2017 (8.5 km^2) surpassed what was collected in 2006 and 2009 enabling a better understanding on the spatial extent of grouper holes in the SL-MPA. Grouper holes throughout the entirety of this newly mapped area, beyond those already analyzed within the comparison extent, were identified and enumerated as well.

Average hole depths, widths, and heights throughout the comparison region were measured and calculated (Fig. 2). These attributes were compared to the hole depths and widths measured by Wall et al. (2011) with the purpose of determining if the holes were being actively maintained (same depth or deeper) or abandoned (shallower). Only holes from the 2017 dataset that could be directly linked to ones present in 2009 within the comparison area were measured. To identify these holes, the 'Near' function in the ArcGIS analysis toolbox was employed which identified holes from the 2009 and 2017 datasets which were within 5 m of one another (ESRI 2016). The holes identified from the 2009 dataset were then used select the matching holes from 2006 which were initially identified by Wall et al. (2011) to include in the hole structure trend analysis.

[Figure 2]

For each dataset, hole depths were determined using the profile tool in CARIS BASE Editor 5.1 (CARIS 2018) and each profile was taken such that it intersected the deepest portion of the hole. The hole height was calculated by subtracting the depth of the sides of the hole from its maximum depth; if a hole had sides that were at different depths, hole height was based on the deeper side of the hole so as to not positively skew hole heights potentially caused by any piling of sediment during excavation. Hole widths were measured from where the slope went from essentially flat (0° to 1.5°) to inclined (>1.5°) on either side of the hole. This differed from the method used by Wall et al. (2011) so 2006 and 2009 hole heights and widths were recalculated from their respective bathymetry surfaces using the described approach. The slopes were calculated by dividing half the width by the height of the hole. The new measurements of the height, width, and slope of each hole were then averaged. Two t-tests were used to determine if the average structural components changed significantly between 2006–2009 and 2009–2017.

An aspect of the present study that was not part of Wall et al.'s (2011) work was the visual surveys completed in April 2017 in concert with the collection of the multibeam bathymetry dataset. These surveys were completed using a towed platform known as the Camera-Based Assessment Survey System (C-BASS; Lembke et al. 2017) which is towed at speeds of 3 to 4 knots as it collects continuous video and environmental sensor data near the seafloor (3 to 4 m high). Approximately four hours of seafloor imagery were collected along 27.1 km of transect throughout the grouper hole area in the SL-MPA (Fig. 3). The video was then analyzed for fish presence within and near each observed hole. All fishes observed in the imagery were enumerated and identified to the lowest taxonomic level possible. Any individual fish that was smaller than approximately the size of a bigeye (Priacanthidae spp.) or squirrelfish (Holocentridae spp.) was binned into a "Small NoID" (no identification) category. Example imagery from this survey is available as a video (S.1) which can be accessed via the online version of this article in the Supplemental Information section.

[Figure 3]

<C> Results

In Wall et al. (2011), 181 holes in 2006 and 231 holes in 2009 were detected from the multibeam bathymetry data within the area of overlap (Table 1). Using the 2017 multibeam bathymetry data, 3 m x 3 m grid, a total of 317 grouper holes were detected within the comparison area. This number increased to 340 when the 0.5 m x 0.5 m grid was analyzed. Within the 1.64 km^2 comparison area, this results in densities of 193 holes per km^2 and 207 holes per km^2 for the 3.0-meter and 0.5 m grids, respectively. These results indicate a trend of increasing hole density from 2006 to 2017.

[Table 1]

When the entire 2017, 0.5 m x 0.5 m grid bathymetry surface was considered, several areas containing grouper holes outside of the comparison boundary became apparent (Fig. 4) and a total of 456 holes were identified within this 8.5 km^2 area. The locations outside of the comparison area were concentrated to the north and west of its bounds with some just adjacent to its northwest and southeast borders. The broader 2017 dataset illustrates that the originally mapped region in 2006 and 2009 aptly covered the greatest concentration of grouper holes.

[Figure 4]

A total of 188 holes within the comparison area could be linked to holes measured in 2006 and 2009. Based on this subset, the average hole height in 2017 was similar to what was observed in 2006, but less than that estimated from the 2009 data (Table 2). The average widths of the holes decreased in 2009 from 2006 but then increased in size by 2017. The slopes of the holes increased from 2006 to 2009 but then decreased in 2017 and were more comparable to the 2006 average value. A t-test was used to evaluate statistically significant differences in the average height, width, and slopes between 2006–2009 and 2009–2017. All six pairs of average values were found to be significantly different within each category ($p<0.05$).

[Table 2]

When examining the individual changes in widths for each of the 188 holes from 2009 to 2017, a majority experienced a growth in size of approximately 2% to 39% of their width in 2009 (Table 3). For those that decreased in size, most shrank by 70% to 90%. The number of holes that were present in 2009 but not 2017, and vice versa, were also counted ("Filled In" and "Newly Formed"; Table 3). Overall, there was a greater number of newly formed holes (61) than filled in holes (31) by 2017.

[Table 3]

In the four hours of C-BASS imagery collected, a total of 95 holes were captured on film. Of these, 63 holes (~66%) had fish present and no fish were detected in the remaining 32 (Table 4; note: there were likely smaller-bodied fishes, such as Gobidaee spp. or Opistognathidae spp., present but which could not be observed from the towed platform). Of the 63 holes where the towed system imagery detected fish, 19 holes were observed to have Red Grouper present and 7 had an unidentified Grouper (Epinephelinae spp.) species individual (Table 4). This means that just over

40% of the holes observed had an Epinephelinae spp. individual present. Lastly, of the holes in which fish were detected, 84% (53 of the 63 holes) had at least one Lionfish (Pterois) spp. individual in or near the hole and approximately 35% (22 of the 63 holes) had more than two Lionfish spp. individuals present (Table 4). The maximum number of Lionfish spp. individuals observed within and near a single Red Grouper hole was 24 individuals.

[Table 4]

A more detailed look at each hole where fish were observed is presented in Table 5. There were frequently "Small NoID" individuals observed within these macrohabitats. Excluding Grouper spp. and Lionfish spp., bigeyes (Priacanthidae spp.) were the next most frequently encountered species with approximately 11% of the holes having at least one individual present. The other species of larger reef fishes (i.e. angelfishes (Pomacanthidae spp.), butterflyfishes (Chaetodontidae spp.), Red Snapper, and triggerfishes (Balistidae spp.) tended to be rarely observed on the C-BASS imagery with only 1% - 4% of the 95 holes seen having any detectable individuals.

[Table 5]

<D> Discussion

The work presented here was not an exhaustive study into the efficacy of Steamboat Lumps as a marine protected area. However, the results of this research in tandem with the work done by Wall et al. (2011) show that over the last 11 years, the density of Red Grouper holes has continued to increase within the boundaries of the study area. Though the SL-MPA was intended to protect spawning aggregations of Gag *Mycteroperca microlepis* (Coleman et al. 2004), we have documented that there are likely positive side-effects for the local Red Grouper population. This result is even more impactful when you consider that these holes are used by Red Grouper for spawning as well as habitation (Wall et al. 2011). As the Red Grouper population in the Gulf of Mexico continues to recover from past exploitation (SEDAR 2015), this can serve as an example of the importance of properly implemented marine protected areas. To truly comment on the efficacy of the SL-MPA to support a growing local population, data on Red Grouper populations and hole habitat outside of the MPA are necessary. A subsequent analysis to assess the level of illegal fishing that occurs within the SL-MPA (Gledhill and David 2004) could also help to determine if the increase in holes is in fact due to the effective protection of this habitat.

Although the density of holes within the SL-MPA appears to be increasing, analysis of the hole characteristics did not result in such a clear trend. The statistically significant changes in hole width, height, and slope between years demonstrates that these habitats are dynamic and experience significant growth and contraction on fairly short time scales (3 to 11 years). A longer time series is necessary to determine whether average hole widths, heights, and slopes increasing, decreasing, or if they go through continuous cycles of growth and reduction.

Despite an unquantifiable level of fish detection, the towed camera video survey showed that Red Grouper continue to persist in the SL-MPA and that several other species of reef fishes are commonly found among the Red Grouper holes. Work is ongoing to determine the species and habitat-specific "catchabilities" for the C-BASS. As such, these data cannot yet estimate the true densities of the observed reef fishes because we do not know how efficiently the C-BASS captured their presence within and near the holes in the SL-MPA. This limitation could be addressed in future endeavors by combining the towed camera work with a remotely operated vehicle (ROV). This type of visual survey equipment has significantly better maneuverability to allow for more extensive observations of the holes.

Though C-BASS's detection ability for most reef fishes is likely affected by reactive behavior, as is the case for visual surveys in general (Stoner et al. 2008), we believe that Lionfish spp. are an exception to this condition. Previous studies on Lionfish have reported how minimally reactive this species is towards divers, and that at times they can actually be fairly aggressive (Whitfield et al. 2007). Based on this information, and the hundreds of hours of C-BASS imagery that have been collected over the past five years where Lionfish are frequently observed, we believe that Lionfish are minimally reactive towards the system. It is important to note that Lionfish commonly reside in crevices and under overhanging rocks where towed video imagery cannot sample effectively. Therefore, the observations of Lionfish on C-BASS imagery are likely underestimated, but determining to what degree requires further habitat-specific surveys. Nonetheless, the Lionfish observations were a notable part of the towed camera work as nearly 85% of the 94 holes observed with the C-BASS had at least one Lionfish spp. individual present in or near the hole (Table 4).

The spread of Lionfish spp. began along the East Coast of Florida in the early 1980's (Morris, Jr. and Whitfield 2009) but this species wasn't detected in the Pulley Ridge MPA – an area ~400 km south of the SL-MPA – until 2010 (Harter et al. 2017). The last published study using a visual-based survey to evaluate the reef fishes found in the SL-MPA was completed in 2002, fifteen years prior to this 2017 survey (Gledhill and David 2004). The area was scheduled to be resurveyed in 2010 but due to funding issues, SL-MPA was removed from the cruise plan (David and Gledhill 2012). However, Lionfish were observed in 2013 from C-BASS video data collected in the SL-MPA grouper holes area (Grasty 2014). It is therefore likely that Lionfish spp. did not start colonizing the SL-MPA until after 2010, but took less than four years to populate the grouper holes.

Understanding the effects of invasive Lionfish spp. on the native reef fishes in the Gulf of Mexico and how to effectively address their impacts on the Gulf's ecosystems are ongoing endeavors for scientists and fisheries managers (Johnston et al. 2017; Marshak et al. 2018; Harris et al. 2019). A recent study on the grouper holes in the Pulley Ridge MPA by Harter et al. (2017) did not find conclusive evidence of a negative effect of the Lionfish spp. on the other reef fishes that were part of the assemblage. As they state in their work, this was an uncommon finding as other studies examining the impact of Lionfish spp. on the Atlantic, Caribbean, and Gulf of Mexico regions have found evidence to the contrary (Whitfield et al. 2007; Ballew et al. 2016; Hixon et al. 2016). The authors proposed that this apparent neutral existence of Lionfish with the native fishes may be due in part to high colonization of the holes by reef fishes resulting from potential high prey availability which could allow it to coexist with native species. Additional visual survey work in tandem with diet studies would be needed to assess if the same holds true for the grouper hole habitat in the SL-MPA.

Since towed systems can cover more area in a shorter amount of time than some tethered and autonomous platforms (Lembke et al. 2017), the C-BASS facilitated a quick means of collecting data on what species were observed among the holes (i.e. presence confirmation along the transect). Small modifications to towing operations of the C-BASS such as decreased towing speed and upgraded side cameras are expected to result in increased species resolution and potentially increased detection abilities of the larger reef fishes. However, C-BASS would still not be ideal for characterizing small reef fish populations and experiences some level of species-specific bias due to reactive behavior from the larger reef fishes. Additional video data from an ROV or stationary camera system survey are necessary to determine which holes are truly occupied vs. unoccupied, and to estimate the abundance of the other reef fishes. This additional methodology would complement C-BASS' ability to quickly assess the presence of larger reef fish, namely groupers, and the non-reactive, invasive Lionfish spp., and therefore provide a full analysis of the species composition in and near grouper holes. As we have demonstrated here, repetitive acoustic and visual surveys can be highly valuable for documenting and better understanding population changes over time, particularly in this critical dynamic habitat.

<E> Supplemental Information

Supplement: Video from the C-BASS (towed camera) survey in the SL-MPA in April 2017

Supplemental Video S.1. This video is a compilation of several clips of imagery that were collected with the C-BASS in the Steamboat Lumps MPA during the April 2017 survey. The clips presented in this video are examples of what the holes look like on towed camera footage and also depict typical Red Grouper *Epinephelus morio* encounters with the C-BASS. Each Red Grouper in the video has been indicated by a red circle and the playback has been slowed to 0.5x for easier viewing. Although they are present, no other species are indicated by the circles.

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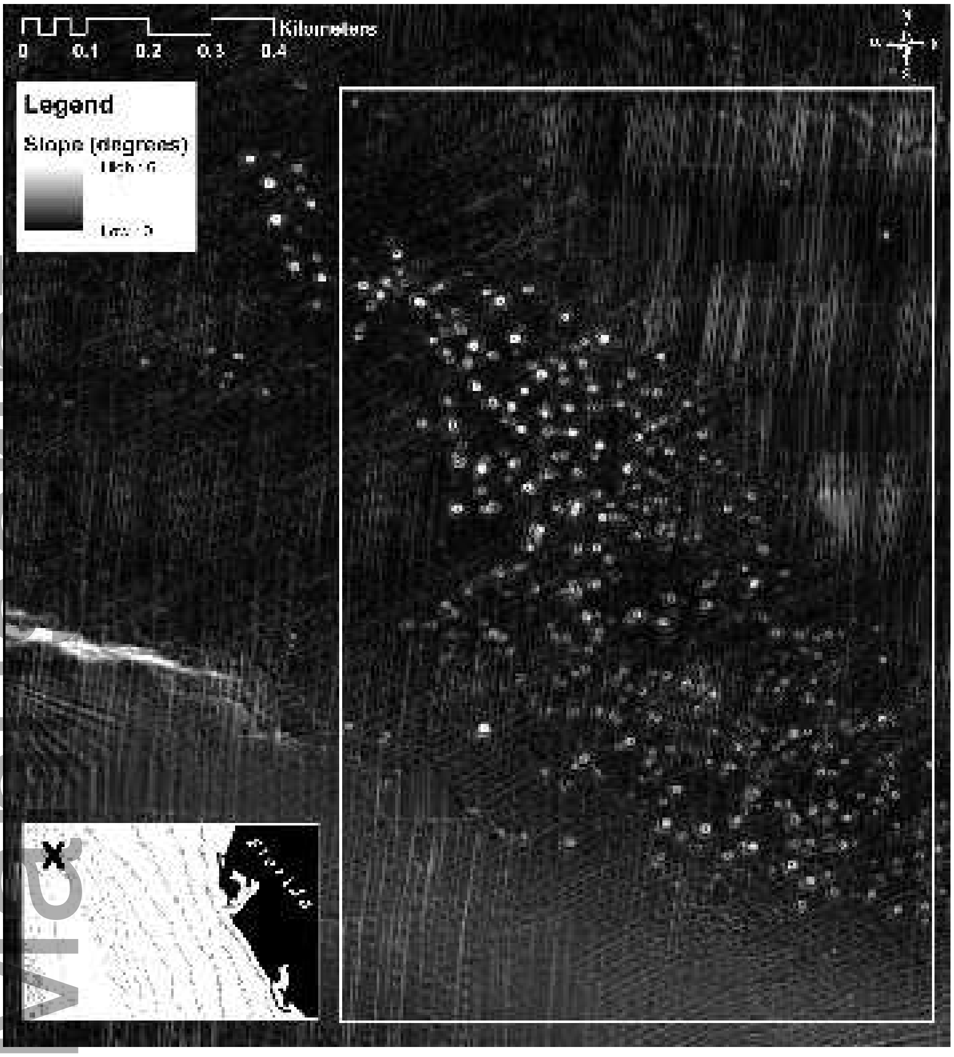

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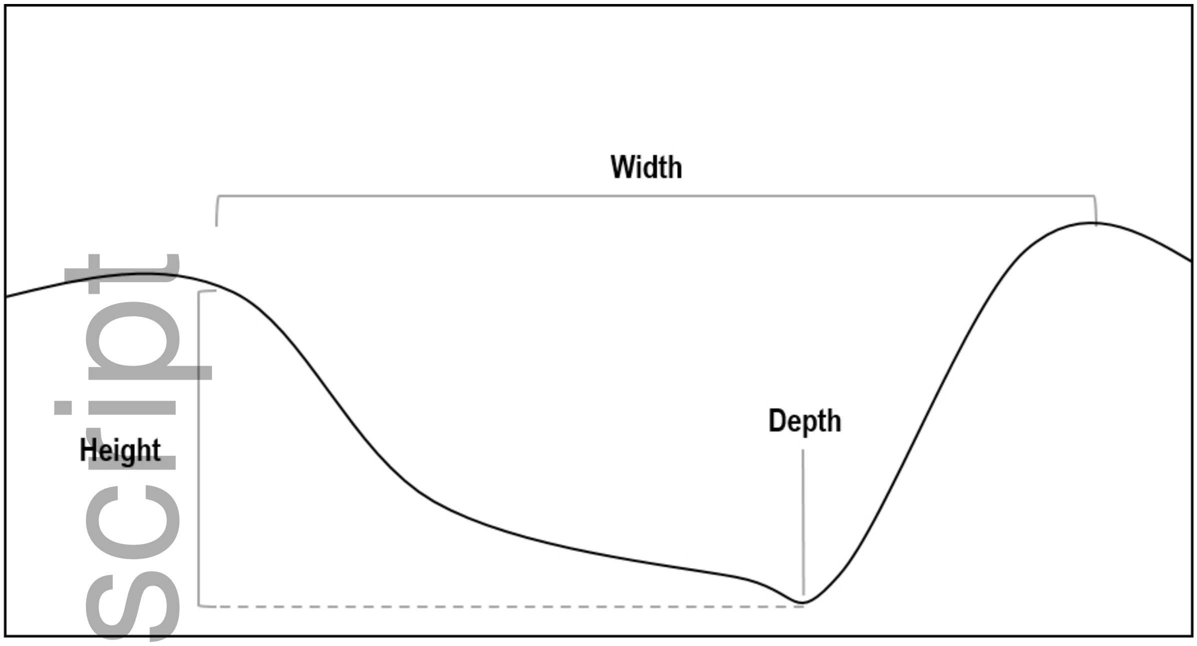

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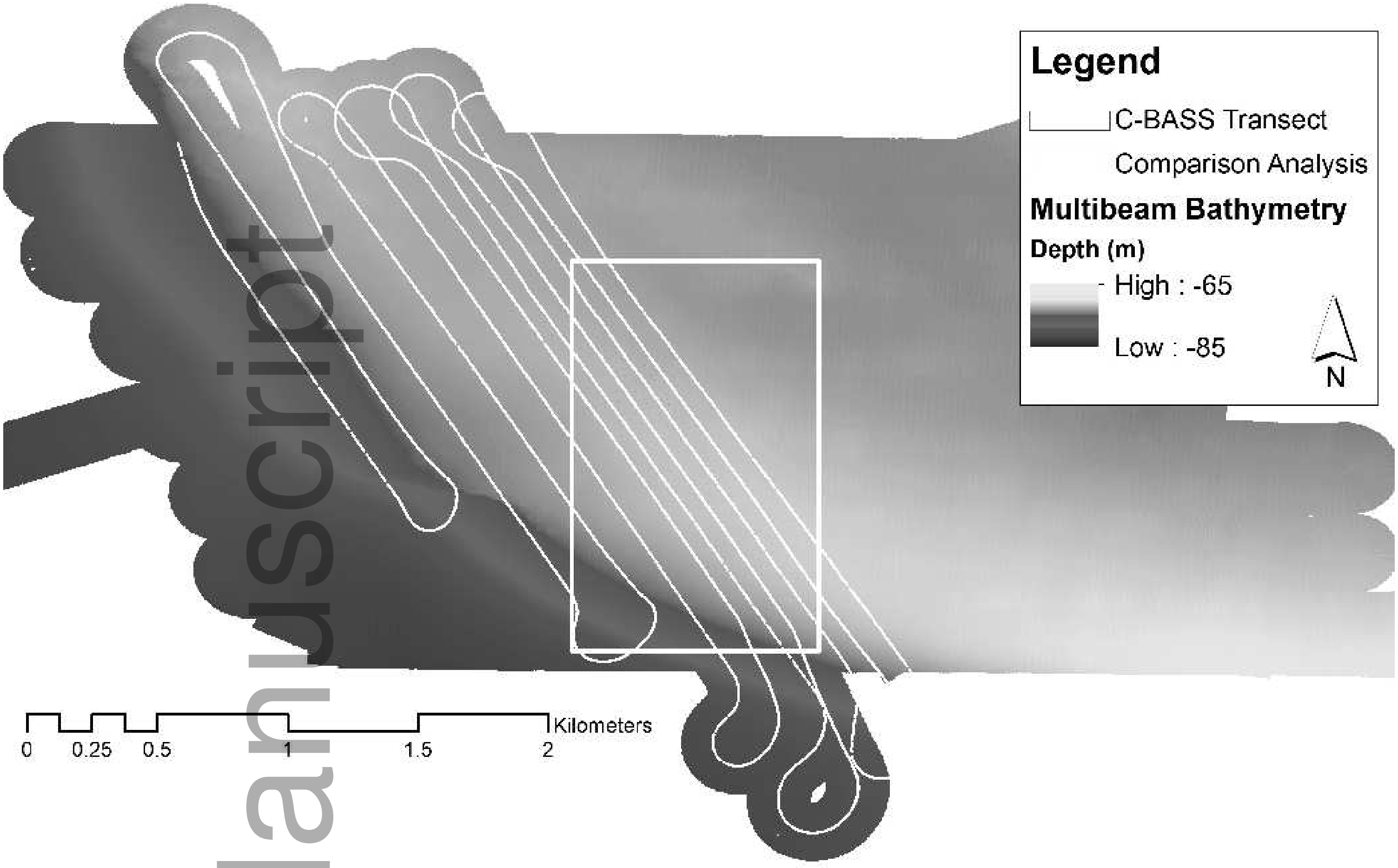

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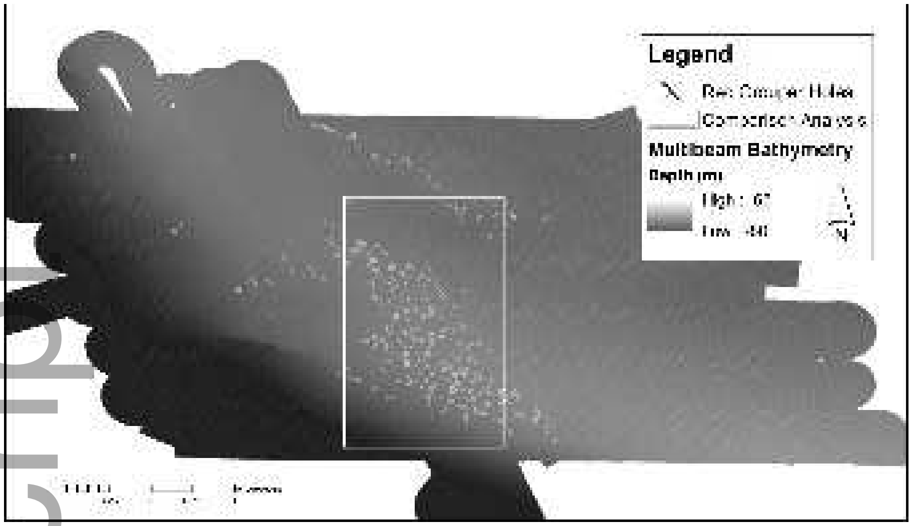

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