Tab E, No. 4(b)

TECHNIQUES FOR MINIMIZING DISCARD MORTALITY OF GOM OF MEXICO RED SNAPPER AND VALIDATING SURVIVAL WITH ACOUSTIC TELEMETRY

GRANT NA14NMF4720326

FINAL REPORT

Submitted To:
Derek Orner
NOAA Fisheries
1315 East-West Highway
Silver Spring, MD 20910

Submitted By:
Gregory W. Stunz, Ph.D.
Judson M. Curtis, Ph.D.
Alex Tompkins, B.S.

Harte Research Institute for GOM of Mexico Studies
Texas A&M University-Corpus Christi
6300 Ocean Drive
Corpus Christi, TX 78412

January 2017

ACKNOWLEDGMENTS

We are appreciative of the National Oceanographic and Atmospheric Administration (NOAA), Bycatch Reduction Engineering Program (BREP), for funding this study (**Grant # NA14NMF4720326**). We would like to thank the many people that contributed to the execution of this study and making it a success: members of the Center for Sportfish Science and Conservation in the Harte Research Institute for GOM of Mexico Studies at Texas A&M University-Corpus Christi: M. Ajemian, M. Robillard, J. Williams, J. Wetz, T. Topping, M. Streich, K. Gibson, C. Downey, Q. Hall, A. Ferguson, and D. Norris for logistical support and field assistance during tagging trials; D. Kehoe, P. O'Flaherty, and P. Sinnott at Lotek Wireless, Inc. for consultation during acoustic transmitter design and for technical support through the duration of the study; Dr. R. Vega, and R. Gamez at the Texas Parks and Wildlife Department, Flour Bluff Marine Development Center for providing facilities, personnel, and resources necessary for conducting preliminary Red Snapper tagging trials and troubleshooting.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

II. ABSTRACT

Mortality associated with regulatory discards of Gulf of Mexico Red Snapper fishery is a major impediment to stock recovery. The primary goal of this study was to determine if rapid recompression using descending devices or venting can effectively reduce barotrauma and increase year-round survival of Red Snapper in the Gulf of Mexico. Red snapper were externally tagged with ultrasonic coded acoustic transmitters containing built-in motion and pressure (i.e. depth) sensors to monitor post-release survival. Using the acoustic profiles generated from these data we compared the effects of temperature, depth, and three different methods of release. Our results showed that temperature was a significant factor in post-release survival, with summer released fish over 5.0 times as likely to perish as fish released in winter. Fishing depth was also a significant factor, with fish captured from 60 meters 3.9 times as likely to perish as fish captured at 40 meters depth. The method of release varied substantially and was dependent upon season and depth related factors. During winter, rapid recompression strategies using the fish descender were highly successful, with 100% survival at both depths. In summer, the fish descender performed well at 40 m depth, but did not perform any better than fish released nonvented at the surface at 60 m depth, and both these release treatments experienced low survival. Visuyal barotrauma impairment scores as a mean to predict mortality increased with depth, as expected, but reached a maximum value around 55 meters. Beyond this depth, barotrauma impairment decreased, likely due to catastrophic decompression events, whereby the swim bladder has ruptured and released the excess gas built up inside the fish to the environment. Thus, these events may mislead observers to conclude that the fish survived the catch-and-release process, when in fact the damage is likely irreversible and that fish undoubtedly will succumb to delayed mortality hours to days later as indicated by our acoustic telemetry data. Lastly, this project began provides information about the feasibility of incorporating descender devices in the recreational sector for frequent use by anglers and explored methods for integrating recreational anglers into the testing of these devices. Results from this project provide essential information about the effectiveness of various release devices in reducing discard mortality, which can be used to refine estimates used in current management models, and provide basic information about post-traumatic activity and mortality that would be applicable to numerous reef fish species.

III. EXECUTIVE SUMMARY

Red Snapper is considered the most economically important reef fish species in the Gulf of Mexico (GOM). Recent estimates show that the stock is still overfished, but is dramatically rebounding. While this recovery is certainly a positive outcome, this increase in stock biomass has resulted in larger fish being captured and high catch-per-unit-effort, which ironically, has resulted in shorter recreational fishing seasons, as annual catch limits are more quickly attained. As a result, Red Snapper captured out of the shortened season as bycatch may represent an estimated 75 – 98% of the total catch in the GOM. Furthermore, recent electronic monitoring data indicates that even during the recreational fishing season approximately 56% of Red Snapper are discarded. Ensuring that the fate of these regulatory discards is accurately documented is certainly essential to make accurate estimates of discard mortality for use in the stock assessment process. Certainly, finding effective release strategies that minimize injury, mortality, and sub-lethal effects, and maximize the chance of post-release survival is critical to the rebuilding of the stock.

The success of catch-and-release as a management strategy depends directly on fish experiencing high post-release survival. For some demersal, deep-water species, this may be difficult to achieve as post-release survival may be severely compromised by pressure-related injuries (i.e. barotrauma) caused by the rapid ascent to the surface associated with fishing activity. A prime example of this problem is presented by Red Snapper in the GOM, where short recreational fishing seasons and strict bag limits result in large numbers of discarded fish with a high risk of post-release mortality. Because of the depth preferences of these fish, individuals commonly experience reduced survival from a variety of factors including barotrauma-related injuries, release strategy, and environmental conditions. Two major techniques have been developed to reduce the damage resulting from decompression: rapidly recompressing a fish by returning it to depth (“rapid recompression”); and, puncturing the swim bladder with a hollow needle (“venting”) to release the pressure resulting from overexpansion. However, there is still much uncertainty over the best release practices for maximizing survival of discarded Red Snapper, and post-release mortality estimates remain far from conclusive due to the substantial variability in survival across depth, temperature, release type, fishing sector, and other factors.

The primary goal of this study was to determine if rapid recompression using forced decent or venting could effectively reduce barotrauma and increase year-round survival of Red Snapper in the northwestern GOM. Currently, there remains much work to be accomplished examining the potential interaction among season, depth, and rapid recompression type on discard survival. Using well-designed experimental studies, the specific objectives of this project were to: (1) Assess the impacts of discard release methods on Red Snapper survival with electronic tagging; (2) Assess the impacts of discard release methods on Red Snapper survival using fishery surveys; and (3) Partner with the fishing community to determine the best practices for releasing Red Snapper. Obviously, even though these devices show high promise in reduction mortality, the actual reduction in large-scale fishing mortality is dependent on their use by fishermen. Thus, a key aspect of this research project involved input from the GOM recreational fishing industry to help develop the most effective and efficient practices to reduce discard mortality and maximize the use in the fishery.

Red snapper were externally tagged with ultrasonic coded acoustic transmitters containing built-in motion and pressure (i.e. depth) sensors to monitor post-release survival. Using the acoustic profiles generated from these data, we compared the effects of temperature, depth, and three different methods of release. Our results showed that temperature was a significant factor in post-release survival, with summer released fish over 5.0 times as likely to perish as fish released in winter. Fishing depth was also a significant factor, with fish captured from 60 meters 3.9 times as likely to perish as fish captured at 40 meters depth. The method of release varied substantially and was dependent upon season and depth related factors. During winter, rapid recompression strategies using the fish descender were highly successful, with 100% survival at both depths. In summer, the fish descender performed well at 40 m depth, but did not perform any better than fish released nonvented at the surface at 60 m depth, and both these release treatments experienced low survival. It seems that perhaps there is a threshold depth during the warmer summer months whereby discard mortality will be high regardless of what release method is used, and attempts at mitigating this mortality using fish descender devices may not have high success.

Examining the impact of depth on barotrauma impairment using fishery surveys and scoring rubric, we found that barotrauma impairment increased with depth, as expected, but reached a maximum value around 55 meters. Beyond this depth, barotrauma impairment scores actually decreased, which was a most unexpected result. The resulting decrease in barotrauma related impairment was due to catastrophic decompression events, whereby the swim bladder has ruptured and released the excess gas built up inside the fish to the environment. Thus, leading to visual symptoms that were not longer present, despite mortal barotrauma injuries show by our acoustic observations. The release of these gases creates internal space for organs to return to their initial location prior to capture and the subsequent pressure change that is responsible for expanding the swim bladder, displacing the organs, and making them externally visible. Additionally, catastrophic decompression and the release of excess gas returns the fish to neutral (or negative) buoyancy, which allows the fish to submerge unassisted in many cases when discarded. Thus, using barotrauma scoring indices may mislead observers to conclude that the fish survived the catch-and-release process beyond certain depths, when in fact the damage is likely irreversible and that fish undoubtedly will succumb to delayed mortality hours to days later as indicated by our acoustic telemetry data.

We partnered with several organizations and entities to disseminate information on our experiences using fish descender devices and lay the groundwork for future development of collaborative efforts between scientists and the recreational fishing community. The use of SeaQualizers or other fish descending devices is only effective for reducing discard mortality for recreationally caught red snapper if recreational anglers use these devices. This project began gathering information about the use of descender devices in the recreational sector, and explored methods for integrating recreational anglers into the testing of these devices. We established a partnership with the organization FishSmart that is currently being further developed and will result in a large-scale survey and questionnaire that will be administered to recreational anglers, allowing them to provide useful fishery-dependent feedback on the utility of these devices for reducing discard mortality of red snapper and other reef fish species.

IV. PURPOSE

A. Description of the Problem

The world's fisheries have been the subject of much attention as one-third are overfished and 50% are fully exploited (Pauly et al. 2002), and overfishing has clearly contributed to their demise (Jackson et al. 2001). A prime example in the Gulf of Mexico (GOM) is the Red Snapper (*Lutjanus campechanus*) fishery, one of the most economically important fisheries in the region that has been classified as overfished since 1988 (Goodyear 1988). Overfishing of the Red Snapper population has recently ended for the GOM, but it still maintains an overfished status - a paramount concern for this fishery (Cowan 2011). Several management strategies have been employed to rebuild the stock (e.g. bag limits, size limits, trip quotas, and closed seasons), and the stock is showing signs of recovery. Currently, a 16 inch (40.6 cm) size limit is in place with a severely limited fishing season for recreational fishers (~ 45 d). As a voracious feeder, Red Snapper are routinely captured in and out of season. Originally, this catch consisted of large numbers of undersized fish resulting in a high rate of regulatory discards. Recently, as the population size is improving, even large live fish are often released. With a daily limit of only two fish, anglers often release legal-sized fish, seeking out the largest fish possible. In many instances, Red Snapper fishermen have a discard rate of up to 75% (Dorf 2003), resulting in a fishery characterized by frequent catch-and-release, as anglers release small individuals, cull "legal" fish for larger size, or catch snapper outside of the short season. Consequently, the number of regulatory discards is high. There is clearly an essential management need for information as to the discard mortality associated with these releases. However, the principal setback is the severe knowledge gap on how the mortality rate of these discarded fish could be affecting management of Red Snapper.

A major concern with releasing (i.e., discarding) Red Snapper is that fish routinely experience severe barotrauma from being quickly ascended from depth (Gitschlag and Renaud 1994; Burns et al. 2004; Rummer and Bennett 2005; Curtis et al. 2015). The resulting mortality can be highly variable and is considered to be depth-dependent. Previous research has found mortality rates between 36-48% for fish captured in depths greater than 30 m (Gitschlag and Renaud 1994; Burns et al. 2002). Previous model estimates for management purposes assumed a 40% mortality rate for the recreational fishery in the western GOM and 15% for the eastern GOM. Gulf-wide recreational averages were 27.5% for 1981-1996 and 21% for 1997-2002 and commercial fishery estimates were between 71% and 88% (SEDAR 2005).

Given that Red Snapper can live at depths in excess of 100 m, rapid ascent associated with fishing causes the fish to move from several atmospheres of pressure to surface pressure (1 atmosphere) in a few seconds. This expansion displaces and can damage the internal organs and then compresses them as the fish comes from greater depths (Rummer and Bennett 2005; Rummer 2007). Common physical effects also include everted stomachs, exophthalmia (eyes forced from orbits), forcing of the intestines out of the anus, and distortion of scales and subcutaneous flesh. Some barotrauma associated symptoms in Red Snapper can be relieved by returning the fish to depth; however, injuries associated with exophthalmia, rupturing of the swim bladder, or internal hematomas can result in delayed mortality or require extensive recovery time. During this time period, fish are likely more susceptible to predation or may experience periods of decreased growth due to reduced foraging ability.

Two major techniques have been developed to reduce the damage resulting from decompression: (1) rapidly recompressing a fish by returning it to depth (i.e., forced descent or "rapid recompression"); and, (2) puncturing the swim bladder with a hollow needle (i.e., venting) to release the pressure resulting from overexpansion. Previous research on forced descent recompression has concentrated on rockfishes (*Sebastes* spp.) and other deepwater species in the Pacific as a method of combating the effects of barotrauma caused by catch-and-release fishing (Hannah et al. 2008; Jarvis and Lowe 2008; Pribyl et al. 2011). The method of resolving barotrauma issues in rockfishes has been the use of fish descender hooks, which descend fish back to depth and release them when the weight hits bottom. Studies found that recompression of Pacific rockfish improved survival (Jarvis and Lowe 2008; Hochhalter and Reed 2011), and using a descender hook is a valid option to explore in decreasing mortality of species undergoing this type of capture stress. More recently, technological developments have created pressure-sensitive release devices (e.g. The SeaQualizer^{TM}) to avoid premature release of discarded fishes. However, this new technology remains to be tested experimentally against other release techniques in recreational fisheries of the GOM.

Unlike rapid decompression via forced descent, venting has had considerable use in the GOM recreational reef fish fisheries. Studies on the efficacy of venting have found variable results. Some showed the action was beneficial (Collins et al. 1999; Sumpton et al. 2008), while others consider venting as an ineffective tool for increasing survival (Render and Wilson 1994, 1996; Burns et al. 2002), or that there was not an effect either way (Lee 1992; Brown et al. 2010). Moreover, it is likely that the benefits of venting may differ among species and with conditions (water temperature, presence of predators, etc.). Proper venting technique is also probably a major factor in the practice's success in improving survival (Wilde 2009; Scyphers et al. 2013). After the 2008 federal mandate to vent all fish caught in federal waters, Red Snapper discard mortality was estimated to decrease to 10% in the recreational fishery and 68% in the commercial fishery (SEDAR 2013). However, it should be noted that these statistics made two major assumptions: 1) All fishermen were actually venting, and 2) Fish that swim out of sight of the angler indeed survived. Certainly, these key assumptions are in need of rigorous scientific investigation as they could great influence stock assessment conclusions. While these aforementioned results represent the best science available, the SEDAR process unraveled serious questions about the accuracy of these data (SEDAR 2013). Thus, a major recommendation was further documentation of the fate of discarded fish, especially on a long-term basis (Campbell et al. 2014).

While the efficacy of venting in reducing the effects of barotrauma remains controversial (Wilde 2009), our strong preliminary data from previous studies show both rapid recompression and venting may increase Red Snapper survival under certain conditions. With previous NOAA support, we experimentally simulated rapid ascent/descent of Red Snapper using very controlled conditions (i.e., temperature, no predators, etc.) in hyperbaric chambers. These experiments showed that both venting and descending fish can substantially increase the survival of captive individuals (Drumhiller et al. 2014). Similar positive, but less conclusive results were found in field studies using snapper fitted with motion (i.e., accelerometer) sensor acoustic transmitters (Curtis et al. 2015). However, these field studies pointed toward clear depth and temperature effects that required further scientific investigation.

These previous field experiments (Curtis et al. 2015) highlighted a potential issue that mortality may depend on season, with higher survival in winter months. The funding provided through this BREP grant enabled us to replicate our previous treatments to test additional hypotheses seasonally, and thus gain a much more comprehensive understanding. ***Accordingly, the primary goal of this study was to determine if rapid recompression using forced decent or venting could effectively reduce barotrauma and increase year-round survival of Red Snapper in the northwestern GOM.*** Currently, there remains much work to be accomplished examining the potential interaction among season, depth, and rapid recompression type on discard survival. Using well-designed experimental studies we addressed several key objectives that are outlined below. Obviously, whether these devices work (or not), the actual reduction in mortality is dependent on their use by fishermen. Thus, a key aspect of this research project involved input from the GOM recreational fishing industry to help develop the most effective and efficient practices to reduce discard mortality.

B. Objectives of the Project

The specific objectives of this study were to:

(1) Assess impacts of discard release methods on Red Snapper survival with electronic tagging.

(2) Assess impacts of discard release methods on Red Snapper survival with fishery surveys.

(3) Partner with the fishing community to determine the best practices for releasing Red Snapper.

V. APPROACH

A. Description of the Work Performed

Objective 1: Assess impacts of discard release methods on Red Snapper survival with electronic tagging

Preliminary Laboratory Studies

During the planning phase, it was determined that a different vendor (Lotek Wireless, Inc.) could provide acoustic transmitters that were better suited to answering our objectives for this particular project than the acoustic technology provided by Vemco as initially proposed. Specifically, acoustic transmitters provided by Lotek do not incur tag collisions, which allowed for greater numbers of fish to be tagged in a small area without signal interference. Furthermore, rapid transmission rates associated with Lotek tags provided more usable data during the initial post-tagging period. These two characteristics provided by Lotek tag technologies were much better suited towards answering our objectives regarding post-release mortality. In transitioning to this new vendor, we needed to perform a preliminary in-lab trial to test the new tag sensor technologies, determine the necessary tag size for an appropriate fish to tag weight ratio, and modify our external tagging protocol if necessary. Despite these not being an original objective written into the proposal, we thought it was necessary to conduct these preliminary in-lab trials to ensure these technologies would be suitable for answering our field tagging objectives. Six acoustic transmitters and two receivers were provided on loan by Lotek for preliminary testing of these tag technologies. These were either dummy (inactive) tags or had minimal battery life remaining. We additionally ordered two active tags with differing programmed specifications (e.g. motion sensor sensitivities) to determine which specification would be more appropriate.

Fish were collected using bandit reel gear equipped with five 11/0 circle hooks baited with Atlantic Mackerel (*Scomber scombrus*) in approximately 90-95 ft water depth at two sites: MI-686-A and MI-685-B (N27°57’, W96°32’). Sea surface temperature was 14°C. Fish were captured, de-hooked, and vented by puncturing in the abdomen posterior to the pectoral fin using a venting tool (Team Marine USA^{TM} pre-vent fish venting tool). Visible barotrauma symptoms and total length (mm) were recorded for each captured fish. These fish were then placed in one of two re-circulating live wells supplemented with oxygen flow (1/32 L•min^{-1}) onboard the research vessel. Seventeen fish were captured in total. Of these 17 fish, one perished at the surface, and one was intentionally discarded for exceeding desired size requirements. Fifteen fish were kept and transported to dock. At dock, fish were transferred from vessel live wells to a Texas Parks & Wildlife (TPWD) fingerling transport trailer in fish bags, and then transported to the TPWD Flour Bluff hatchery. At the hatchery, fish were recovered from transport tanks in a large rubber net, dipped for 1-2 min in a fresh-water bath to eliminate marine parasites, and placed into a 6400-L re-circulating holding tank set at 18°C and a salinity of 29 ppt. All fifteen fish survived transport from vessel to holding tanks.

After an acclimation period of one week, eight fish were captured from the hatchery tank using a net, fitted with a Lotek acoustic transmitter (see tagging protocol below), then released back into the same tank. Two fish were fitted with Vemco transmitters (one dummy tag and one sentinel tag), for comparison with Lotek tags, and also released back into the same tank. One Lotek acoustic receiver and one Vemco receiver were placed in the tank to record detections. Eight fish without transmitters remained in the holding tank (Figure 1). Fish were held in the hatchery tank for 30 d where they were fed to satiation three times weekly, and water conditions were monitored each day. After 30 d, all fish were euthanized in an ice slurry in accordance with American Fisheries Society standards (IACUC protocol #13-14). After removing fish from tank, active Lotek tags were fixed to stationary pipes in the tank to record acoustic detections for an additional three days. Acoustic receivers were then removed from the hatchery tank and data was downloaded using respective proprietary vendor software (WHS Host and VUE).

Figure 1. Hatchery tank where preliminary tagging trials occurred. A subset of Red Snapper were tagged with a variety of transmitters of varying size and specifications. Acoustic receivers (seen towards back of tank) recorded acoustic detections from the tagged fish and transmitters fixed to stationary poles.

Field Studies

The northwestern GOM of Mexico off the south Texas coastline contains predominantly soft, mud benthic habitat with small areas of isolated natural hard-bottom substrate. The major source of hard structure is provided by artificial reef habitats comprised of standing and reefed oil and natural gas platforms. Two artificial reefs approximately 30 and 45 km east of Port Aransas, Texas were selected as study sites for these experiments: site MI-712-A (approximately

N27°50’, W96°30’) resided at 40 m water depth and MI-A-7 (approximately N27°51’, W96°11’) at 60 m water depth (Figure 2). Three to four Lotek acoustic receivers were placed on each of these structures by scuba divers prior to the date of fish tagging. Once tagging was complete and acoustic tags had expired after approximately 17 days, these receivers were then retrieved by scuba divers.

Red snapper were caught at the two study sites with hook-and-line sampling gear using 5/0 circle hooks baited with squid (*Loligo sp.*) or rough scad (*Trachurus lathami*). Data recorded during fishing operations included hooking time, landing time, and release time allowing us to calculate overall fight time and handling time for each fish. Once landed, fish were measured for total length (mm) and assessed (presence/absence) for six externally visible barotrauma symptoms: everted stomachs, swollen and hard abdomen, exopthalmia (eyes forced from orbits), intestines protruding from the anus, formation of subcutaneous gas bubbles, and bleeding from the gills (Diamond and Campbell 2009). A barotrauma impairment score (scale: 0-1) was calculated by the sum of visible symptoms divided by the total number of possible symptoms (six). Fish that appeared moribund from severe barotrauma, foul, or deep hooking were not tagged.

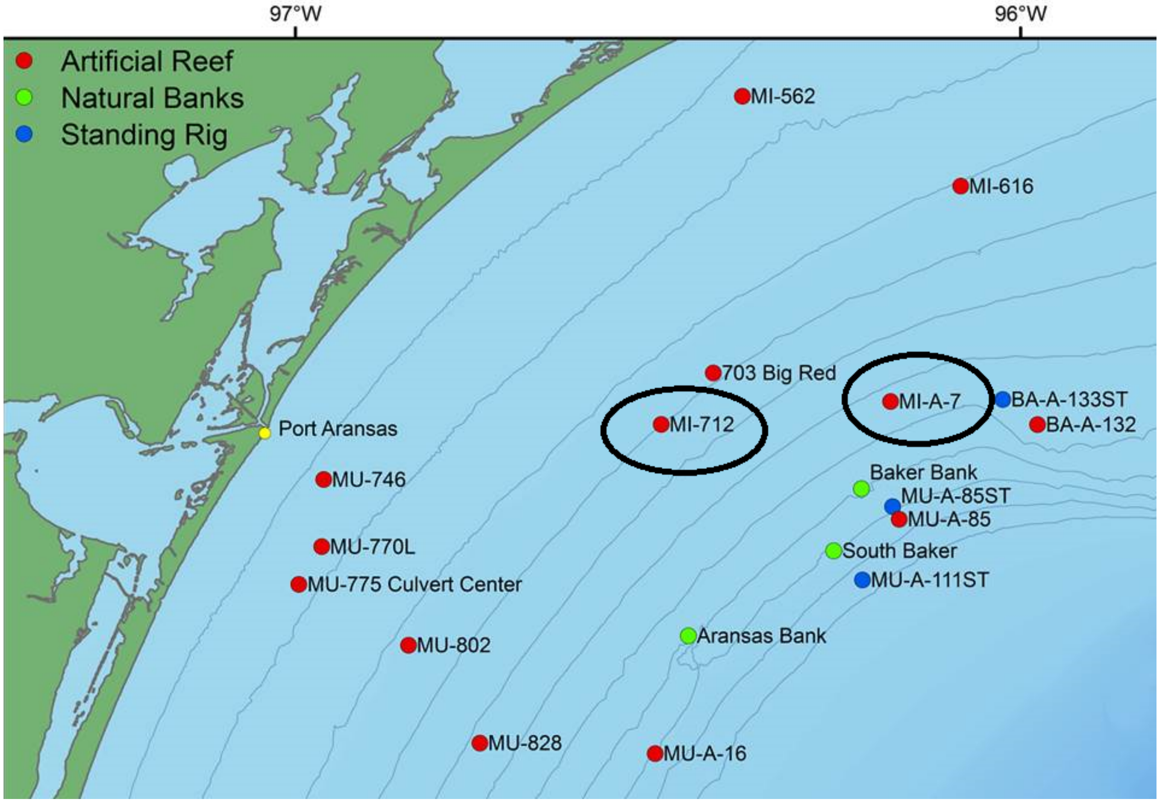


Figure 2. Map of the study sites (circled in black) in the Gulf of Mexico off the South Texas coast. Site MI-712-A (approximately N27°50’, W96°30’) resided at 40 m water depth and MI-A-7 (approximately N27°51’, W96°11’) at 60 m water depth.

Acoustic Tagging

Red snapper were externally tagged with Lotek dual-mode MR-series ultrasonic coded transmitters (Lotek Wireless, Inc., series MM-MR-11-45-PM, 46x9 mm, 76 kHz, ping interval: 3s, estimated battery life: 17 days) containing built-in motion and pressure (i.e. depth) sensors. Tag specifications (e.g. tag size, motion sensitivity, ping interval, etc.) were chosen based on preliminary laboratory studies conducted prior to field tagging. These tags are capable of rapid transmission rates (3/sec), but most importantly, do not incur tag collision issues, and can be programmed with pressure and motion sensors to monitor depth and activity of fish upon release. Depth is calculated by an algorithm that converts pressure sensors to a depth value (max depth <100 m). Since one goal of our study was to explore survival under a variety of release treatments, fish were rapidly (<3 min) tagged externally without anesthesia to best replicate recreational fishing practices and minimize artifacts associated with tagging related surgeries (i.e. venting and use of only survivors; IACUC protocol #13-14). To prevent unavoidable venting associated with traditional incision and suture internal tag implantation, we developed, and validated through in-lab trials, a protocol to attach tags to fish externally, and have successfully used this protocol in previous studies (Curtis et al. 2015; Johnson et al. 2015). Lab trials showed that tag presence did not impair fish behavior and that tag retention using our external attachment method was 100% for the month long study duration. Tags were positioned below the anterior (3rd-6th) dorsal spines approximately 2-3 cm below the dorsal edge. Fish were punctured between pterygiophores below the anterior dorsal spines using a sterile stainless steel hollow surgical needle. Tags were positioned below the anterior dorsal spines and attached with a plastic "cinch-up" external Floy® tag that is attached to the acoustic transmitter and passed between the 4th and 5th pterygiophores and secured. During the tagging procedure, fish were held in a tagging cradle with gills submerged in oxygenated water (Figure 3). An externally visible dart tag containing identification and reward information was also inserted into the posterior dorsal spine region.

Figure 3. Red Snapper positioned in tagging/measuring cradle with Lotek ultrasonic acoustic transmitter (MM-MR-11-45-PM) using external tagging procedures

Release treatments

Prior to tagging, fish were randomly assigned to one of three release treatments: (1) nonvented surface release (control), (2) vented surface release, and (3) descended release. Vented surface released fish were punctured in the abdomen posterior to the pectoral fin using a venting tool (Team Marine USA pre-vent fish venting tool – industry partner in the study) to allow escape of excess gas built up in the swim bladder. Once all residual gas had been vented, these fish were tagged and released at the surface. Nonvented surface release fish were not vented prior to tagging and then released at the surface, and acted as a control for venting and descending treatments. To descend fish, we used the SeaQualizer^{TM} (our other industry partner), a new forced descent tool that combines the utility of a low-impact (i.e., no penetrating hook necessary) "fish-grip" design with pressure-sensitive gauges that can disengage the grips at a pre-determined depth setting (~ 15, 30 or 50 m; **Error! Reference source not found.**). After a fish is captured, it is transferred to a separately dedicated rod and reel bearing a SeaQualizer device attached to a bottom weight. The SeaQualizer device is attached to the lower jaw of the fish and at the desired depth, a spring automatically opens the grips and releases the fish. This setup is one of several rapid recompression tools, which all attempt to return the fish to depth quickly to counteract the effects of barotrauma through rapid recompression of the swim bladder and without venting.

Figure 4. Picture of acoustically tagged Red Snapper being descended to depth on a weighted line using the SeaQualizer fish descender device.

Experimental design

Four tagging trials occurred over two seasons (summer and winter), and at two depths (40 and 60m). Thirty fish at each of the four trials were acoustically tagged and released using one of the three experimental treatments: nonvented, vented, and descended, with ten replicates being performed for each release treatment (Figure 5). During each of these trials, we measured water temperature at incremental depths using a Hydrolab DS-5 water quality multiprobe to detect the presence of thermoclines in the water column.

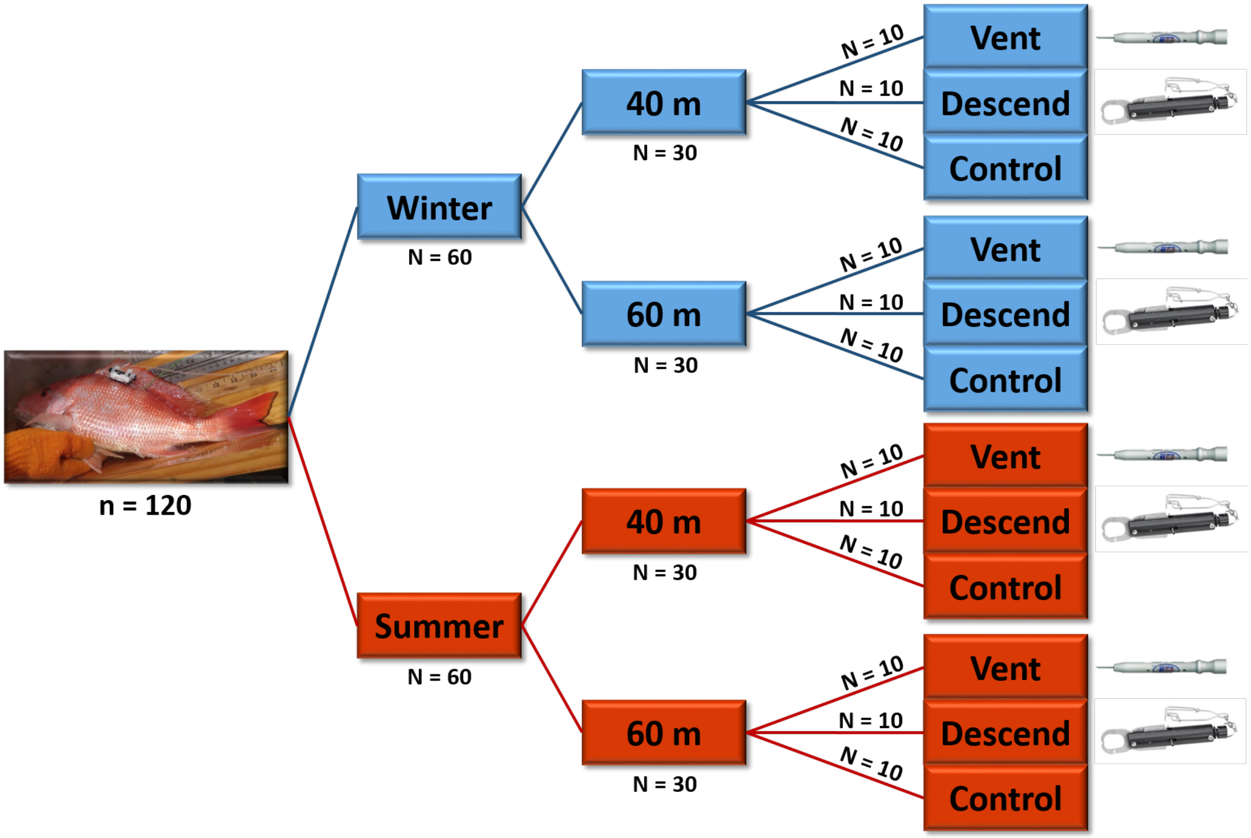


Figure 5. Experimental design of field tagging trials. Sixty fish were tagged in summer and sixty in winter. Within each season, thirty fish were tagged at 40m and thirty at 60m. Ten fish were replicated at each treatment level - vented, descended, and control (nonvented) within each depth.

Fate classification

Acoustic receivers were retrieved from study sites approximately one month after acoustic tags expired and data were uploaded to Lotek WHS Host software and then exported into the statistical program R for analysis (R Development Core Team 2016). Motion and depth profiles for each fish plotting these values over time were generated using tag sensor data. Using these unique acoustic profiles, the fate of each individual was classified into one of three categories: survival, delayed mortality, or emigration. Fish classified as survivors exhibited continuous detections after release, with frequent changes in vertical depth movements in the water column. Delayed mortality events were classified by initially active motion and depth movements followed by a sudden drop-off to depth equal to the seafloor bottom. Fish that emigrated from the array were not included in final survival calculations, as they did not remain in the acoustic array for sufficient duration of time to be informative with high confidence for fate classification. This results in survival estimates that are err on the more conservative side. If we considered half of the emigrants to be survivors (also likely conservative), survival estimates would be much higher; however, we wanted to use a precautionary approach and use only fish with absolute known fates, which provides the more conservative estimates of survival.

Survival analysis

Percent survival was calculated using the binomial distribution for two outcomes: survival and mortality. Survival estimates ($\hat{S}$) were calculated following equations in (Pollock and Pine 2007):

$$\hat{S} = \frac{x}{n}$$

with a standard error of:

$$SE(\hat{S}) = \sqrt{\frac{\hat{S}(1-\hat{S})}{n}}$$

where x is the number of survivors, and n is the total number of tagged fish minus the fish classified as emigrants for each treatment level.

The probability of survival post catch-and-release was calculated using the product limit estimate (Kaplan and Meier 1958) built into the ‘survival’ package in R (Therneau and Grambsch 2000). At each time interval (day), survival probability is calculated by dividing the number of survivors (x_i) by the number of individuals at risk (n_i). The Kaplan-Meier estimate of total survival probability ($\widehat{K}$) is calculated by multiplying all probabilities of survival at all time intervals preceding the time interval of interest:

$$\widehat{K}(i) = \prod_{i=1}^{j} (1 - x_i/n_i)$$

The Cox proportional hazards model (Cox 1972), also built into the ‘survival’ package in R (Therneau and Grambsch 2000), was used to examine the relationship between survival and multiple explanatory variables. This model has been used extensively in public health studies but has only recently been applied to survival analysis in fisheries (Sauls 2014; Curtis et al. 2015). The Cox model is a semi-parametric regression method for survival data. It provides an estimate of the treatment effect on survival after adjustment for other covariates in the model and gives an estimation of the hazard ratio (in this case the proportional risk of death) among levels within each of these explanatory variables. For survival analysis, this method is advantageous over logistic regression models because it can account for survival times and censored data, whereas regression models do not. Additionally, hazard ratios between covariates may be estimated without needing to specify the underlying baseline hazard, which may not be known. The Cox proportional hazards model is given by:

$$h(t) = h_0(t)\exp\left(\sum_{i=1}^{p} \beta_i X_i\right)$$

where $h_0(t)$ is an unspecified function representing the baseline hazard, β_i are regression coefficients, and X_i are the explanatory variables or covariates in the model. The three covariates used in the Cox proportional hazards model for this study were release method, season, and depth.

Objective 2: Assess impacts of discard release methods on Red Snapper survival with fishery surveys.

Barotrauma assessment

We used standardized vertical longline (VLL) gear (a.k.a. handline, or bandit gear) to rapidly target and collect red snapper to assess the extent of barotrauma impairment related to depth and temperature. Vertical longline sampling allows for direct quantification of fish (via catch) and is a method already extensively used by many GOM SEAMAP partners to develop long standing time series of catch data. Additionally, vertical longline represents the most common harvest gear in the commercial fishery for Red Snapper, so impairment scenarios encountered by our VLL sampling would be reflective of barotrauma impairment experienced in the fishery. Our VLL sampling design follows the SEAMAP protocol and uses multiple hook sizes to capture various size classes of reef fish, with Red Snapper being the most commonly caught species (>90% of catch). We have been conducting VLL surveys since 2013 as part of a concurrent fishery-independent sampling and monitoring program funded by Texas Parks & Wildlife, and have been collecting barotrauma impairment data along with these sampling events that we will use to assess depth related effects on barotrauma impairment and discard mortality. Most of these earlier surveys occurred during summer months at a range of depths; however, more targeted efforts to maintain a winter/summer balance were conducted in 2015 in concurrence with this BREP project, enabling us to incorporate any seasonal (temperature) effects regarding barotrauma effects into the longer-term dataset.

The gear configuration and sampling procedure described below have been adopted by NOAA SEAMAP as a standardized method for vertical longline sampling throughout the GOM. The mainline is 167 m of 400 lb (181kg) test with a 6/0 Rosco snap swivel crimped onto the end. The backbone is 6.5m of 300 lb (136kg) test monofilament. The top of the backbone has a crimped loop to attach the 6/0 Rosco snap swivel from the mainline and the bottom of the backbone has a 2/0 Rosco snap swivel to attach a 4 kg sash weight. The crimps used at the top and bottom of the backbone are 2.3 mm double copper crimp sleeves. Ten gangions are attached to the backbone described above. Each gangion is has a total length of 45.72 cm (18 inches). Gangions are made using 100 lb. test camouflage monofilament twisted together, terminating in one of 3 hook sizes: 8/0, 11/0 and 15/0. All gangions are baited with a piece of Atlantic mackerel (*Scomber scombrus*), cut proportionally to the size of the hook. The vertical longline is fished for 5 minutes. After the five minute soak period, the gear is brought to the surface, and the status of each hook recorded (species caught, bait present, or bait absent). All fish present will be removed from their respective hooks (1-10, shallowest to deepest), and length (standard length, fork length and stretch total length) will be recorded. Fish were then assessed (presence/absence) for six externally visible barotrauma symptoms: everted stomachs, swollen and hard abdomen, exopthalmia (eyes forced from orbits), intestines protruding from the anus, formation of subcutaneous gas bubbles, and bleeding from the gills (Diamond and Campbell 2009). A barotrauma impairment score (scale: 0-1) was calculated by the sum of visible symptoms divided by the total number of possible symptoms (six). Once impairment scores were obtained, fish were placed on ice for further processing for a variety of other projects.

Fishery-based recaptures

In addition to the VLL survey data assessing barotrauma impairment, this project had several fishery-based opportunities to monitor post-release survival and site fidelity of discarded Red Snapper. The two sites used in this project are fished both by recreational anglers during the recreational season and by commercial fishermen year-round. These individuals had an opportunity to recapture and report our 119 externally tagged animals, which provided important survival information. Recapture events are extremely useful in determining movement and survival of tagged fish, and for this project, helps us corroborate the acoustic detection data and fate classification used during tagging trials.

Objective 3: Partner with the fishing community to determine the best practices for releasing Red Snapper.

Engagement with the recreational fishing community

In order to engage the recreational fishing community, partnerships and collaborations were formed with various sportfishing entities. FishSmart, a program that promotes smart catch-and-release fishing, donated over one-thousand SeaQualizers for distribution to recreational anglers in the southeast Atlantic and Gulf of Mexico. Devices were primarily distributed by state agencies at fishing tournaments and dockside creel stations, and online at FishSmart's website. Additional to the free SeaQualizer, participating anglers received a best-use practices pamphlet explaining proper fish handling, release procedures, and device operation. We partnered with the Corpus Christi Big Game Fishing Club (CCBGFC) to distribute SeaQualizers to Texas offshore recreational anglers at various club gatherings. A graduate student from our group attended biweekly tournaments hosted by the CCBGFC to distribute SeaQualizers to willing anglers and promote the use of rapid recompression devices. Additional SeaQualizers and best-use practice pamphlets were distributed at meetings held by the Port Aransas Boatmen's Association, an entity comprised of both private anglers and offshore charter captains. Various fishing club banquets and dinners were attended by staff from our group to promote rapid recompression devices and disseminate best-use practices for catch-and-release fishing of deep sea fish.

Our group is highly active on various social media outlets such as Facebook and Twitter. Posts discussing rapid recompression devices and discard mortality issues were distributed via these outlets. Using these indiscriminate methods of disseminating information, thousands of people are reached directly and indirectly by our social media postings. Using a social media professional, metrics describing the total outreach footprint of our social media postings were compiled for both Facebook and Twitter.

Scientist ride-along trips to assess descender device performance

Members from our group participated in observer trips aboard offshore recreational angling vessels. These observer trips assessed the utility and angler perceptions of the SeaQualizer rapid recompression device. The captain of each observed vessel was given a free SeaQualizer to keep and use on the trip as part of the FishSmart collaboration effort. During the observer trips, various data were collected such as fishing location, fishing depth, structure type, rod-and-reel fight times, time fish spent on deck, species captured, degree of barotrauma, total lengths of fish, and angler perceptions on the SeaQualizer. Both quantitative and qualitative data were collected to assess rapid recompression device performance and angler perceptions on the feasibility of using the devices on normal fishing excursions. Barotrauma reflex scores (BtR) were assigned to fish by dividing the total number of visible barotrauma symptoms by six, the total number of possible visible barotrauma symptoms. Observer trips were performed on private fishing vessels, one guided vessel with a federal reef fish permit, and one headboat. Private vessels were offered fuel compensation and guided vessels were offered a $250 cash compensation for each observer. Headboats were compensated by purchasing a ticket for each observer attending the trip.

Survey development

After discussing with anglers to obtain their perceptions of rapid recompression devices, team members compiled a list of questions to distribute to SeaQualizer recipients via a short online survey. The questionnaire aimed to assess anglers' previous knowledge of rapid recompression devices and their perceptions on the feasibility of using them on a normal fishing trip. Additional questions assessed how often anglers were using their SeaQualizer and to what extent they are successful in reducing discard mortality.

iSnapper discard data

Our group and several others developed a smartphone application, iSnapper, responsible for collecting catch data from both federally and state managed fisheries. Anglers can report their catches and discards through a user-friendly interface compatible with most smartphone operating systems. One component of the reporting process includes a section where users can report both the number of discards and the release method for each discard from the fishing trip. This ancillary method of data collection can provide key data on various release methods anglers are employing to improve post-release survival.

B. Project Management

Gregory W. Stunz, Ph.D., Endowed Chair - Fisheries and Ocean Health, Director at Center for Sportfish Science and Conservation, and Professor of Marine Biology, was Principal Investigator of the project. Dr. Stunz was in charge of overall project oversight, dissemination of findings, and coordination between TAMU-CC and cooperative partners on this project. He co-authored all progress reports and the final report.

Judson M. Curtis, Ph.D., Assistant Research Scientist at Center for Sportfish Science and Conservation was the project's lead scientist, and was in charge of executing day-to-day operations for all preliminary laboratory trials and field tagging experiments, training students, analysis of results, and dissemination of findings including submitting manuscripts to peer-reviewed scientific journals. He co-authored all progress reports and the final report.

Alex Tompkins, M.S. Student, was responsible for assisting with preliminary laboratory trials and field tagging experiments. He also was instrumental in the partnerships with the fishing community by engaging recreational anglers, and gathering feedback on the use of descender devices by recreational anglers.

Monitoring of Project Performance:
Greg Stunz, Ph.D. monitored the project performance throughout the award period and submitted semi-annual progress reports to the NMFS program officer Derek Orner as required. Performance and financial administration was also conducted by the Office of Sponsored Research Administration at Texas A&M University-Corpus Christi.

VI. FINDINGS

A. Actual Accomplishments and Findings

Objective 1: Assess impacts of discard release methods on Red Snapper survival with electronic tagging.

Preliminary Laboratory Studies

All fifteen red snapper survived the 30 d holding period in the hatchery tank, and exhibited healthy activity and feeding behavior during this entire time period. Acoustic detections were downloaded for both Vemco and Lotek acoustic receivers and the performance of these two vendors was compared. Basic tag specification comparisons and results from the in-lab trials are presented in **Table 1.** Fish total lengths for fish used in the in-lab trials were 496 ± 15 mm (mean ± SE), and the handling times ranged between 1:27 to 5:15. Vemco V13 dummy tags were used for the first several tagged individuals to develop proficiency using the new tag attachment method. After proficiency was acquired, active tags were attached to fish. The tag to body weight ratio did not exceed 2.0%.

Table 1. Acoustic transmitter specifications for the preliminary in-lab tag testing. Transmitters were a mixed bag of dummy and active tags of varying sizes from Lotek and Vemco vendors. Key: "Tag wt" = tag weight in grams; "Lotek B.I." = ping interval in seconds elapsed of Lotek tags; "Vemco B.I." = ping interval in seconds elapsed of Vemco tags; "Sensitivity" = motion sensor sensitivity; "Fish TL" = fish total length in mm; "Handling time" = elapsed time taken from capture of fish, attachment of acoustic tag, and return to tank; "Tag:Body wt" = tag to body weight ratio in air.

Tag Specifications						Preliminary Tagging Trials			Data Analysis	
Vendor	Tag Name	Tag wt (g)	Lotek B. I. (s)	Vemco B. I. (s)	Sensitivity	Fish TL (mm)	Handling time	Tag:Body wt (air)	Vemco Detections	Lotek Detections
Lotek	MM-MR-8-SO	6	10	60	n/a	445	1:27	0.5%	0	0
Lotek	MM-MR-11-45	17	5	30	n/a	475	2:08	1.2%	18834	117793
Lotek	MM-MR-11-45	17	5	30	n/a	485	2:55	1.1%	17034	131733
Lotek	MM-M-16-25-TP	29	2	n/a	n/a	540	4:30	1.4%	n/a	n/a
Lotek	MM-R-16-50	35	n/a	60	n/a	510	3:19	2.0%	12307	n/a
Lotek	MM-MR-16-50-PM	35	5	60	5 (max)	560	2:22	1.5%	5366	119437
Lotek	MM-MR-16-25-PM	29	3	240	5 (max)	500	3:02	1.7%	1477	101109
Lotek	MM-MR-16-25-PM	29	3	240	1 (min)	525	2:07	1.5%	2256	118455
Vemco	Vemco V13 dummy	12.3	n/a	n/a	n/a	425	5:15	1.2%	n/a	n/a
Vemco	Vemco Sentinel tag	12.3	n/a	60	n/a	n/a	n/a	n/a	19639	n/a

Lotek transmitters tested included a range of sizes (6 – 35 g) and ping intervals (2 – 10 s). Some Lotek tags operate on a dual frequency (69 and 76 kHz), which enables them to be detected by either Vemco or Lotek receivers. Vemco transmitters operate solely on the 69 kHz frequency. These dual mode tags were extremely useful and informative for comparing these two vendor technologies, and the results generated from these tags in particular comprised the basis for our decision to use Lotek transmitters moving forward in the field experiments. Our group has extensive experience with Vemco transmitters and knew the capabilities of these transmitters; thus, minimal Vemco transmitters were used during these particular trials, as the main focus was to test the novel Lotek technologies and determine their applicability and feasibility for answering our objectives. Data analysis showed that the dual mode tags we tested (Tag names: MM-MR-11-45 and MM-MR-16-50-PM) capable of transmitting Lotek frequencies as fast as every 5 s (compared to every 30 s for Vemco frequencies), generated around 10x as many detections on Lotek receivers as Vemco receivers over the same time period (**Figure 6**; **Table 1**). The rapid ping interval coupled with the ability to avoid tag collisions were two key specifications that were determining factors in our decision to use Lotek transmitters. Given that discard morality typically occurs within the first 72 hours post-release (Curtis et al. 2015), it was vital to obtain as many possible data points within this critical time period and Lotek transmitters provided this capability.

We also conducted a sensitivity analysis with the motion sensors built into the Lotek transmitters. Two transmitters (MM-MR-16-25-PM) were identical in all specifications except one contained the most sensitive motion sensor configuration and the other contained the least sensitive configuration. A third, larger transmitter (MM-MR-16-50) was included in the analysis for additional validation. Once all fish had been removed from the hatchery tank, acoustic transmitters with motion sensors were placed at the bottom of the hatchery tank and left for one day. After approximately a 24-hr period (~ 11:00), all transmitters were then fixed to a stationary pole in the hatchery tank. Motion sensors report a binary output – active or rest. The maximum sensitivity transmitters reported several periods of 'active' motion while fixed to the stationary pole (**Figure 7**). The least sensitive transmitter continuously reported 'rest' motion once it was affixed to the pole. From these results, we concluded that it was necessary to use the least sensitive transmitter configuration for our field tagging experiments, in order to ensure that fish experiencing delayed mortality and residing on the seafloor would not be mistakenly classified as still alive due to an erroneous 'active' motion sensor. The fate classification would be further corroborated by the depth sensor information, which proved to be much more valuable than the motion sensors once field studies were completed.

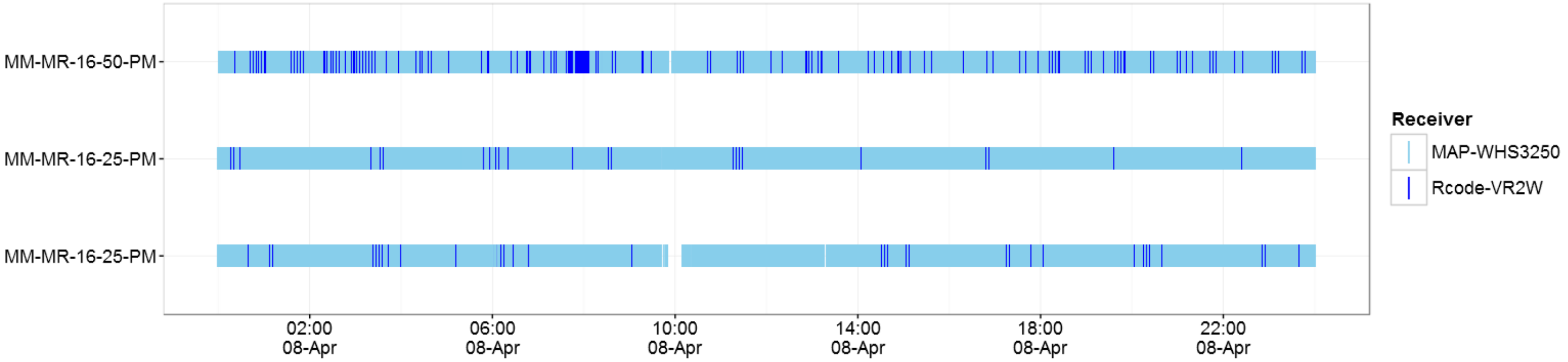


Figure 6. Acoustic transmitter data from preliminary in-lab trials that shows the number of detections over a 24-hr period (08-Apr) for three acoustic transmitters capable of producing frequencies detectable by both vendors. MAP-WHS3250 represents acoustic data detected by Lotek receivers, and Rcode-VR2W represents acoustic data detected by Vemco receivers.

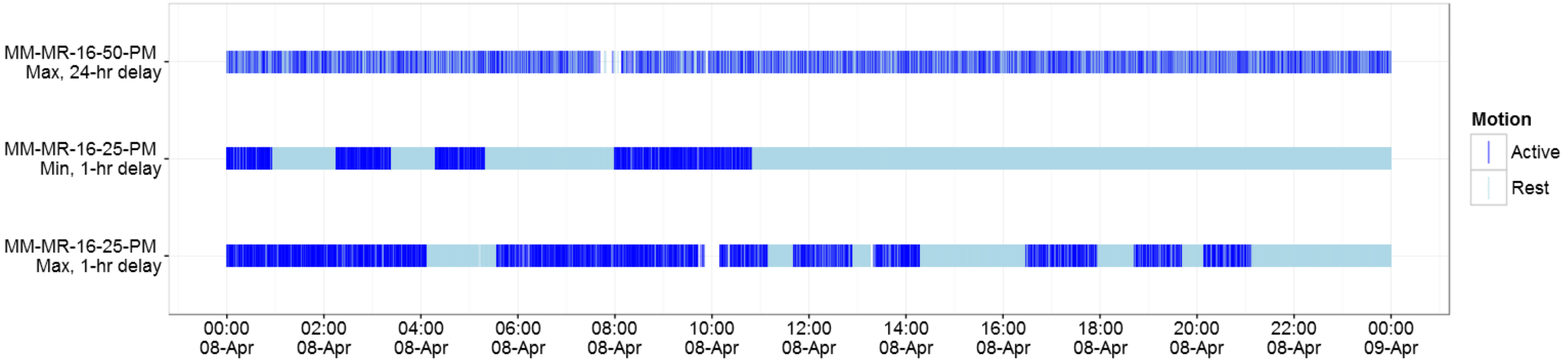
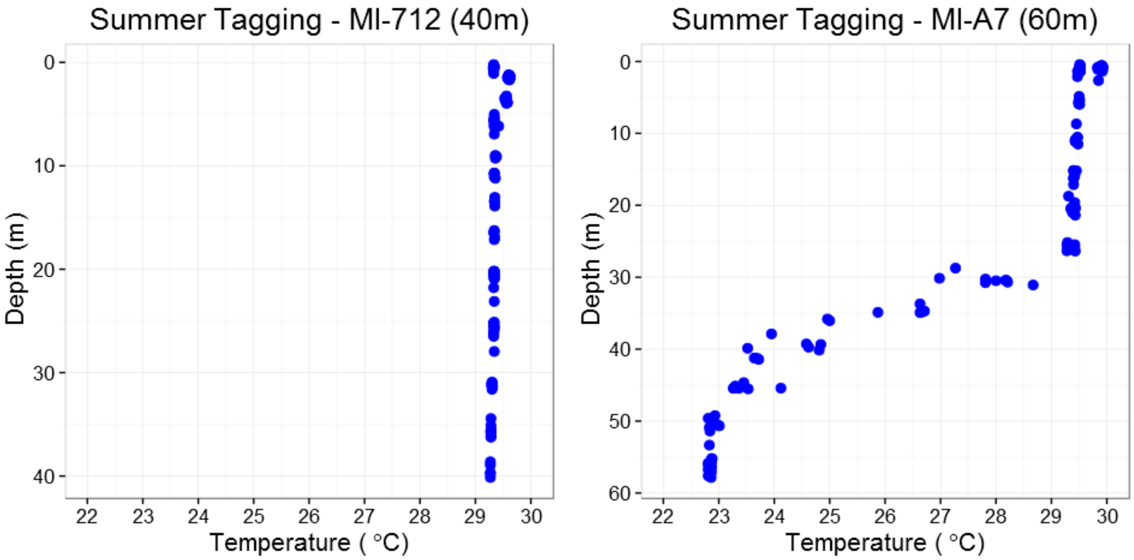


Figure 7. Motion sensitivity analysis test from preliminary in-lab trials showing the number of acoustic detections registered as 'active' versus 'rest'. The three acoustic transmitters represented were equipped with motion sensors with differing tag specifications and sensitivities.

Field Tagging

For each of the four tagging trials, water temperature was measured at various depth intervals to determine, if any, thermoclines existed in the water column (**Figure 8**). During summer tagging, we saw a significant thermocline at the 60 m site (MI-A-7), with water temperatures at the surface measuring 29ºC and measuring 23ºC at the seafloor, and the thermocline beginning at approximately 30 m depth. We saw a well-mixed water column of 29ºC with no thermocline present at the shallower 40 m site (MI-712-A). The lack of a thermocline at this depth was unexpected as typically we have seen substantial thermoclines develop around 25-30 m at these 40 m sites in previous CTD profiles. During winter tagging trials at the 60 m site, we saw a fairly well-mixed water column, with a surface temperature of 19ºC and a bottom temperature of 20ºC. At the shallower 40 m site, we saw a reverse thermocline, with surface water temperature of 17.5ºC increasing to 20ºC at the seafloor, with the thermocline beginning around 20 m depth. This reverse thermocline is typical of late winter months in this area as colder, nearshore waters stratify over the warmer deep water layer in the absence of high activity storms that mix the water column and homogenize the temperature.



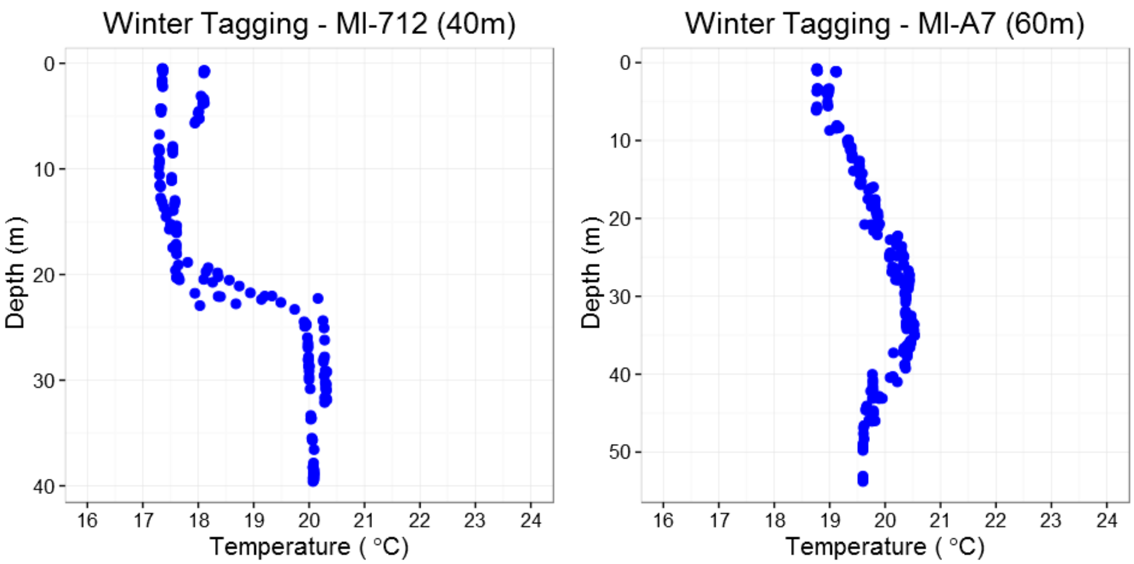


Figure 8. Water temperature by depth profiles on dates of tagging trials for each depth (40m or 60 m) and season (summer or winter). Note: range of x-axis and y-axis values differ depending on season and depth. Data collected using a Hydrolab DS-5 water quality multiprobe.

Red snapper tagged during summer trials measured 534.8 ± 6.1 mm (mean ± standard error), and 545.2 ± 6.0 mm during winter trials. There were no significant differences between season (Anova, p = 0.231), between site (p = 0.980), among any of the three release treatments (p = 0.776), or any of the interactions between these variables (**Figure 9**). Because of this equal size distribution, total length was not considered as a factor in survival models. We measured barotrauma impairment scores for each fish prior to tagging to determine the effect of barotrauma on survival estimation. There was not a significant difference in barotrauma impairment for fish tagged between season (Anova, p = 0.254), or depth (p = 0.146). Fish averaged an impairment score of 0.30 ± 0.01 (mean ± standard error). The most typical symptoms exhibited were hard abdomen, followed by an everted stomach. These two symptoms seem to be the least harmful and most reversible. More severe symptoms including exopthalmia or gas bubbling from scales were usually followed by quick mortality on deck or upon release at the surface. These fish were not used for tagging experiments, as the focal point was obtaining delayed mortality information using various release treatments. Furthermore, any fish that were not hooked in the side of the mouth were discarded without tagging to control for latent hook related mortality.

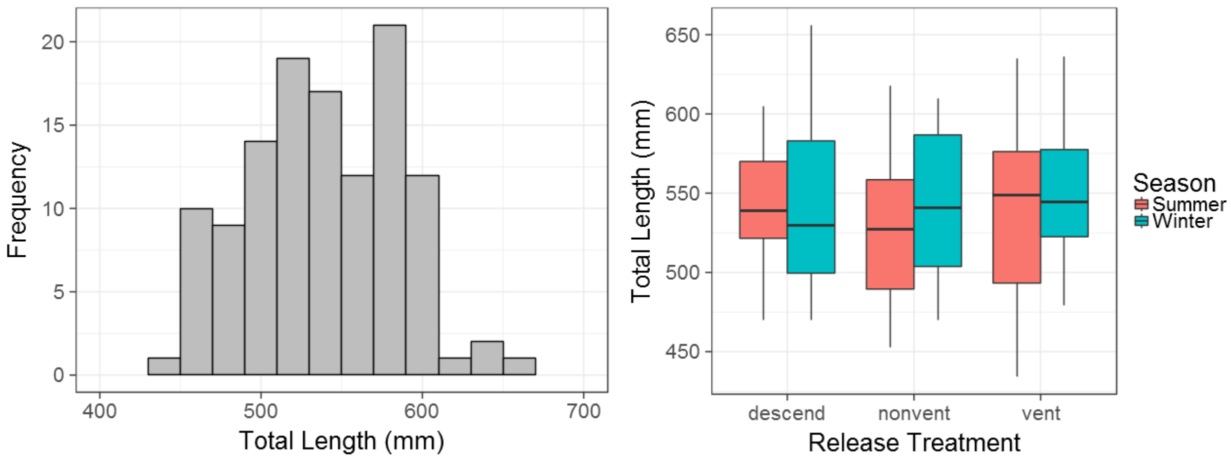


Figure 9. Left panel: Histogram of total length (mm) of tagged Red Snapper from all field trials (binwidth = 20 mm). Right panel: Boxplots showing median total length (mm) of tagged Red snapper for each season and release treatment.

Acoustic Detections

After transmitters had expired, receivers were recovered by scuba divers and acoustic data was downloaded. All individuals were detected by acoustic receivers. For summer trials, fish were tagged on 03-Sept-2015 and 04-Sept-2015 at sites MI-A-7 (60 m) and MI-712-A (40 m). Transmitters' battery life extended for approximately 17 days and expired by 20-Sept-2015 (**Figure 10).** The total number of acoustic detections registered for the summer season was 9,964,166 for all 60 fish tagged. Mean residence time for these summer fish was 7.13 ± 0.82 days (mean ± standard error). For winter trials, fish were tagged on 27-Feb-2016 and 28-Feb-2016 and tags expired by 15-Mar-2016 (**Figure 11).** The total number of acoustic detections registered for the winter season was 9,523,751 for all 59 fish tagged. Winter fish stayed around the site slightly longer than summer fish; mean residence time for winter fish was 10.33 ± 0.94 days (mean ± standard error). For both seasons, a large proportion of tagged fish seemed to exhibit high site fidelity and near continuous residency on the site. This signature is misleading, however, when solely examining overall acoustic detections, as these detections do not include sensor information, which may lead to artificially higher estimates of residence times. For this reason, and especially when considering discard mortality, it is imperative that acoustic sensor information (i.e. pressure and motion) be incorporated into residency estimates.

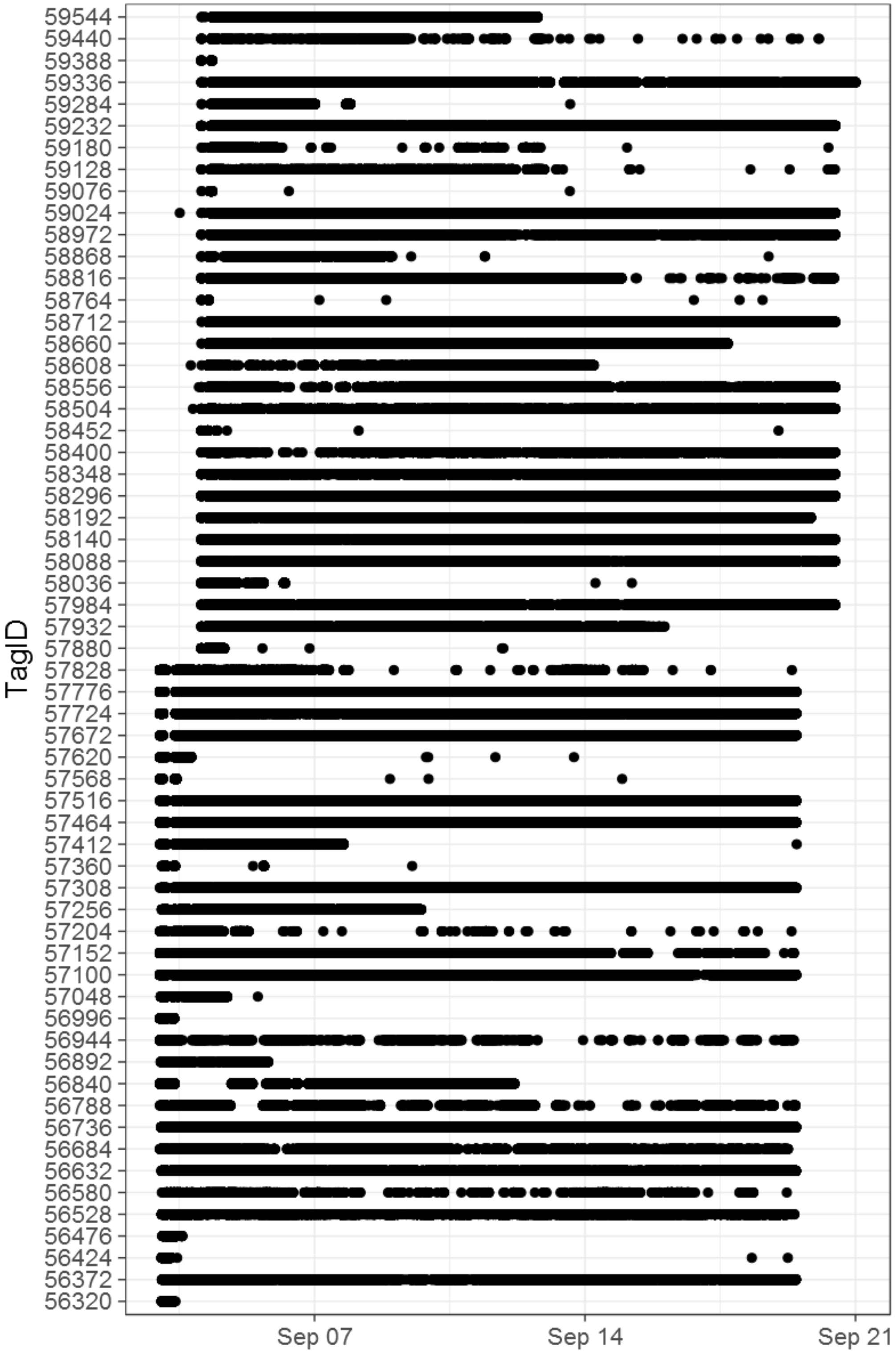


Figure 10. Abycus plot showing total number of acoustic detections for all fish tagged in summer (n=60). Fish were tagged on Sept 3rd and 4th and transmitters expired on Sept 20th.

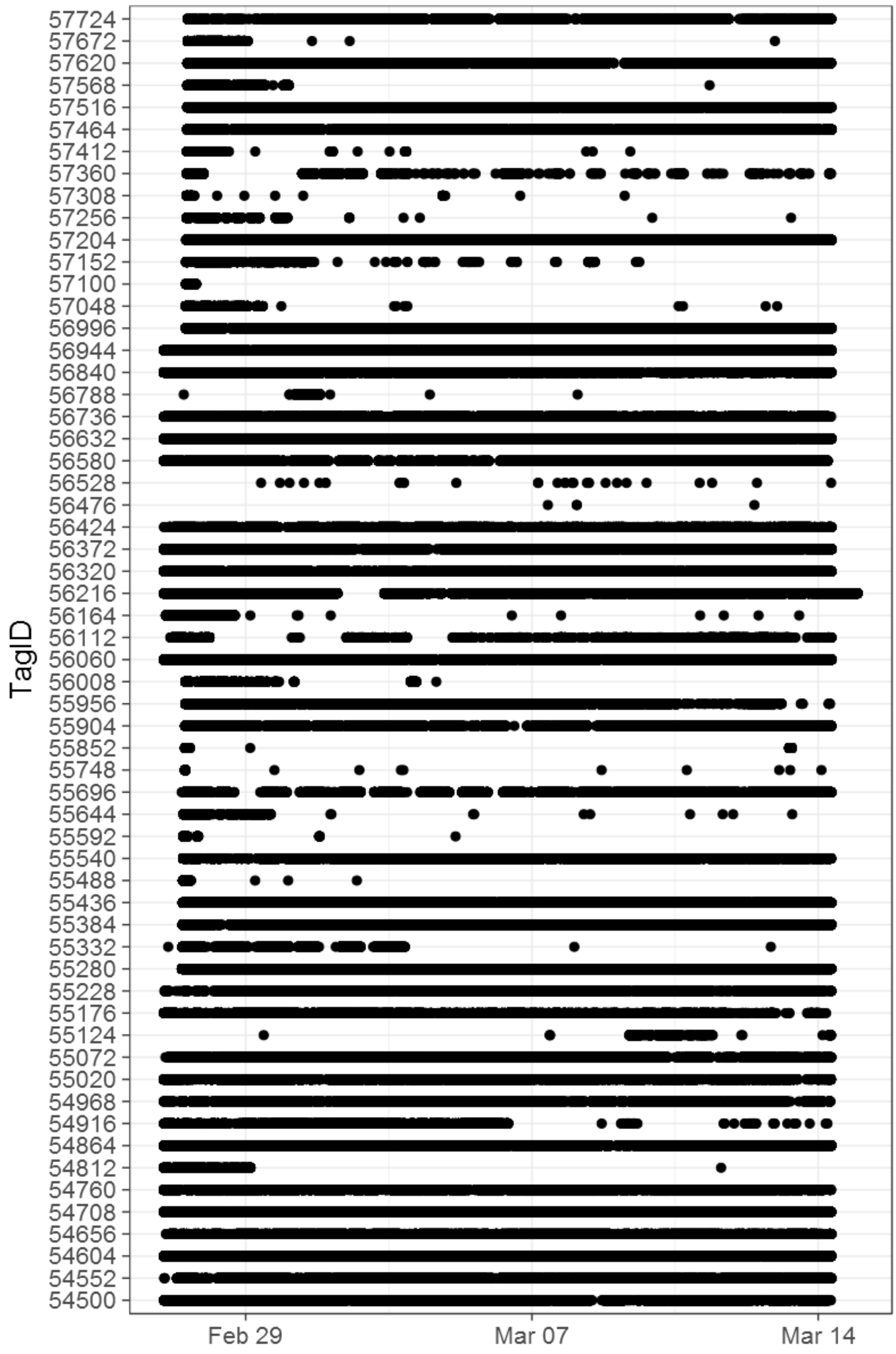


Figure 11. Abycus plot showing total number of acoustic detections for all fish tagged in winter (n=59). Fish were tagged on Feb 27th and 28th and transmitters expired on Mar 15th.

Fate Classification

Using the built-in acoustic sensor data (i.e. pressure and motion) provided by the Lotek transmitters, we were able to better classify the fate of individuals based on their acoustic profiles compared to basic acoustic detections (presence/absence). Three unique profiles emerged that represented survival, delayed mortality, or an emigration event. Survivors registered continuous detections for at least three days and had frequent changes in motion and vertical depth movements in the water column (**Figure 12)**. The second profile was indicative of fish experiencing delayed mortality. These fish appeared healthy upon release, and had initial active motion and pressure values detected by acoustic returns, but soon after exhibited a sudden drop-off to zero motion and depth of the seafloor within a period of 3-4 days (**Figure 13**). The third profile was fish that rapidly emigrated from the site, beyond the range of our acoustic array, and did not return (**Figure 14**). Emigrants were the least informative in assessing survival or mortality as they did not remain within the acoustic array for a sufficient period to time to classify as a survival or delayed mortality event. It is possible that these fish left the array and survived at another site, but it is also possible that once out of the range of acoustic detection, these fish perished. Due to this unknown fate, these 'emigrant' fish were right censored in survival models. Acoustic profiles were generated for all 119 fish and their fate was categorized based on the three acoustic profiles that emerged from acoustic motion and pressure sensor data (see Appendix for all fish profiles).

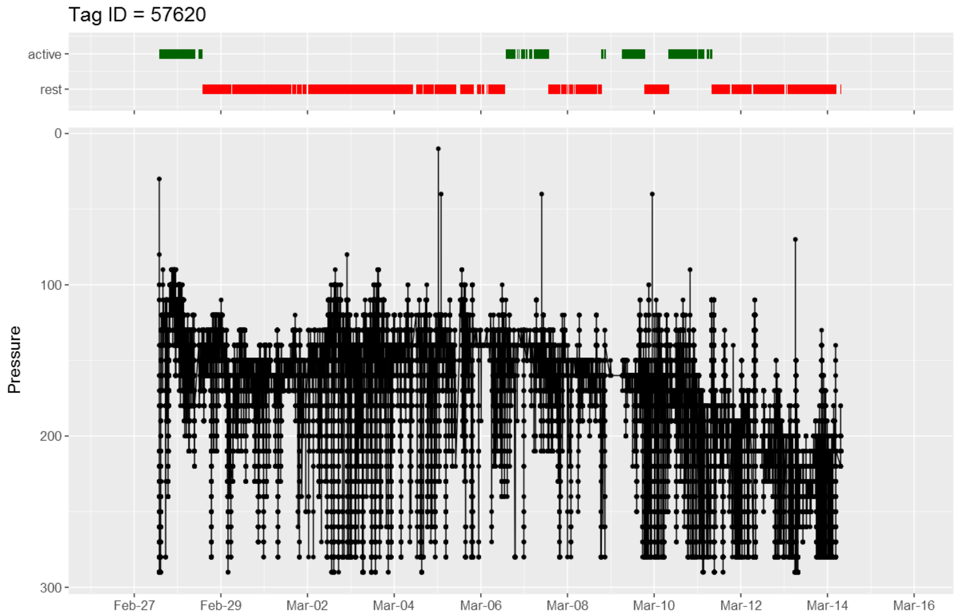


Figure 12. Acoustic telemetry motion (top panel) and pressure (bottom panel) profile of one acoustically tagged Red Snapper classified as a **survivor** post-release (TagID = 57620). Points represent individual acoustic detections and are connected by lines for visualization. Survivors exhibit healthy and active vertical movements in the water column.

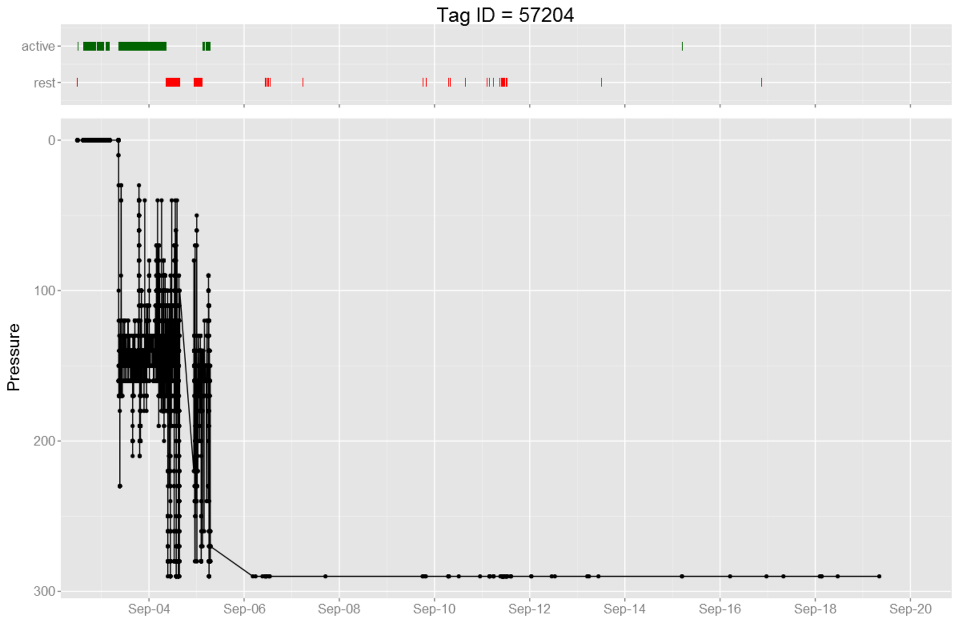


Figure 13. Acoustic telemetry motion (top panel) and pressure (bottom panel) profile of one acoustically tagged Red Snapper classified as a **delayed mortality** event post-release (TagID = 57204). Points represent individual acoustic detections and are connected by lines for visualization. Profile shows that within 2 days the fish is no longer exhibiting any motion or vertical movement, and has fallen to the seafloor and perished.

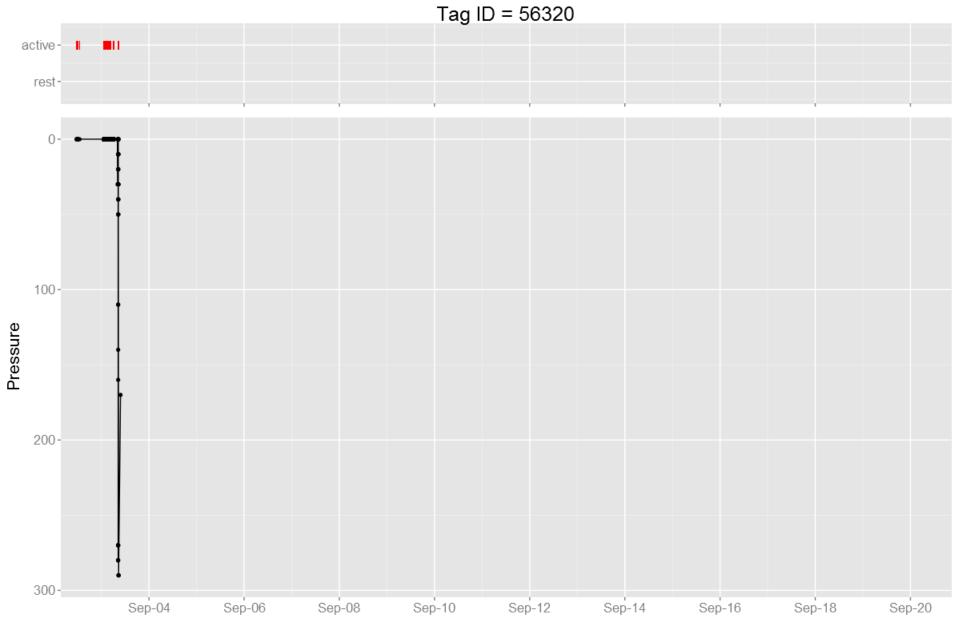


Figure 14. Acoustic telemetry motion (top panel) and pressure (bottom panel) profile of one acoustically tagged Red Snapper classified as an **emigrant** post-release (TagID = 56320). Points represent individual acoustic detections and are connected by lines for visualization. Fish pinged immediately following release but quickly moved outside the range of detection by our acoustic array and did not return.

Survival Analysis

Using the fate classification method based on acoustic sensor data described above, we were able to compare the effects of depth, temperature, and release treatment on survival and mortality rates for Red Snapper in the field. **Table 2** shows the summary of the results for survival classification based on acoustic profiles by season, depth, and release treatment. Survival estimates and standard errors are derived from equations detailed in the approach section.

Table 2. Summary table of results of Red Snapper experimental trials. *Tagged*: number of fish tagged and released. *Emigrant:* fish whose fate was unclassifiable as survive or mortality. M*ortality:* fish that exhibited immediate or delayed mortality (perished in < 3 days). *Survive*: fish that exhibited long term (> 3 days) survival. *n*: number of fish that survived minus emigrants for each treatment level. *S^:* survival estimate. *SE(S^)*: standard error of the survival estimate.

	Tagged	**Emigrant**	**Mortality**	**Survive (x)**	***n***	***S^***	**SE(*S^*)**
Summer - 40 m							
Descend	10	2	1	7	8	0.88	0.12
Nonvent	10	4	2	4	6	0.67	0.19
Vent	10	3	3	4	7	0.57	0.19
Subtotal	30	9	6	15	21	0.71	0.10
Summer - 60m							
Descend	10	1	6	3	9	0.33	0.16
Nonvent	10	5	3	2	5	0.40	0.22
Vent	10	3	7	0	7	0.00	0.00
Subtotal	30	9	16	5	21	0.24	0.09
Winter - 40 m							
Descend	10	3	0	7	7	1.00	0.00
Nonvent	10	0	0	10	10	1.00	0.00
Vent	10	1	1	8	9	0.89	0.10
Subtotal	30	4	1	25	26	0.96	0.04
Winter - 60 m							
Descend	9	1	0	8	8	1.00	0.00
Nonvent	10	2	2	6	8	0.75	0.15
Vent	10	3	2	5	7	0.71	0.17
Subtotal	29	6	4	19	23	0.83	0.08

Mean percent survival was compared between the summer and winter seasons at each of the two depths: 40 m vs. 60 m (**Figure 15**). Survival in the summer at 40 m depth was 71 ± 10% (mean ± standard error), and was much greater than at the 60 m depth in summer, where it was 24 ± 9%. In the winter, mean percent survival between the two depths was much closer. At 40 m, winter survival was 96 ± 4%, and at 60 m, it was 83 ± 8%. From these results, we see clear influences of both temperature and depth on overall survival.

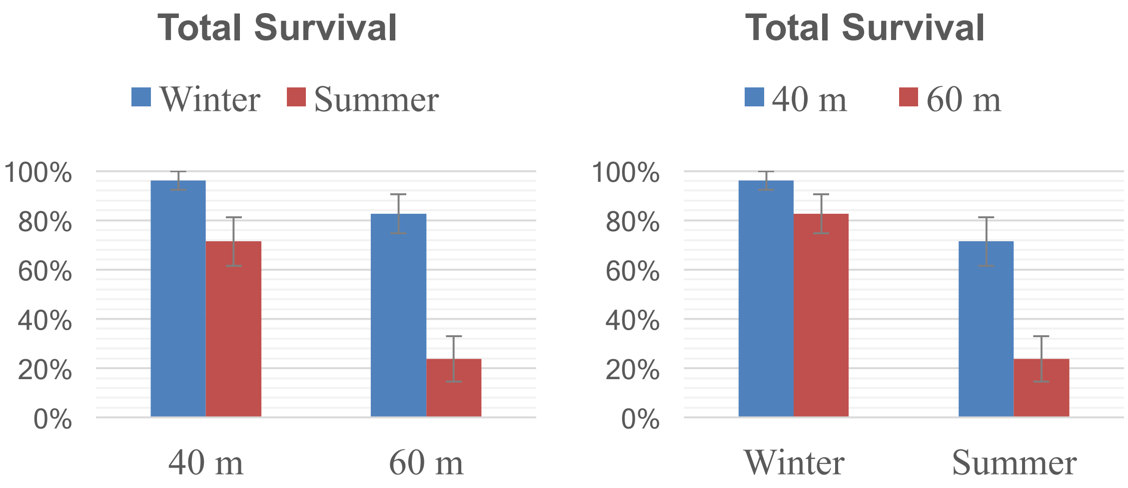


Figure 15. Survival (% mean ± standard error) of Red Snapper in winter and summer for fish tagged at the two sites (40 m and 60 m). Figures represent the same data; one visualized with depth along the x-axis and the other with season along the x-axis.

Survival among the three different release treatments (descend, nonvent, vent) were compared between season and depth (**Figure 16**). In the summer, all three release treatments performed well at 40 m, with survival rates above 50%. There was not much difference in survival between vented and nonvented treatments, but descended fish experienced higher survival than either of these two treatments. At the deeper depth of 60 m, however, there was less clear value in using the descend treatment, as it fared similar to the nonvented (control) treatment. Survival for both these treatments was low, indicating that depth effects may supersede any form of release treatment in determining the survival of discarded fish. Vented fish surprisingly did not have a single fish surviving at the 60 m depth in summer.

In the winter, overall survival was much higher, yet there was still some benefits to using certain release treatments over others. The descend treatment saw 100% survival at both the 40 and 60 m depths. Nonvented fish had a slight reduction in survival with depth; at 40 m survival all fish survived, while that figure declined to 75% in the deeper waters. Vented treatments had slightly lower survival than either of the other two treatments and had a slight depth effect, with survival being greater at the shallower 40 m depth.

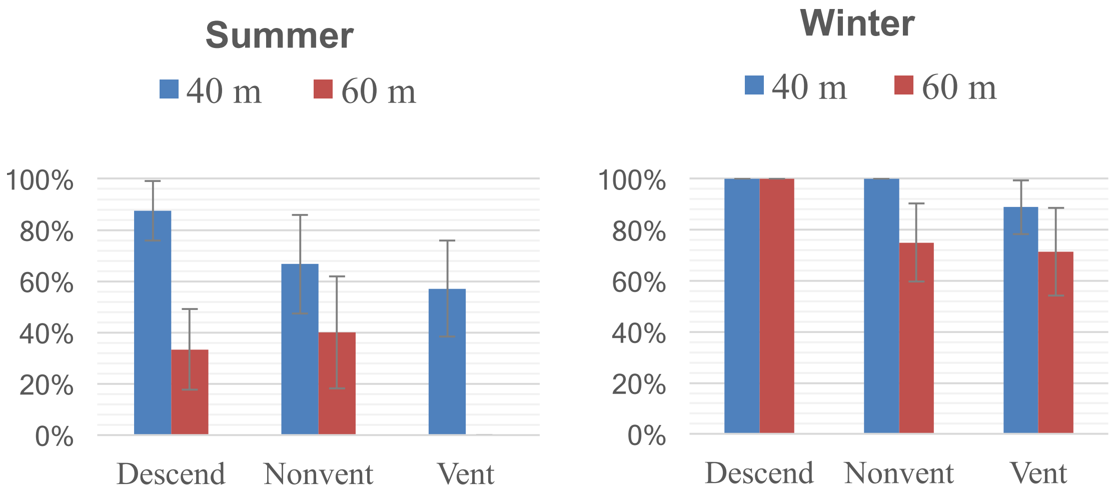


Figure 16. Survival (% mean ± standard error) of Red Snapper in summer (left panel) and winter (right panel) for each release treatment by depth.

Survival probabilities were calculated for each explanatory variable (release treatment, season, depth) based on the Kaplan-Meier product limit estimate (**Figure 17**). The 'survdiff' function in the survival package was used to test for differences between two or more survival curves for each level of the explanatory variables using the chi-square statistic for a test of equality. The survival probability did not differ between release treatments ($\chi^2 = 4.1$, $df = 2$, $p = 0.128$). There was a significantly greater probability of survival for fish released in winter compared to fish released in summer ($\chi^2 = 13.1$, $df = 1$, $p < 0.001$), and a significantly greater probability of survival for fish tagged and released at the shallower depth of 40 m compared to the deeper depth of 60 m ($\chi^2 = 10.5$, $df = 1$, $p < 0.01$).

The Cox proportional hazards model was used to compare the relationship between survival and multiple explanatory variables and compute a hazard ratio, or proportional risk of death, for each covariate level (**Table 3**). For release method, the descended release treatment experienced the highest probability of survival; thus, was used as the baseline level to which release treatments nonvent and vent were compared. Vented fish performed significantly worse in terms of survival than descended fish. Based on the calculated hazards ratio, vented fish were 2.9 times, and nonvented fish 1.5 times as likely to perish as fish descended using SeaQualizer devices. Fish released in summer were at significantly greater risk of dying; summer released fish were over 5.0 times as likely to perish as fish released in winter. Lastly, fish released at 60 m were at significantly greater risk of perishing; they were 3.9 times as likely to perish as fish released at 40 m depth.

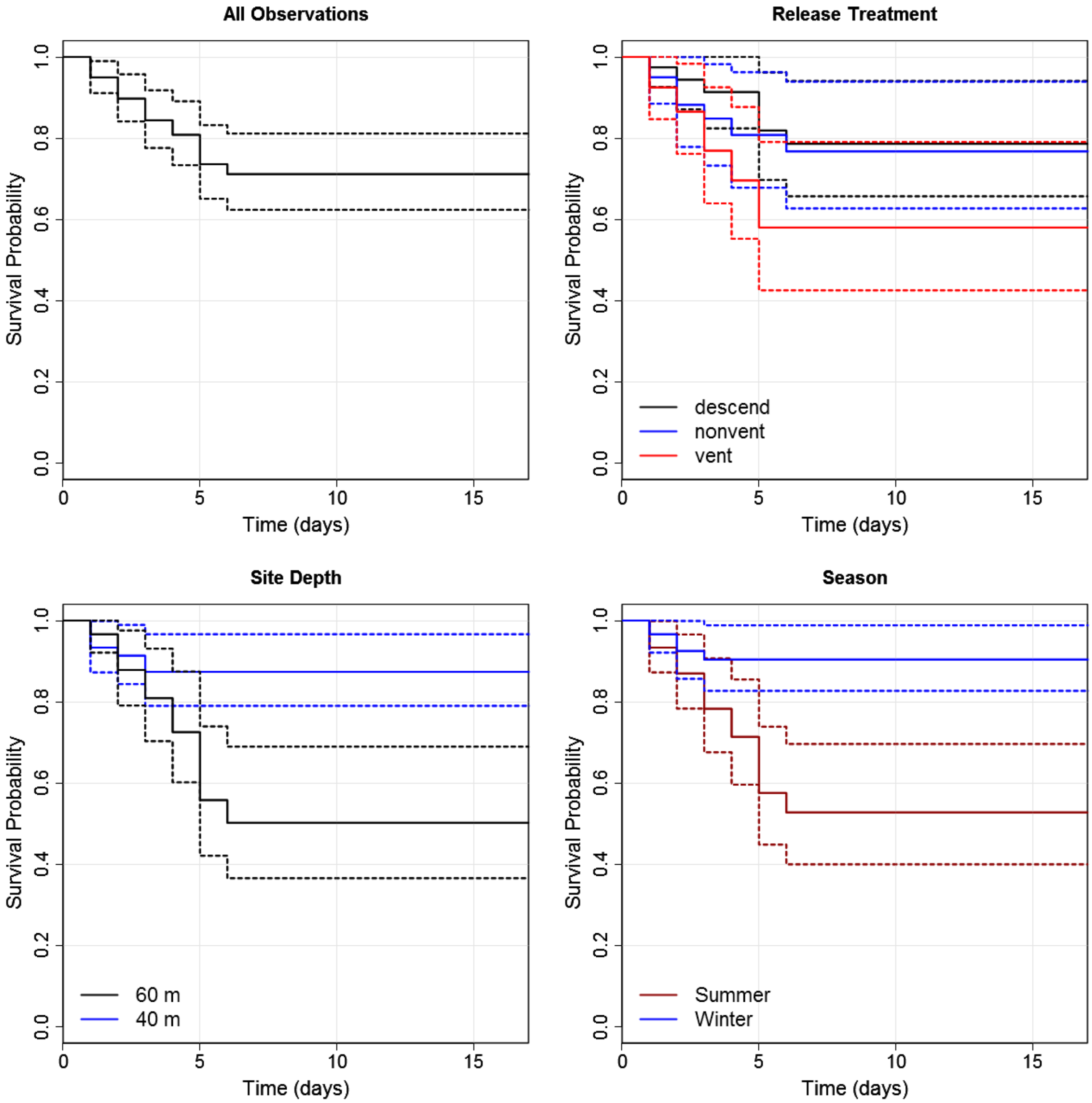


Figure 17. Kaplan-Meier survival curves plotting survival probability over time for each of the factors considered in survival analysis. Dotted lines represent 95% confidence intervals. All observations (*n*=119; top left), Release treatment (top right), Site depth (bottom left), and Season (bottom right).

Table 3. Cox proportional hazards model using treatment, season, and depth as covariates. The hazard ratio shows the proportional risk of each level of a particular treatment against the baseline risk of mortality (e.g. summer fish are 5.0169 times as likely to perish as winter fish, and fish released in 60 m were 3.8853 times as likely to perish as fish released at 40 m).

Covariate	Coefficient (b)	Hazard ratio (e^b)	95% C.I. for e^b	P
Descend	*(baseline)*			
Nonvent	0.3886	1.475	0.515 - 4.223	0.4690
Vent	1.0576	2.8794	1.132 - 7.325	0.0264*
Winter	*(baseline)*			
Summer	1.6128	5.0169	1.889 - 13.323	0.0012**
40 m	*(baseline)*			
60 m	1.3572	3.8853	1.6162 - 9.340	0.0024**

Objective 2: Assess impacts of discard release methods on Red Snapper survival with fishery surveys.

Barotrauma assessment

We analyzed the influence of depth on barotrauma impairment using the full number of observations (*n* = 1588) from our entire VLL dataset (2013-2016). Sampling events occurred from 20 – 90 m depth and represented all four seasons throughout the year, although the largest proportion of events were conducted in the summer months. For each sampling event, barotrauma impairment scores for each individual fish were averaged and plotted against depth (**Figure 18**). Mean barotrauma impairment across all observations was 0.4 ± 0.01 (mean ± standard error), with the most common barotrauma symptoms being hard abdomen followed by stomach eversion. Barotrauma impairment was modeled with a generalized additive model using a loess smoothing spline. Barotrauma impairment increased with depth, as expected, but reached a maximum value at 55 m. Beyond this depth, barotrauma impairment actually decreased, which was a most unexpected result. The resulting decrease in barotrauma related impairment likely is due to catastrophic decompression events, whereby the swim bladder (and possibly other cavities) has ruptured and released the excess gas built up inside the fish to the environment. We have documented these occurrences at several of our deeper VLL sites using camera footage.

The release of these gases creates space inside the fish for internal organs (stomach, intestines) to return to their initial location prior to capture and the subsequent pressure change that is responsible for expanding the swim bladder, displacing the organs, and making them externally visible. Additionally, catastrophic decompression and the release of excess gas returns the fish to neutral (or negative) buoyancy, which allows the fish to submerge unassisted in many cases when discarded. This may mislead observers to conclude that the fish was healthy and survived the catch-and-release process, when in fact the damage is irreversible and that fish undoubtedly will succumb to delayed mortality hours to days later as indicated by our acoustic telemetry data.

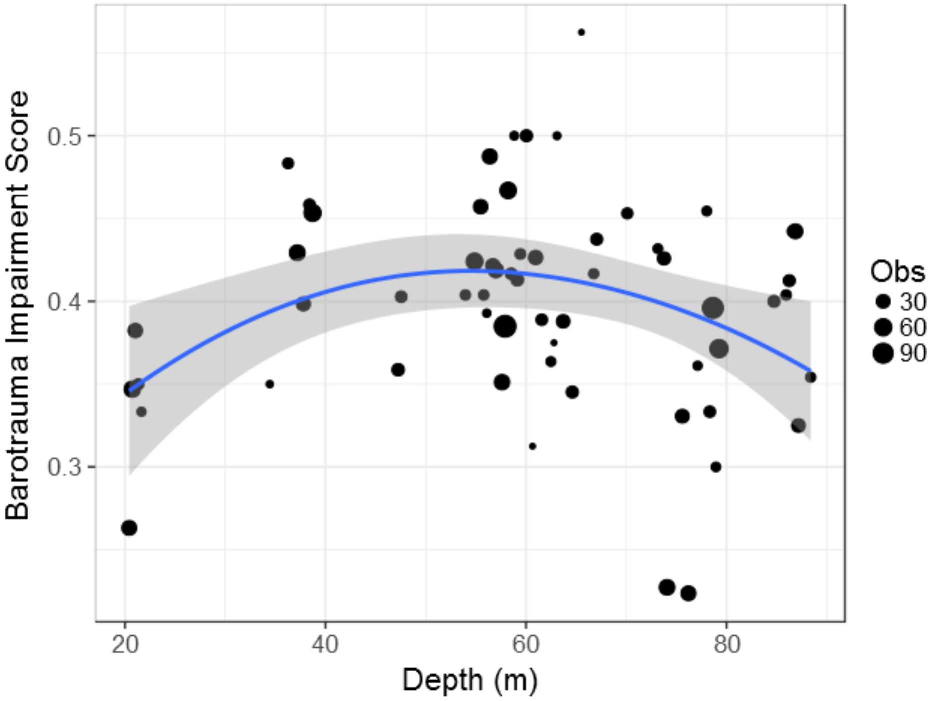


Figure 18. Average barotrauma impairment score measured at depth ranging from 20 – 90 m. Fish were captured using vertical longline (n = 1588). Size of points are relative to the number of observations at each depth sampled. Smoothing spline fit by “loess” generalized additive model.

Fishery-based recaptures

Two fish were recaptured during this project – both by the same commercial fishermen at the same location (MI-A-7, 60 m) on the same date (4/26/16). These fish were initially tagged two months earlier (2/27/16), belonging to the winter trials at the 60 m site, and both had been released using the SeaQualizer fish descender (**Table 4**). The acoustic profiles downloaded from our receivers showed healthy activity throughout the full duration of the transmitter’s 17 d battery life for both fish (**Figure 19**). These fish remained at large for an additional 42 days before being recaptured.

Table 4. Characteristics of two fish that were recaptured as part of the fishery-based assessments and surveys. Both fish were captured on the same site (MI-A-7), the same date by a commercial fishermen.

	Fish Tag ID T427302	**Fish Tag ID T427311**
Tag date	2/27/2016	2/27/2016
Season	Winter	Winter
Location	MI-A-7	MI-A-7
Depth	60 m	60 m
Treatment	descend	descend
TL	499	555
Acoustic fate classification	survivor	survivor
Last acoustic detection	3/14/2016	3/14/2016
Recaptured	4/26/2016	4/26/2016
Days at Large	59	59

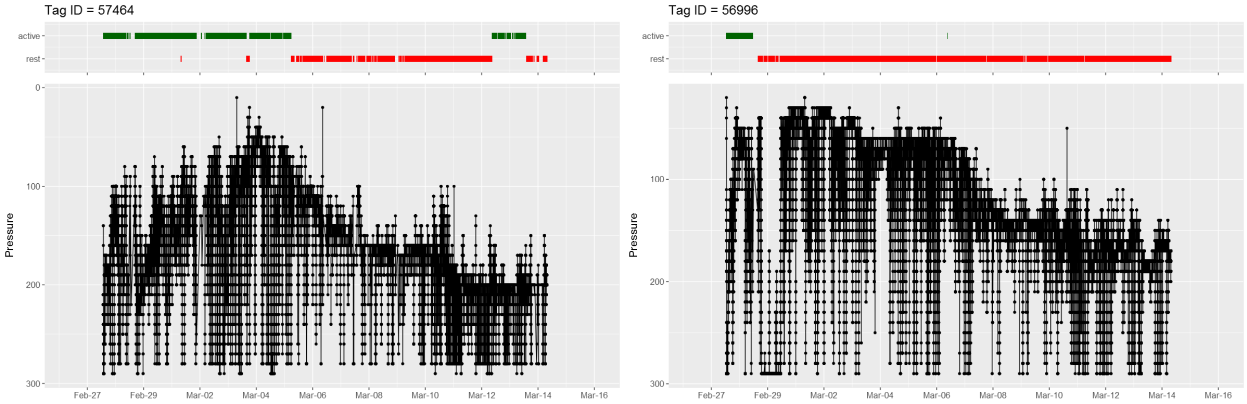


Figure 19. Acoustic profiles of the two recaptured fish: TagID 57464 and TagID 5996. Both fish were tagged in winter at the 60 m depth, and were released using the SeaQualizer fish descender.

Objective 3: Partner with the fishing community to determine the best practices for releasing Red Snapper.

Engagement with the recreational fishing community

Over one-thousand (>1000) SeaQualizers and best-use practices pamphlets were distributed to recreational anglers from South Carolina to Texas as part of the FishSmart collaboration effort. Recipients included private recreational anglers, charter captains with and without federal reef fish permits, and headboat captains. SeaQualizers were distributed from March through September of 2016. The majority of devices were distributed by state agencies at dockside creel stations and fishing tournaments. A total of eighty (80) SeaQualizers were distributed to Texas recreational anglers by members from our group. These eighty devices were distributed at dockside creel stations, fishing tournaments, and CCBGFC and Port Aransas Boatmen's Association meetings and banquets.

From January 1, 2016 to December 31, 2016, our group's Facebook total reach was 359,764 people, while our Twitter account's total impressions was 235,252 people, resulting in a combined outreach power of 595,016 people reached by our postings.

Scientist ride-along trips to assess descender device performance

A total of five (5) observer trips were attended by members from our group. Three of these trips were aboard private recreational fishing vessels, one was aboard a charter boat possessing a federal reef fish permit, and one was aboard a headboat (**Table 5**). All observer trips left out of Port Aransas, Texas. Red Snapper were the only species captured aboard the private and charter vessels. Species captured aboard the headboat consisted of Red Snapper, Vermillion Snapper, Lane Snapper, Gray Snapper, Gag Grouper, Tomtate, Rockhind, Squirrelfish, Queen Triggerfish, King Mackerel, and Spanish Mackerel. On average, two anglers targeting Red Snapper would fish simultaneously aboard the private vessels and charter vessel. At certain times aboard the headboat, such as upon arrival to a new fishing site, over 50 anglers would be fishing simultaneously. Fishing site bottom depths ranged from 30 to 61 meters, with the headboat targeting fish in the deepest water.

Table 5. Various data recorded from the five observer trips onboard either private boats, charter vessels, or headboats. Values with an asterisk do not indicate a mean, but a single value.

Observer Trip Summary Statistics

Variable	Private	Charter	Headboat
Mean Fishing Depth	48	37*	61*
Mean Fight Time (s)	71	121	NA
Mean Deck Time (s)	132	64*	NA
Species Captured	1	1	11
Mean BtR Score	0.28	0.47	0.48
Mean Total Length	508	700	390

Private anglers and chartered anglers held similar perceptions regarding rapid recompression device utility. Captains and deckhands of the private and charter vessels believed the device to be highly successful in reducing discard mortality. Anglers aboard the private vessels actively descended each discard until multiple fish were landed simultaneously. During these situations, anglers would instead use a venting needle to save time and effort. The use of double-hook fishing leaders caused the situations where the SeaQualizer operator would become overwhelmed. This problem did not occur on the charter vessel as the captain limited fishing to two anglers at once and fished with single-hook fishing leaders.

While aboard the headboat, observers offered deckhands an incentive to assist observers by using the SeaQualizer to descend discards when time allowed. Due to time constraint and an overwhelmingly large number of discards being landed simultaneously, no deckhands were able to operate a SeaQualizer. Deckhand perceptions on rapid recompression device utility on headboats was very poor resulting from the time it takes to drop a fish and reel the device back in. With sixty anglers fishing on one vessel, it was difficult for a handful of deckhands to use these devices when dozens of discards were landed within several minutes. The primary method of release used by deckhands on the headboat was venting released fish with a venting needle or pocket knife. Knowledge on the correct use of venting needles was poor. One observer noted a mixture of thirty-six (36) floating Red and Vermillion Snapper off of the bow of the headboat.

Survey development

Survey development is still underway. Partnerships and collaborations are currently being utilized to improve the language and phrasing of questions to avoid any misconstruction. Members of our group, FishSmart, and a socio-economics team from the Harte Research Institute are still developing questions and organizing incentives for future survey deployment. A current copy of the survey is listed in the Appendix.

iSnapper discard data

A large number of anglers reported their catches through the iSnapper app, although a very small proportion consistently reported discards and method of release. App developers and members from our group are currently promoting the app to recreational anglers across the state. We anticipate a large number of users in the upcoming summer fishing season and hope to collect additional data from the discard and release method component of the reporting process.

B. Significant Problems

We did not experience any significant problems during the course of this project. We experienced a few minor but typical scheduling setbacks, but these were taken into account during the planning phase and did not alter our overall goals and objectives or drastically change our proposed methodology. Additional methods were undertaken to validate the switch to a different acoustic vendor. Limitations in the acoustic technology initially proposed forced us to switch vendors from Vemco to Lotek Wireless, Inc to better answer our objectives. Specifically, acoustic transmitters provided by Lotek do not incur tag collisions, which allowed for greater numbers of fish to be tagged in a small area without signal interference. Furthermore, rapid transmission rates associated with Lotek tags provided more usable data during the initial post-tagging period. These two characteristics provided by Lotek tag technologies were much better suited towards answering our objectives regarding post-release mortality. In transitioning to this new vendor, we needed to perform a preliminary in-lab trial to test the new tag sensor technologies, determine the necessary tag size for an appropriate fish to tag weight ratio, and modify our external tagging protocol if necessary. Despite these not being an original objective written into the proposal, we thought it was necessary to conduct these preliminary in-lab trials to ensure these technologies would be suitable for answering our field tagging objectives. The data received were extremely helpful in determining appropriate tag specifications to best answer our objectives, and exceeded our expectations for data collection capabilities in the field experiments. We experienced one acoustic transmitter failure during winter field tagging experiments. This tag was determined to be inactive at the time of tagging; thus, was not included in trials. This resulted in a sample size for winter tagging of 59 (instead of 60), and a total sample size of 119 (instead of 120). Lotek Wireless, Inc. was contacted regarding this tag failure.

C. Need for Additional Work

The work completed in this study contributed to a better understanding of discard mortality estimates that can be applied to stock assessments and red snapper fishery management. However, there is still a significant amount of variability in these estimates depending upon the season, depth, release treatment, and other factors. Thus, there is need for additional work. Our novel approach using acoustic telemetry to estimate delayed mortality should be further replicated to determine if similar mortality estimates are observed in other studies and to bolster the sample sizes necessary for more robust statistical analyses. One drawback in using this technology is the expenses associated with purchasing acoustic transmitters and receivers, which restricts the number of fish tagged for study and therefore the overall sample size. To supplement the low sample sizes associated with acoustic telemetry, simultaneous passive anchor tagging could be used in future experiments. Anchor tags are cheap, easily deployed, and designed for large-volume mark-recapture experiments. Recent analytical methods have been developed to combine both acoustic and passive tag types into a single model for estimating mortality.

Our results from this research have shown that rapid recompression strategies using fish descending devices can indeed increase survival of discarded Red Snapper; however, their effectiveness may be limited to certain fishing depths, and results may vary based on season. This represents a key knowledge gap in our understanding of discard morality dynamics for GOM Red Snapper, and requires further investigation. We found that fish released using a SeaQualizer fish descending device at 40 m had greater survival than vented or non-vented fish released at the surface, but when the fishing depth was increased to 60 m, rapid recompression strategies did not perform any better than surface release treatments, presumably due to catastrophic decompression at this greater depth. It is possible that the benefits of rapid recompression are very depth-dependent, and there may be an ***unknown*** threshold depth negating the benefits of rapid recompression that would be very informative for management. The inclusion of additional depth treatments to complement our existing results performed at 40 and 60 m would enable refinements to the variable benefits of rapid recompression along a depth gradient. This information would provide fishery managers with empirical decision making criteria (i.e., depth, season, etc.) where rapid recompression strategies using descending devices can be successful for enhancing survival of discarded Red Snapper.

The use of SeaQualizers or other fish descending devices is only effective for reducing discard mortality for recreationally caught red snapper if recreational anglers use these devices. This project began gathering information about the use of descender devices in the recreational sector, and explored methods for integrating recreational anglers into the testing of these devices, but there is still much work to be done here as well. The partnerships we have established through this project (e.g. FishSmart) are currently being further developed and will result in a much larger scale survey and questionnaire that will be administered to recreational anglers, allowing them to provide useful fishery-dependent feedback on the utility of these devices for reducing discard mortality of red snapper and other reef fish species.

VII. EVALUATION

A. Attainment of Project Goals and Objectives

The goals and objectives for this project were fully attained as proposed. There were no modifications made to the project goals and objectives. Using acoustic telemetry we were able to assess the impacts of discard mortality on red snapper survival, and compare behavior and estimate mortality of red snapper experiencing barotrauma in field trials. We also evaluated how differences in temperature, depth, and release treatment might influence the amount of discards. Using fishery surveys coupled with vertical longline data, we established an index of barotrauma impairment, and examined how this impairment may change based on depth and temperature. Lastly, we were successful in engaging recreational anglers and disseminating information on fish descender devices. We gathered useful fishery-dependent data on their utility for reducing discard mortality in the recreational fishery, as well as the preference and feasibility for their use by recreational anglers.

B. Dissemination of Project Results

This project garnered outstanding interest by the general public, recreational anglers, scientists, and the fisheries management community. Scientific output of this work resulted in up to three manuscripts that will be submitted to peer-reviewed scientific journals for publication. These manuscripts are currently in preparation and are anticipated to be submitted later this year. Multiple oral and poster presentations have been given at local and national scientific meetings and symposia, including the American Fisheries Society Annual Meetings and local chapters. These attended scientific forums included: TPWD Artificial Reef program 4th Annual Science and Research Consortium, 2017 Texas Chapter of the American Fisheries Society Annual Meeting, 7th Annual Graduate Program in Marine Biology Symposium, 6th Annual Marine Science Graduate Student Organization Student Research Forum, NOAA Educational Partnership Program Eighth Biennial Education and Science Forum, and the 6th Annual Graduate Program in Marine Biology Symposium.

Outreach specifically aimed at the recreational fishing community and the wider general public was performed at various non-scientific gatherings comprised primarily of recreational anglers. These gatherings included: CCBGFC fishing tournaments, banquets, fundraisers, and parties, Port Aransas Boatmen's Association monthly meetings, Coastal Conservation Association – Corpus Christi Chapter weekly banquet meetings, dockside creel stations during the federal open season for Red Snapper, and through social media posts on Facebook and Twitter. Additional educational pamphlets were created by our team describing the benefits associated with rapid recompression devices. These pamphlets were distributed to all SeaQualizer recipients who received their device from one of our team members. Contact information and sources describing best catch-and-release practices were provided in these pamphlets, and these resources continue to be available online.

Finally, PI Stunz serves on the Gulf of Mexico Fishery Management Council and former member of the Science and Statistical Committee. Thus, these affiliations will help ensure these results are conveyed to the managers in the most efficient manner. PI Stunz also attending several workshops in St, Pete, FL (2012; 2013) and Annapolis, MD (2013), where the results of this study were the subject and a major scientific contribution to the workshop material.

REFERENCES

Brown, I. W., W. D. Sumpton, M. McLennan, D. Mayer, M. J. Campbell, J. M. Kirkwood, A. R. Butcher, I. Halliday, A. Mapleston, D. Welch, G. A. Begg, and B. Sawynok. 2010. An improved technique for estimating short-term survival of released line-caught fish, and an application comparing barotrauma-relief methods in red emperor (Lutjanus sebae Cuvier 1816). Journal of Experimental Marine Biology and Ecology 385(1–2):1–7.

Burns, K. M., C. C. Koenig, and F. C. Coleman. 2002. Evaluation of multiple factors involved in release mortality of undersized red grouper, gag, red snapper, and vermilion snapper. Mote Marine Laboratory Technical Report No. 790 funded by NOAA under MARFIN Grant #NA87FF0421.

Burns, K. M., R. R. Wilson, and N. F. Parnell. 2004. Partitioning release mortality in the undersized red snapper bycatch: Comparison of depth vs. hooking effects. Mote Marine Laboratory Technical Report No. 932 funded by NOAA under MARFIN Grant #NA97FF0349.

Campbell, M. D., W. B. Driggers, B. Sauls, and J. F. Walter. 2014. Release mortality in the red snapper fishery: a synopsis of three decades of research. SEDAR31-DW22. Fish Bulletin 112:283–296.

Collins, M. R., J. C. McGovern, G. R. Sedberry, H. S. Meister, and R. Ardieck. 1999. Swim Bladder Deflation in Black Sea Bass and Vermilion Snapper: Potential for Increasing Postrelease Survival. North American Journal of Fisheries Management 19(January 2017):828–832.

Cowan, J. H. 2011. Red snapper in the Gulf of Mexico and U.S. South Atlantic: Data, Doubt, and Debate. Fisheries 36(7):319–331.

Cox, D. R. 1972. Regression Models and Life-Tables. Journal of the Royal Statistical Society 34(2):187–220.

Curtis, J. M., M. W. Johnson, S. L. Diamond, and G. W. Stunz. 2015. Quantifying delayed mortality in discarded Red Snapper using acoustic telemetry. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7(1):434–449.

Diamond, S. L., and M. D. Campbell. 2009. Linking "sink or swim" indicators to delayed mortality in red snapper by using a condition index. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:107–120.

Dorf, B. A. 2003. Red snapper discards in Texas coastal waters - A fishery dependent onboard survey of recreational headboat discards and landings. Fisheries, Reefs, and Offshore Development 36:155–166.

Drumhiller, K. L., G. W. Stunz, M. W. Johnson, M. R. Robillard, and S. L. Diamond. 2014. Venting or Rapid Recompression Increase Survival and Improve Recovery of Red Snapper with Barotrauma. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 6:190–199.

Gitschlag, G. R., and M. L. Renaud. 1994. Field experiments on survival rates of caged and released red snapper. North American Journal of Fisheries Management 14(1):131–136.

Goodyear, C. P. 1988. Recent trends in the red snapper fishery of the Gulf of Mexico. NOAA Fisheries Service, SEFSC, Miami Laboratory, CRD 87/88-16.

Hannah, R. W., S. J. Parker, and K. M. Matteson. 2008. Escaping the Surface: The Effect of Capture Depth on Submergence Success of Surface-Released Pacific Rockfish. North American Journal of Fisheries Management 28:694–700.

Hochhalter, S. J., and D. J. Reed. 2011. The Effectiveness of Deepwater Release at Improving the Survival of Discarded Yelloweye Rockfish. North American Journal of Fisheries Management 31(5):852–860.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. G. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. M. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530):629–638.

Jarvis, E. T., and C. G. Lowe. 2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, Sebastes spp.). Canadian Journal of Fisheries and Aquatic Sciences 65(7):1286–1296.

Johnson, M. W., S. L. Diamond, and G. W. Stunz. 2015. External Attachment of Acoustic Tags to Deepwater Reef Fishes: an Alternate Approach When Internal Implantation Affects Experimental Design. Transactions of the American Fisheries Society 144(4):851–859.

Kaplan, E. L., and P. Meier. 1958. Nonparametric Estimation from Incomplete Observations. Journal of the American Statistical Association 53(282):457–481.

Lee, D. P. 1992. Gas Bladder Deflation of Depressurized Largemouth Bass. North American Journal of Fisheries Management1 12(3):662–664.

Pauly, D., V. Christensen, S. Guenette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. Nature 418(6898):689–695.

Pollock, K. H., and W. E. Pine. 2007. The design and analysis of field studies to estimate catch-and-release mortality. Fisheries Management and Ecology 14(2):123–130.

Pribyl, A. L., M. L. Kent, S. J. Parker, and C. B. Schreck. 2011. The Response to Forced Decompression in Six Species of Pacific Rockfish. Transactions of the American Fisheries Society 140(2):374–383.

R Development Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org/. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org/.

Render, J. H., and C. A. Wilson. 1994. Hook-and-line mortality of caught and released red snapper around oil and gas platform structural habitat. Bulletin of Marine Science 55(2–3):1106–1111.

Render, J. H., and C. A. Wilson. 1996. Effect of gas bladder deflation on mortality of hook-and-line caught and released red snappers: implications for management. Pages 244–253*in* F. Arreguin-Sanchez, J. L. Munro, M. C. Balgos, and D. Pauly, editors.Biology, fisheries, and culture of tropical groupers and snappers. ICLARM Conference Proceedings 48, 449 pp.

Rummer, J. L. 2007. Factors affecting catch and release (CAR) mortality in fish: Insight into CAR mortality in red snapper and the influence of catastrophic decompression. Red Snapper Ecology and Fisheries in the U.S. Gulf of Mexico 60:123–144.

Rummer, J. L., and W. A. Bennett. 2005. Physiological effects of swim bladder overexpansion and catastrophic decompression on red snapper. Transactions of the American Fisheries Society 134(6):1457–1470.

Sauls, B. 2014. Relative survival of gags Mycteroperca microlepis released within a recreational hook-and-line fishery: Application of the Cox Regression Model to control for heterogeneity in a large-scale mark-recapture study. Fisheries Research 150:18–27. Elsevier B.V.

Scyphers, S. B., F. J. Fodrie, F. J. Hernandez, S. P. Powers, and R. L. Shipp. 2013. Venting and Reef Fish Survival: Perceptions and Participation Rates among Recreational Anglers in the Northern Gulf of Mexico. North American Journal of Fisheries Management 33(6):1071–1078. Taylor & Francis.

SEDAR. 2005. SEDAR 7 - Stock assessment report of SEDAR7, Gulf of Mexico red snapper. SEDAR, North Charleston, SC.

SEDAR. 2013. SEDAR 31 - Gulf of Mexico Red Snapper Stock Assessment Report. SEDAR, North Charleston, SC.

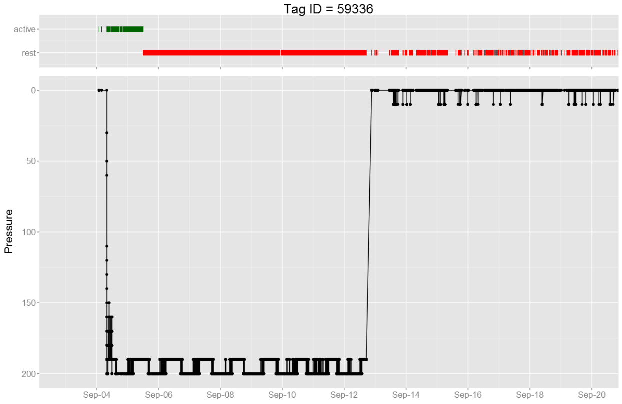
Sumpton, W. D., D. Mayer, I. W. Brown, B. Sawynok, M. McLennan, A. R. Butcher, and J. M. Kirkwood. 2008. Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag-recapture data. Fisheries Research 92(2–3):189–195.

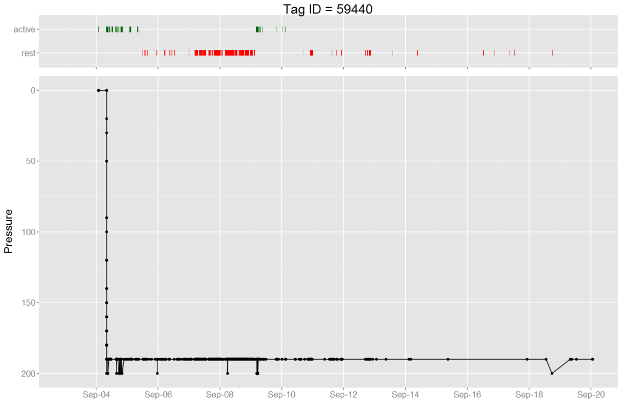
Therneau, T. M., and P. M. Grambsch. 2000. Modeling survival data: extending the Cox model. Springer, New York.

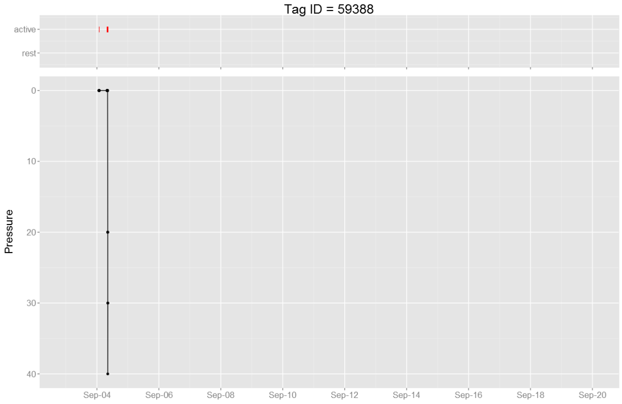
Wilde, G. R. 2009. Does venting promote survival of released fish? Fisheries 34(1):20–28.

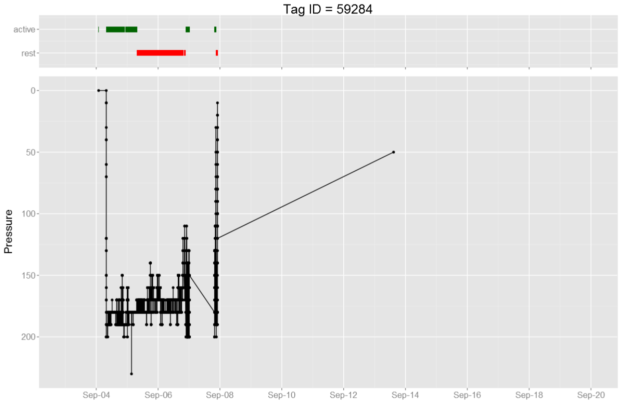
APPENDICES

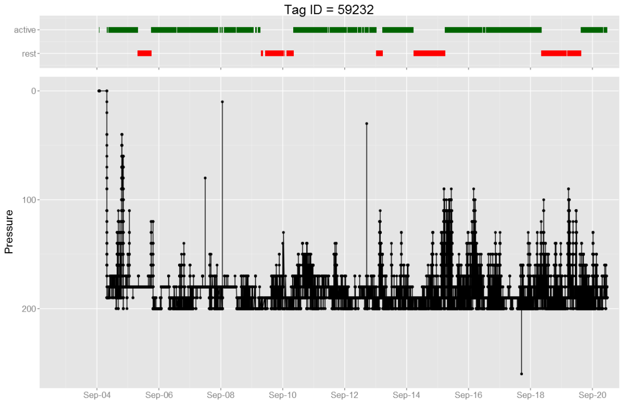
Appendix A: Summer Field Trials

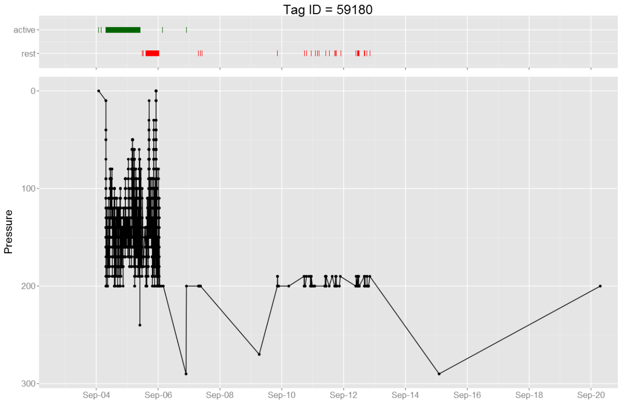

Tag ID = 59336

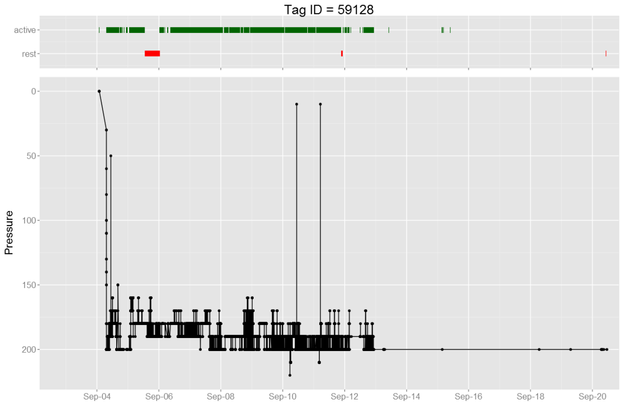

Tag ID = 59440

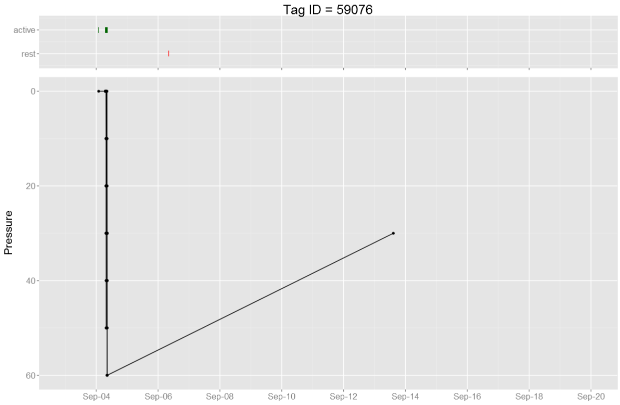

Tag ID = 59388

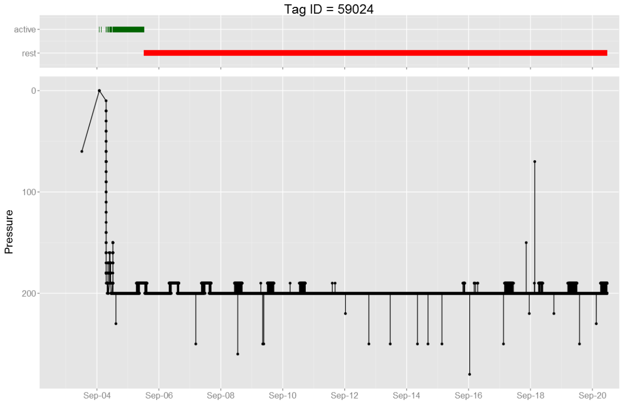

Tag ID = 59284

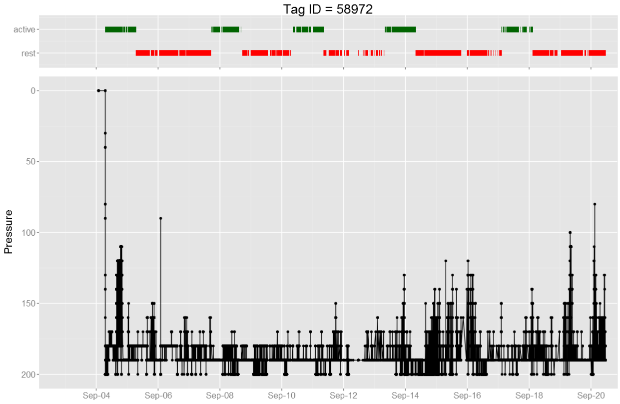

Tag ID = 59232

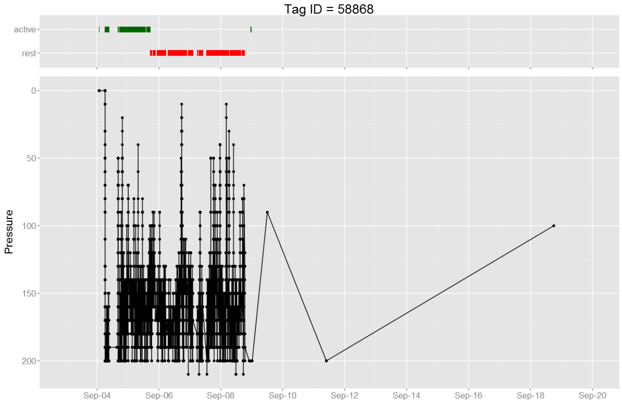

Tag ID = 59180

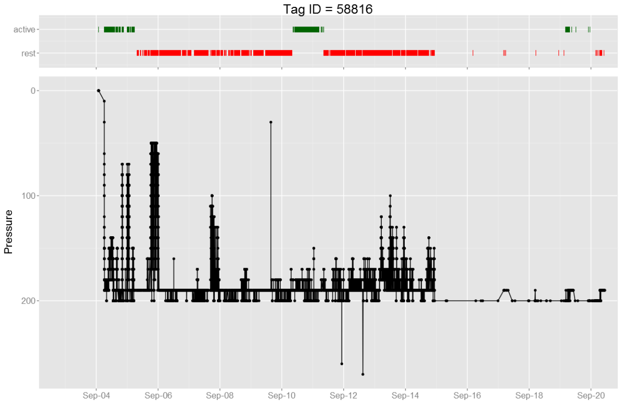

Tag ID = 59128

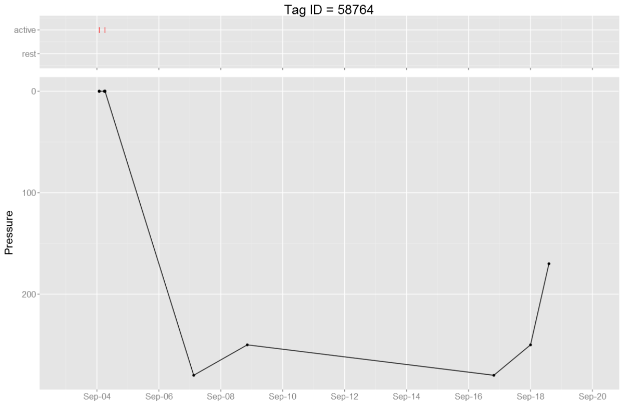

Tag ID = 59076

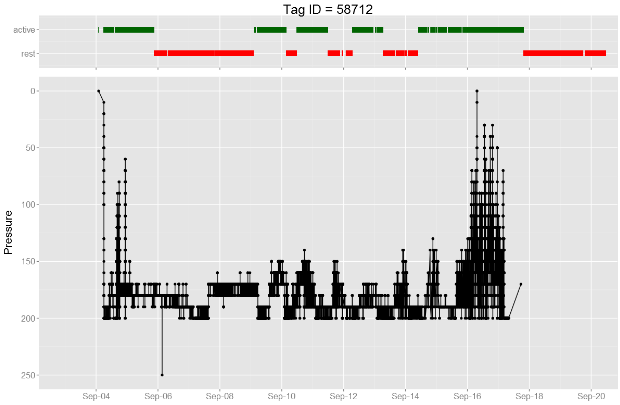

Tag ID = 59024

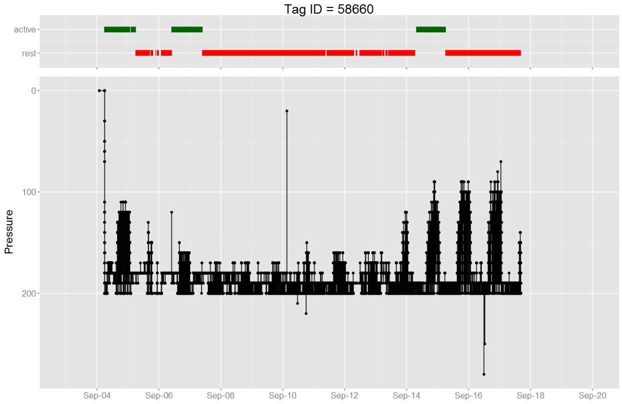

Tag ID = 58972

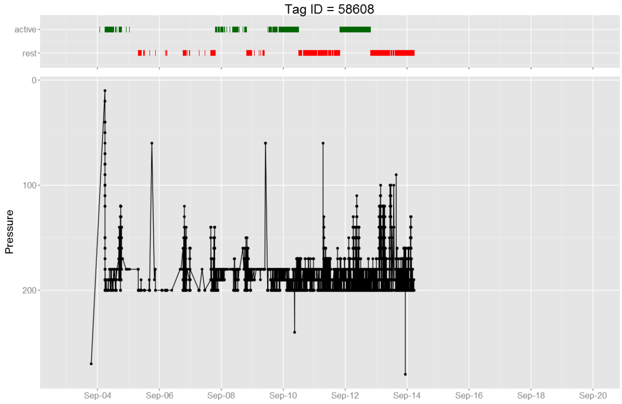

Tag ID = 58868

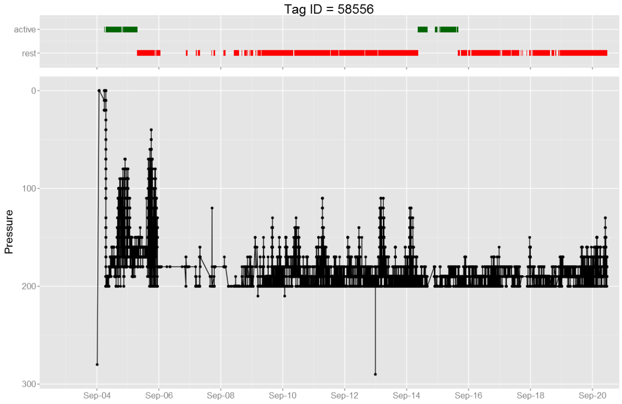

Tag ID = 58816

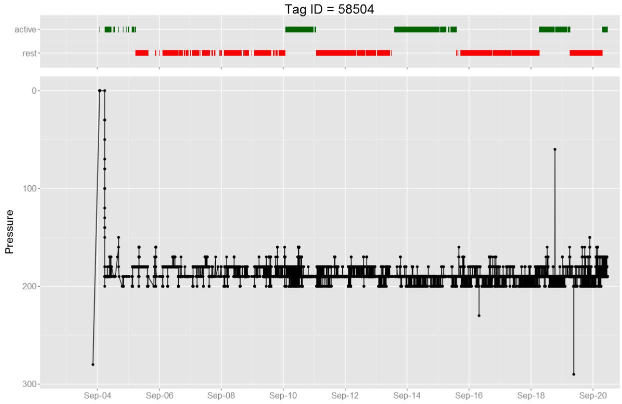

Tag ID = 58764

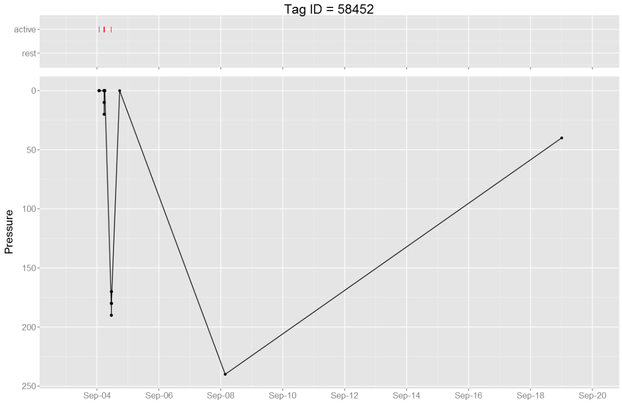

Tag ID = 58712

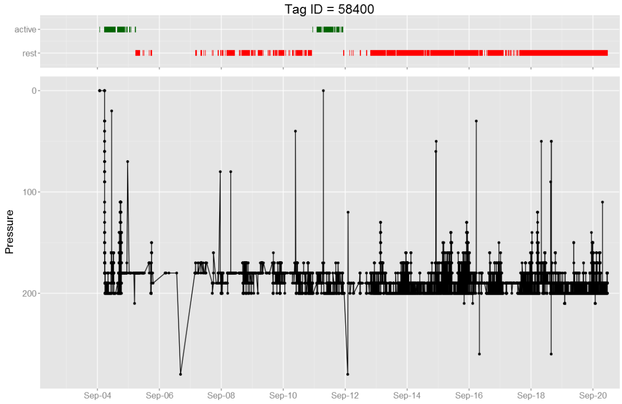

Tag ID = 58660

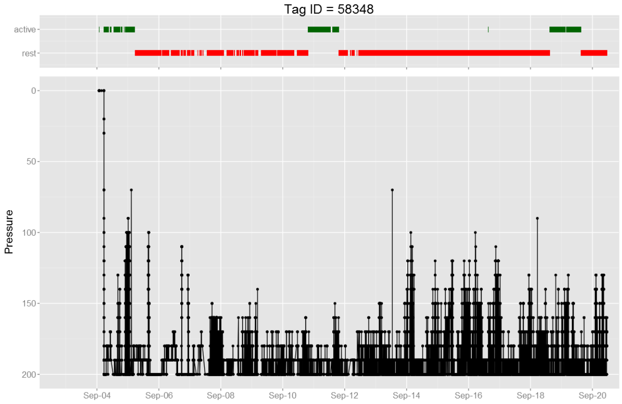

Tag ID = 58608

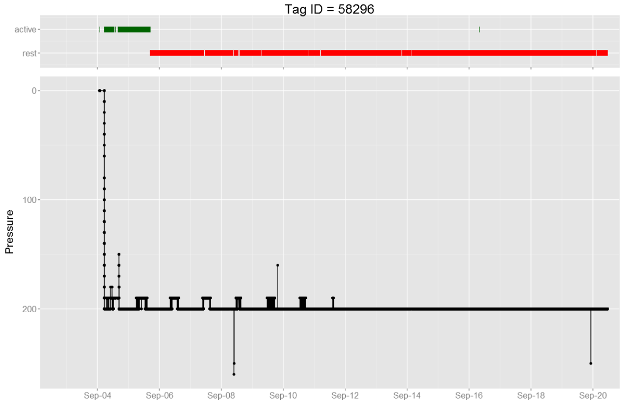

Tag ID = 58556


Tag ID = 58504

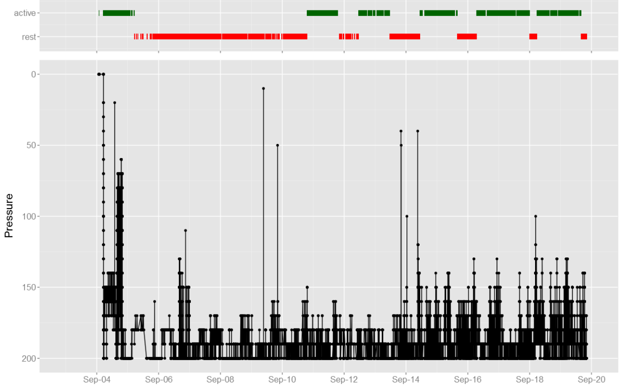

Tag ID = 58452


Tag ID = 58400

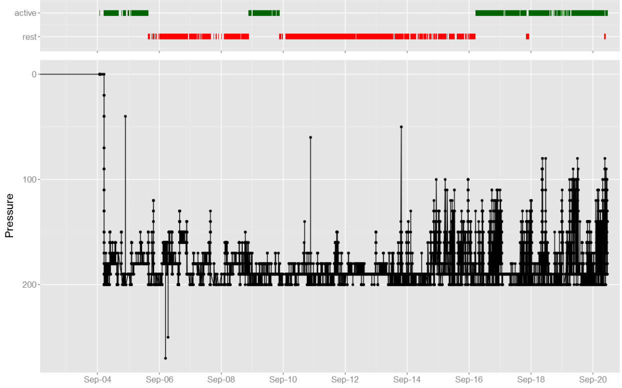

Tag ID = 58348


Tag ID = 58296

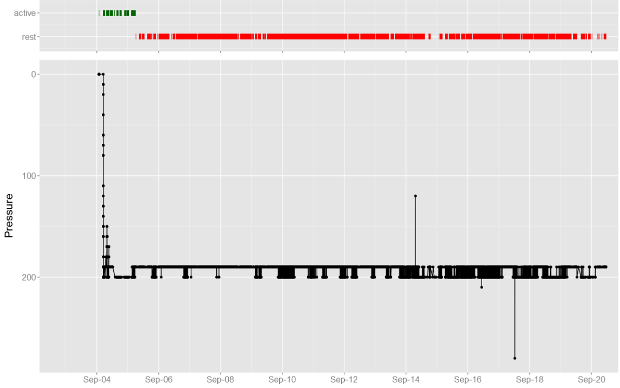
Tag ID = 58192



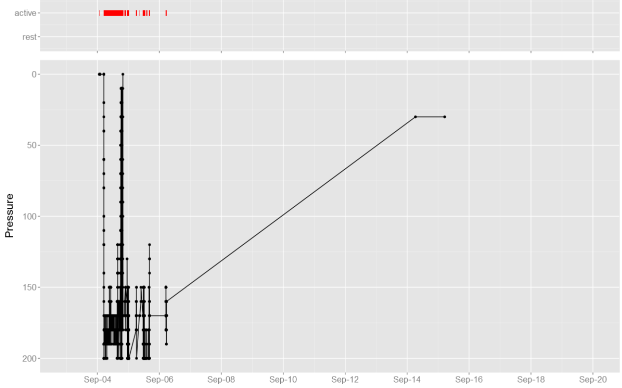
Tag ID = 58140



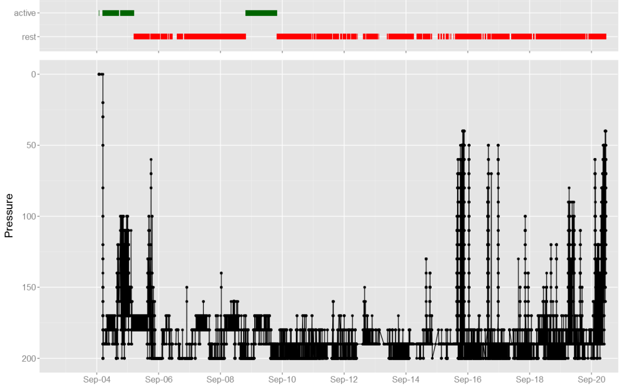
Tag ID = 58088



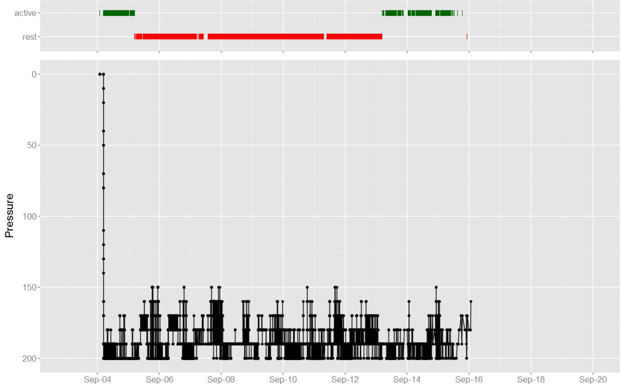
Tag ID = 58036



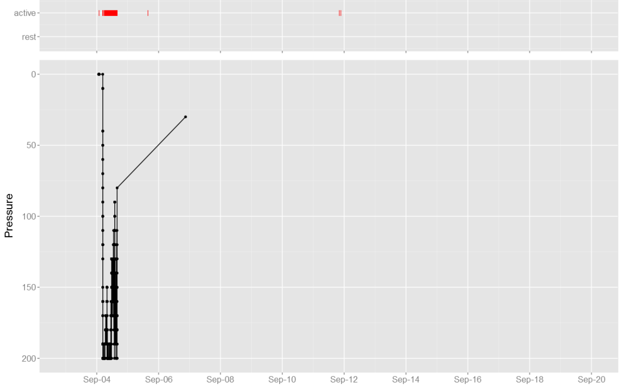
Tag ID = 57984



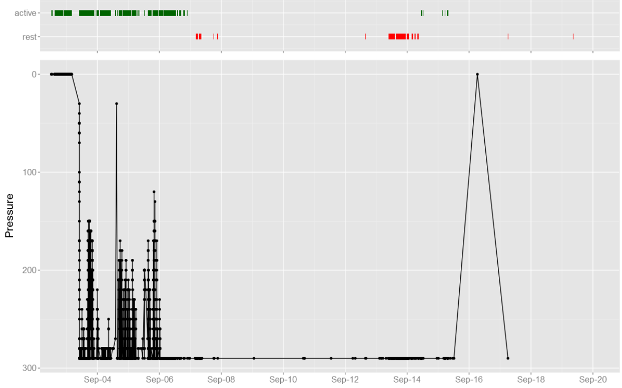
Tag ID = 57932

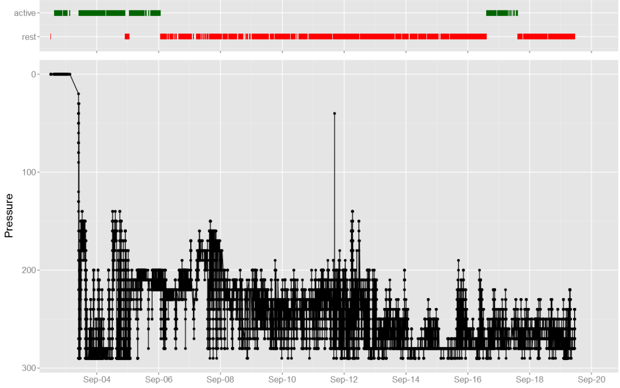


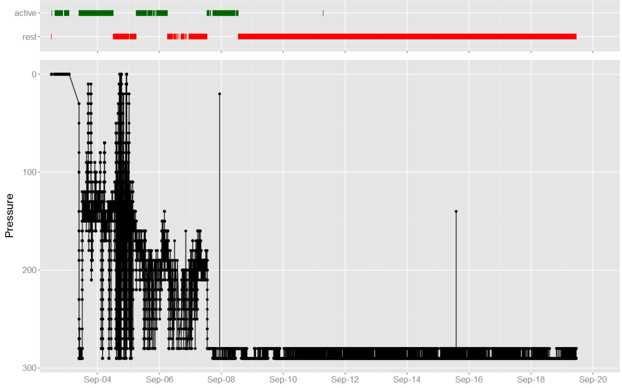
Tag ID = 57880

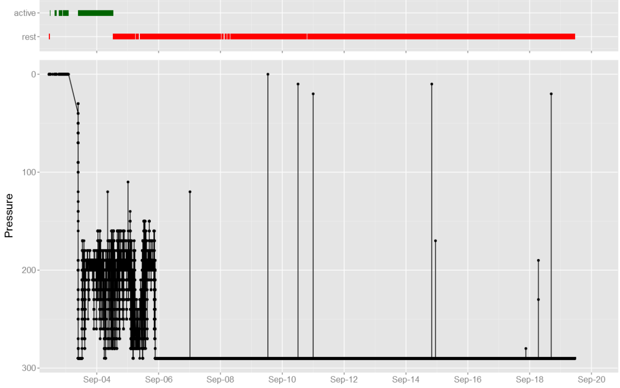


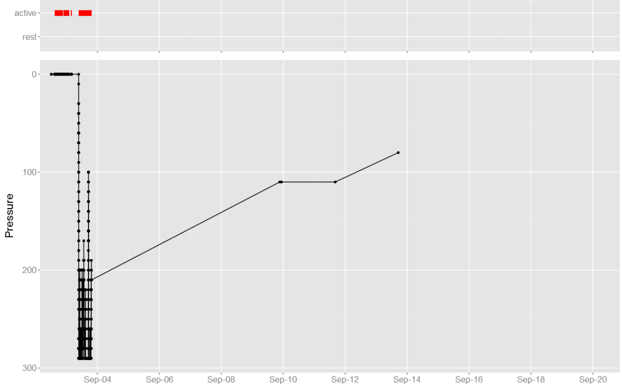
Tag ID = 57828

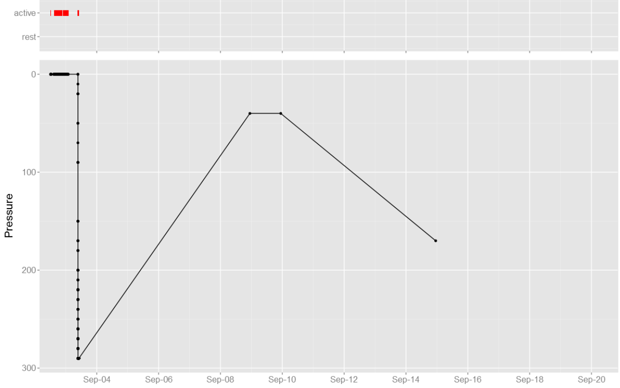


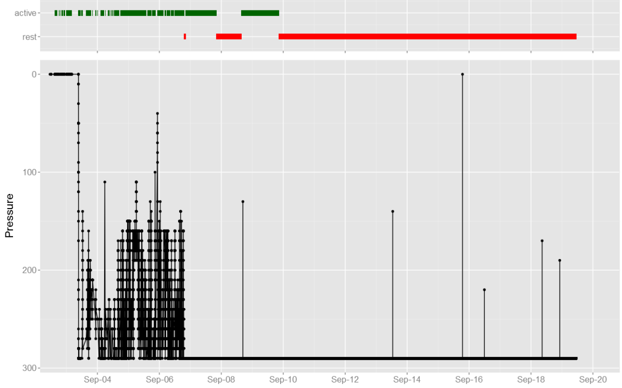

Tag ID = 57776

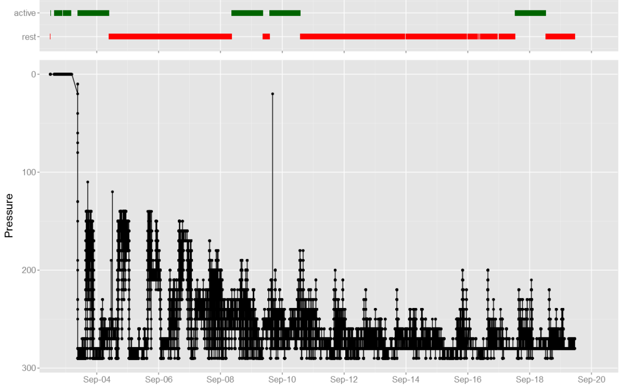

Tag ID = 57724

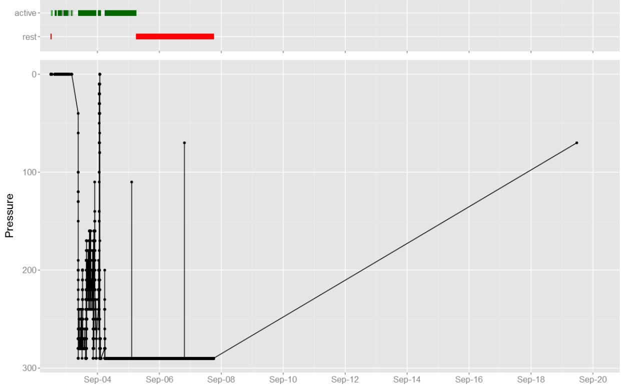

Tag ID = 57672


Tag ID = 57620

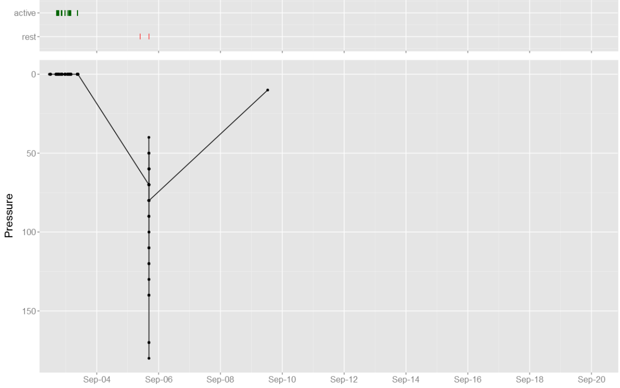

Tag ID = 57568


Tag ID = 57516

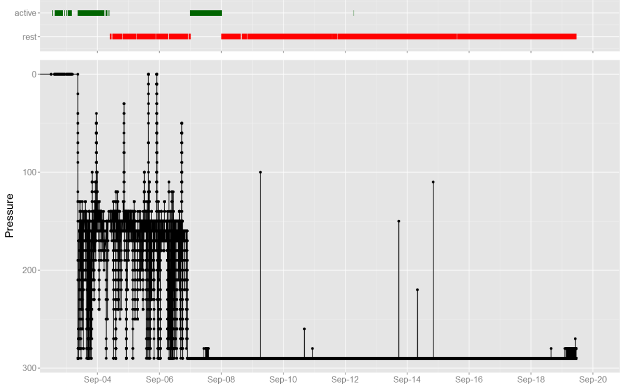

Tag ID = 57464


Tag ID = 57412

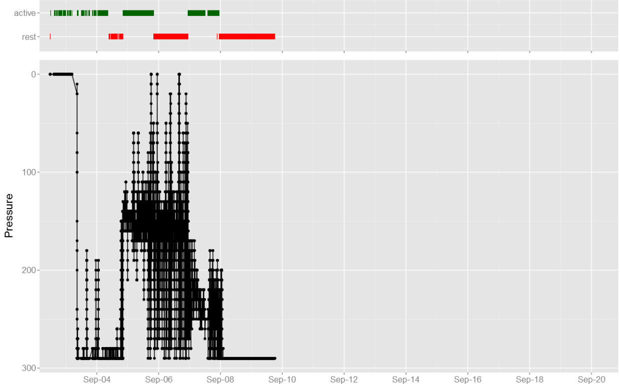
Tag ID = 57360



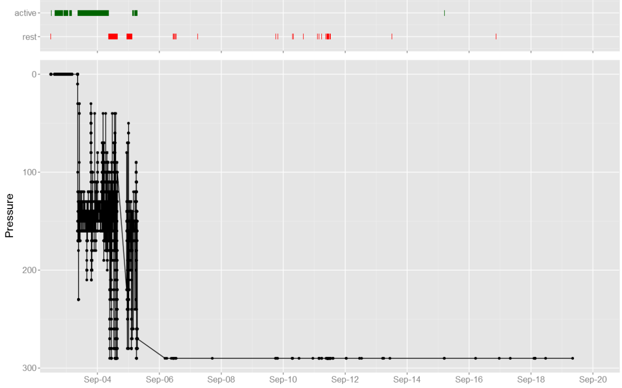
Tag ID = 57308



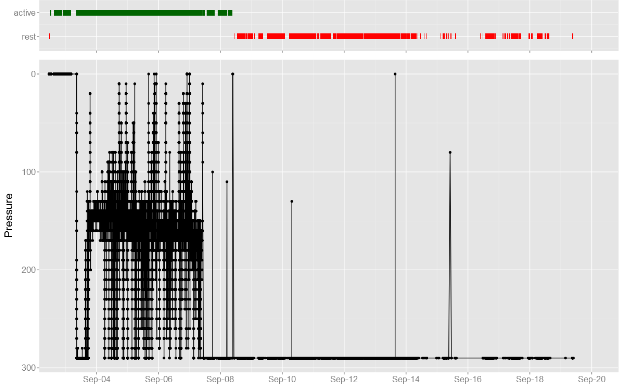
Tag ID = 57256



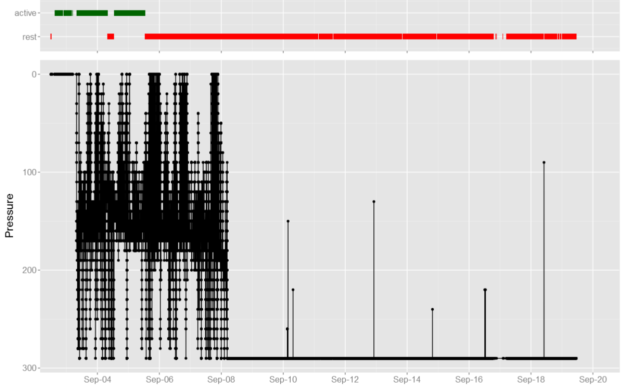
Tag ID = 57204



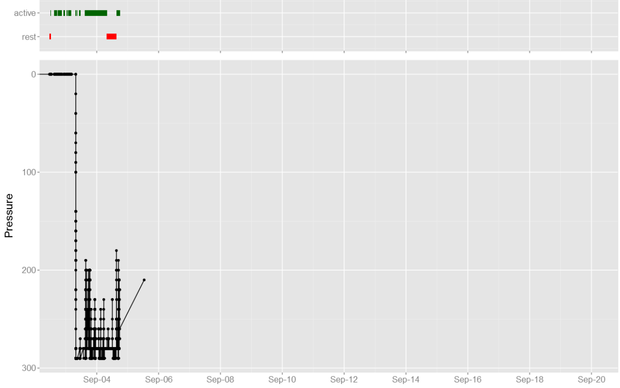
Tag ID = 57152



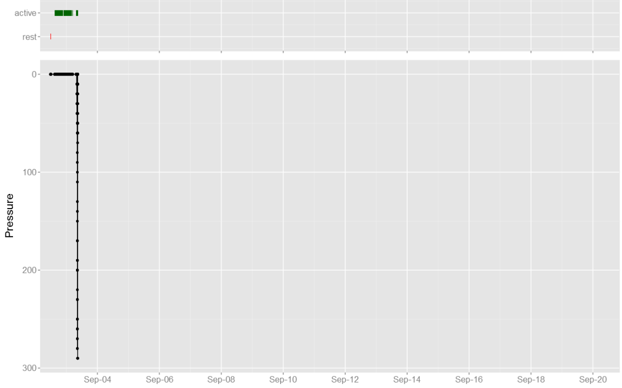
Tag ID = 57100

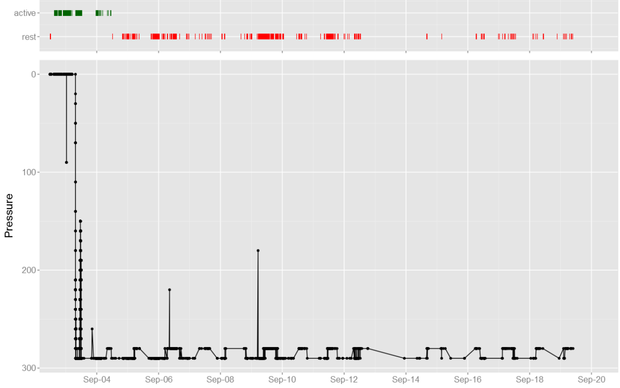


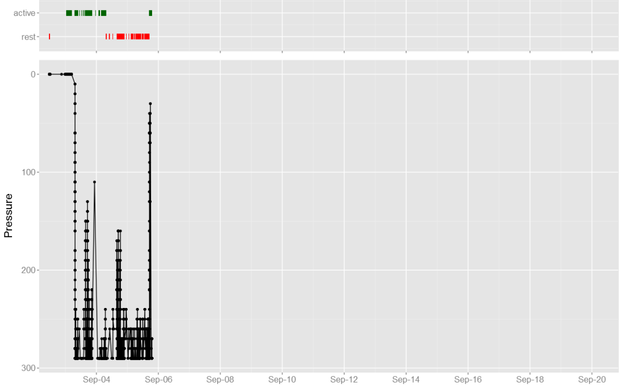
Tag ID = 57048

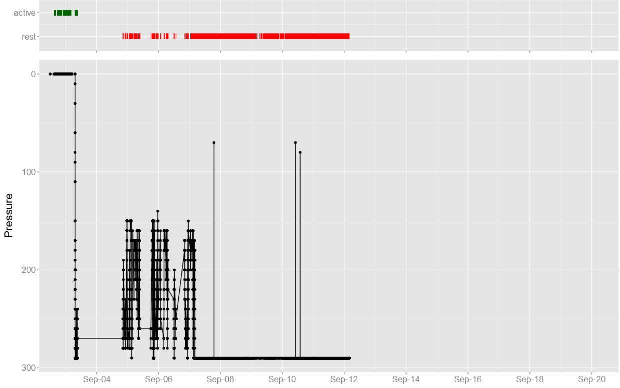


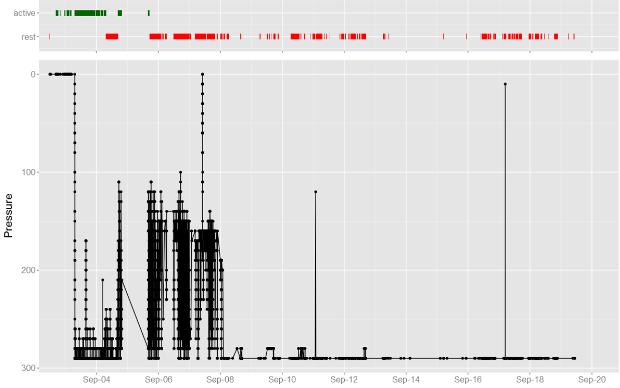
Tag ID = 56996

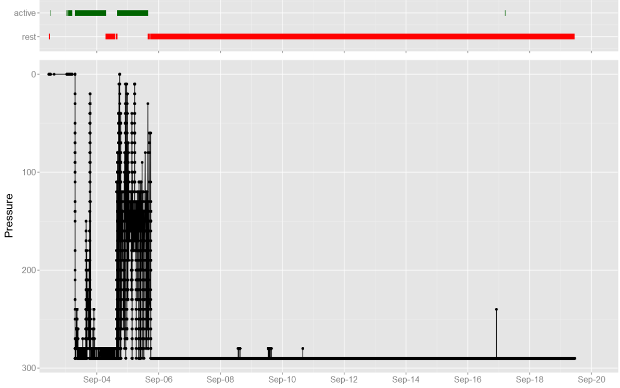


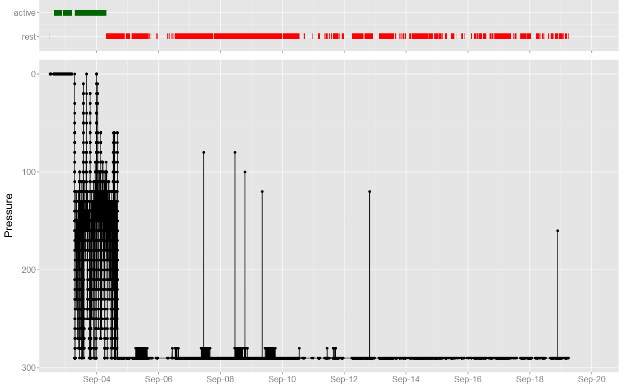

Tag ID = 56944

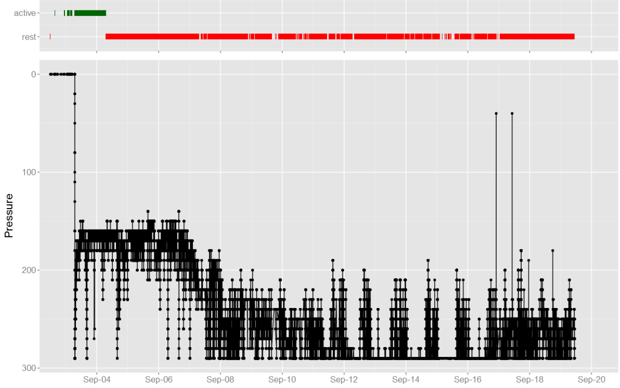

Tag ID = 56892

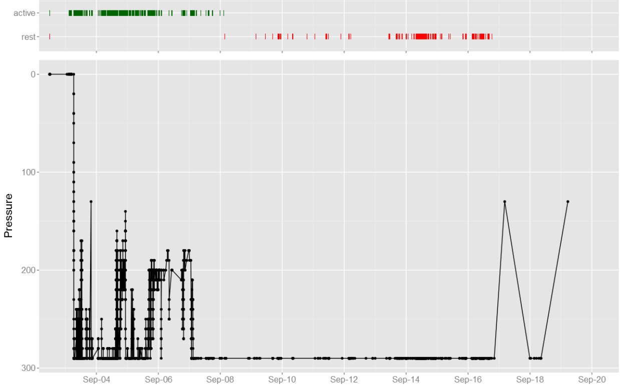

Tag ID = 56840

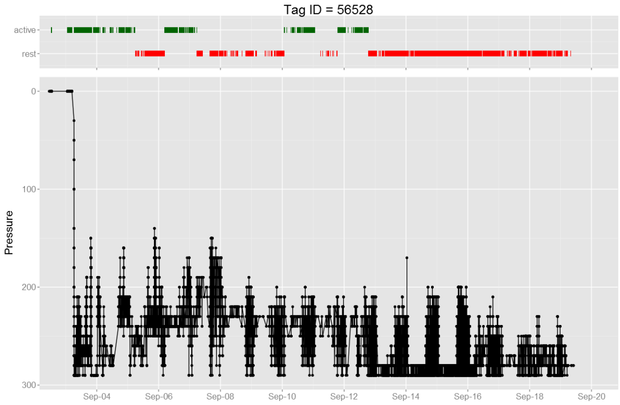

Tag ID = 56788

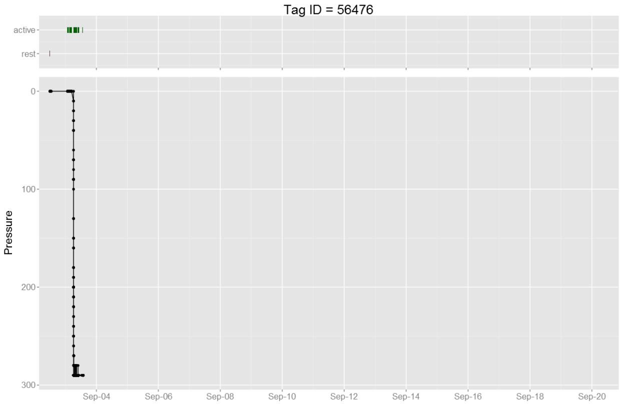

Tag ID = 56736

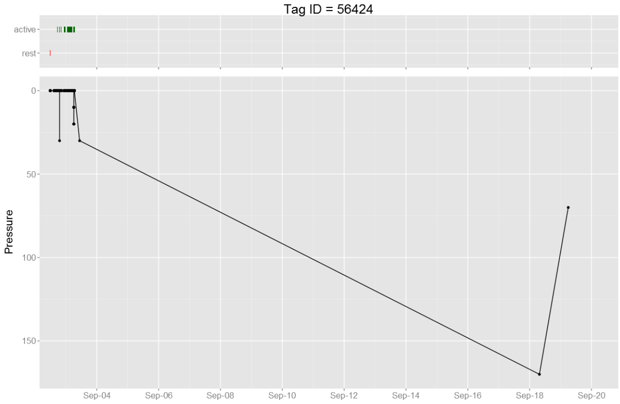

Tag ID = 56684

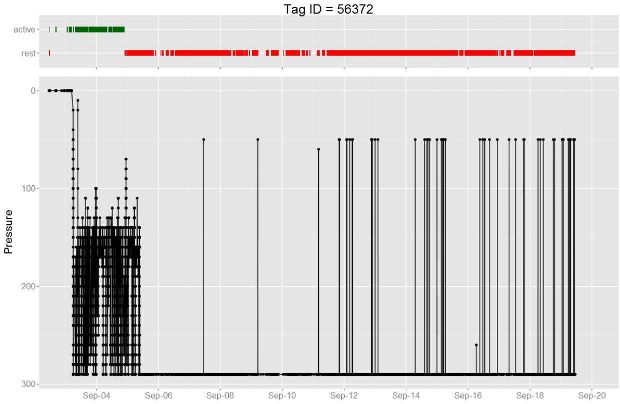

Tag ID = 56632

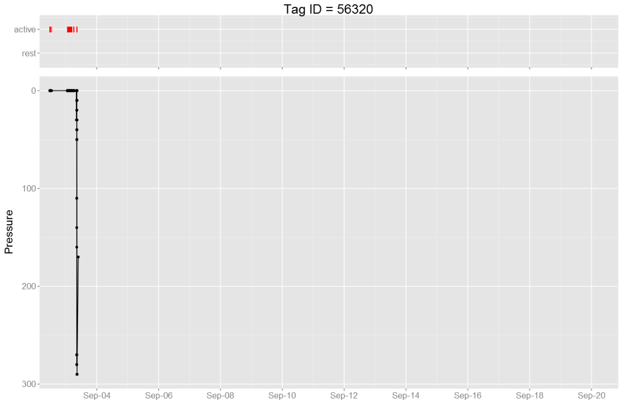

Tag ID = 56580

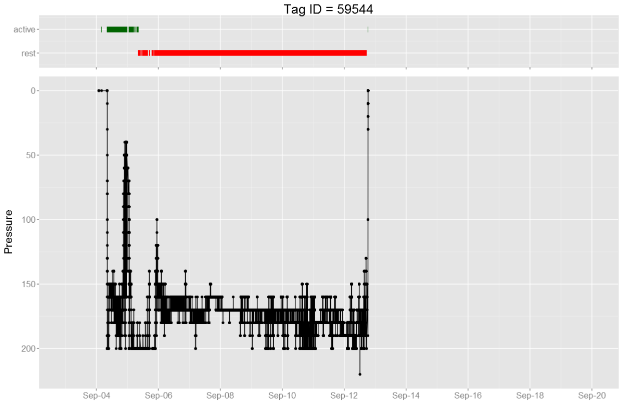

Tag ID = 56528
active
rest
Pressure
0
100
200
300
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20


Tag ID = 56476
active
rest
Pressure
0
100
200
300
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20


Tag ID = 56424
active
rest
Pressure
0
50
100
150
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20

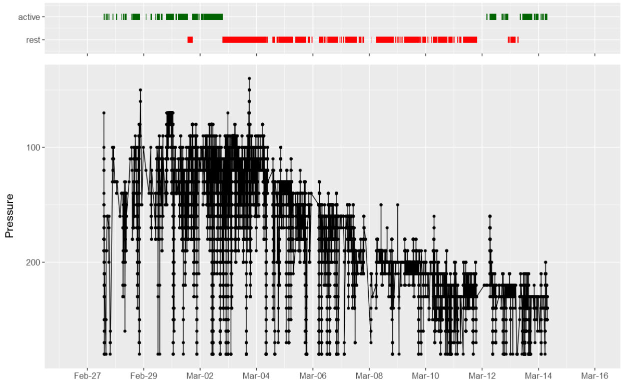

Tag ID = 56372
active
rest
Pressure
0
100
200
300
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20


Tag ID = 56320
active
rest
Pressure
0
100
200
300
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20

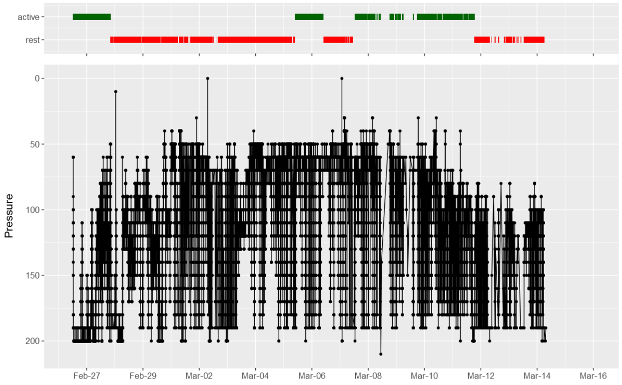

Tag ID = 59544
active
rest
Pressure
0
50
100
150
200
Sep-04
Sep-06
Sep-08
Sep-10
Sep-12
Sep-14
Sep-16
Sep-18
Sep-20

Appendix B: Winter Field Trials

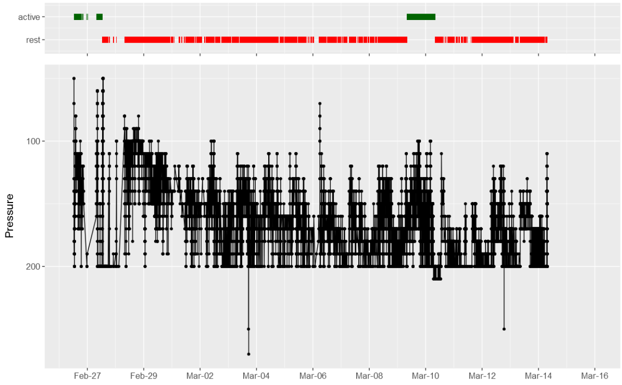
Tag ID = 57724



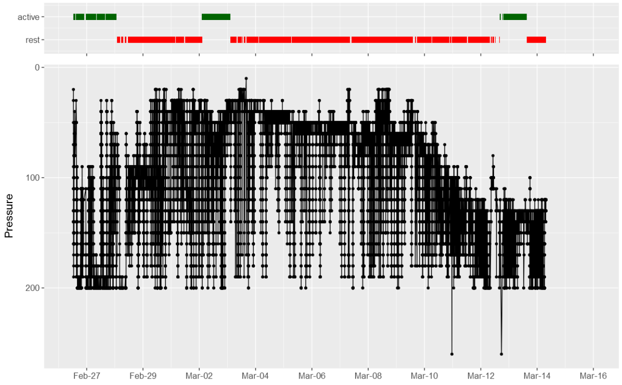
Tag ID = 54500



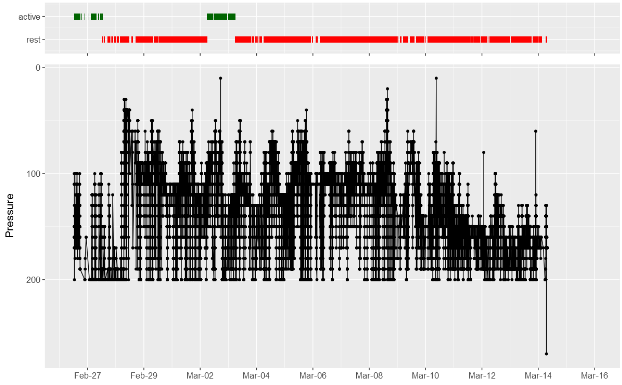
Tag ID = 54552



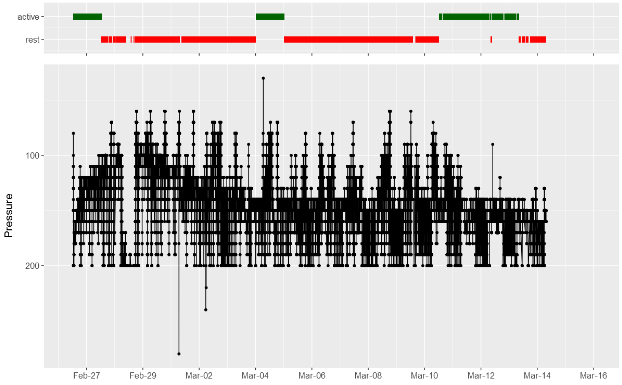
Tag ID = 54604



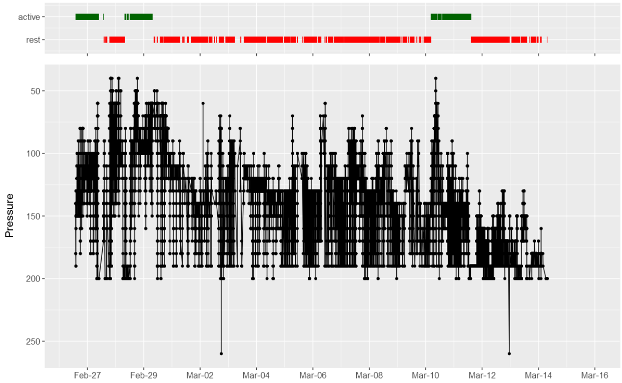
Tag ID = 54656



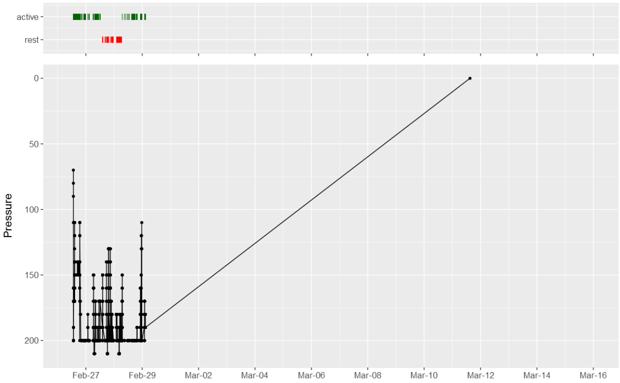
Tag ID = 54708



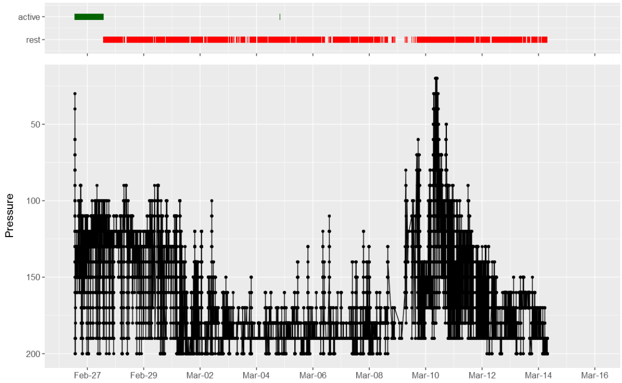
Tag ID = 54760



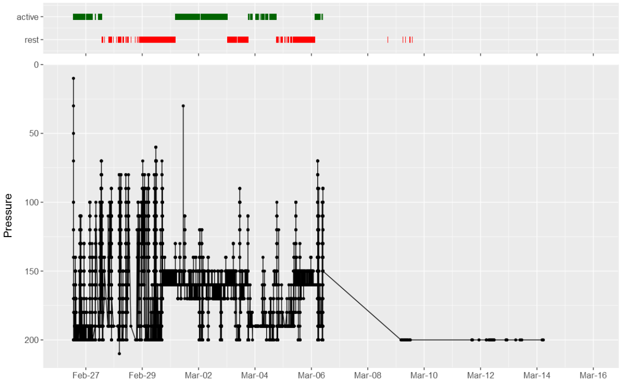
Tag ID = 54812



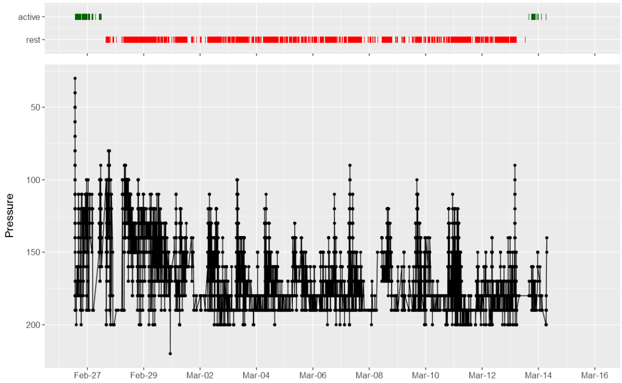
Tag ID = 54864



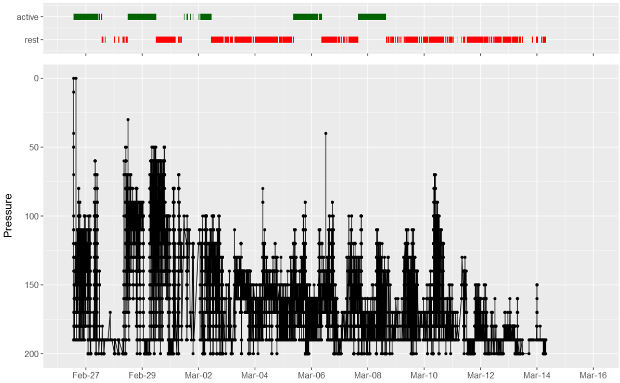
Tag ID = 54916



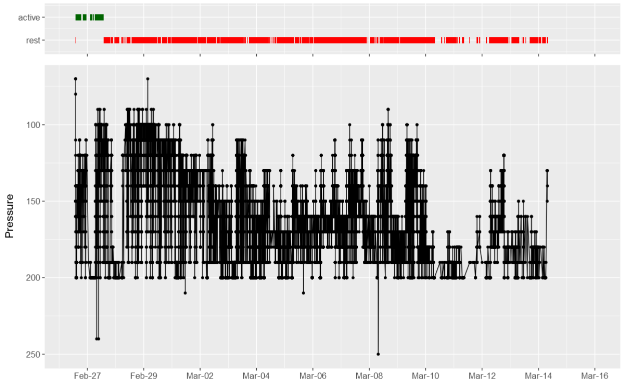
Tag ID = 54968



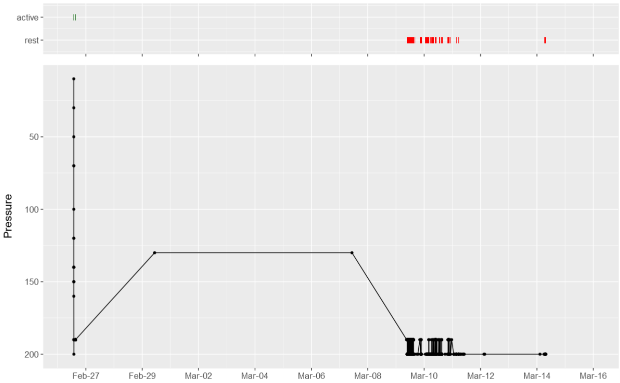
Tag ID = 55020

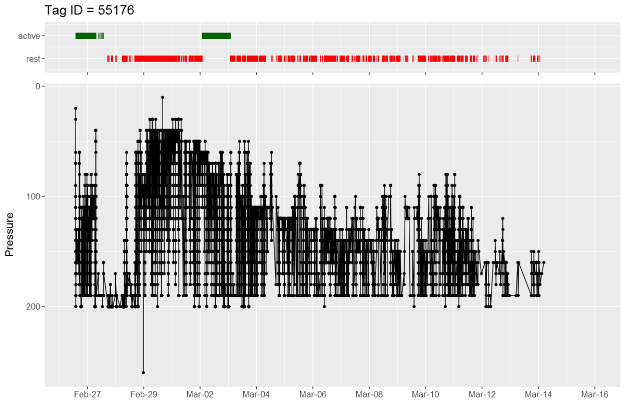


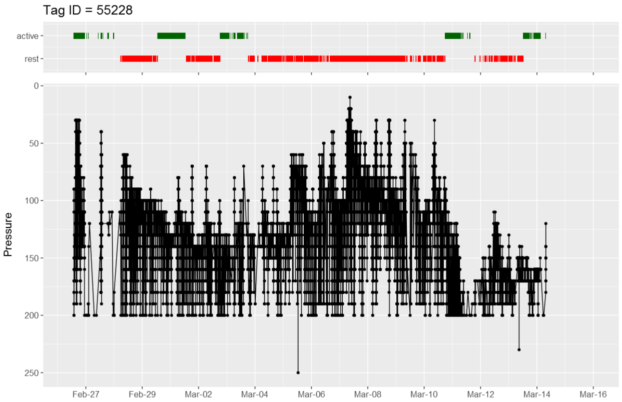
Tag ID = 55072

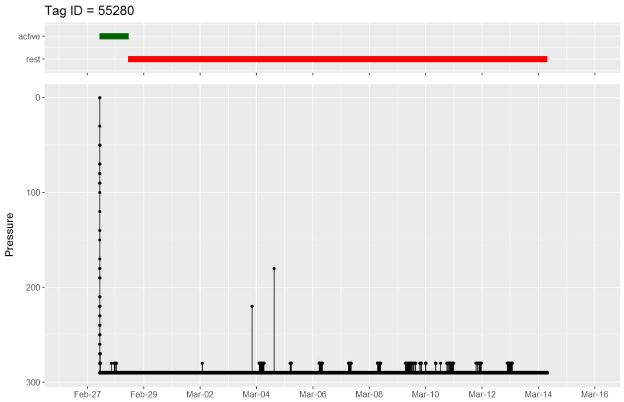


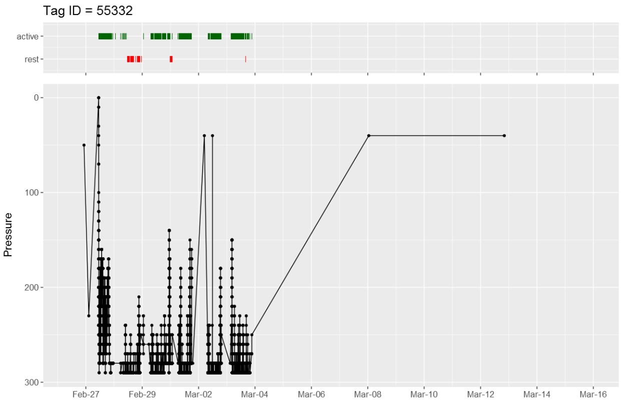
Tag ID = 55124

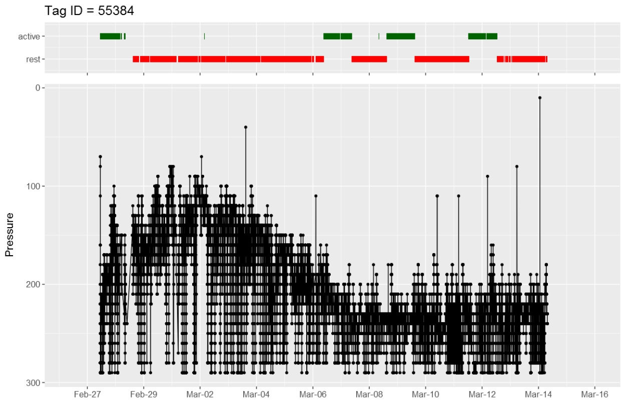


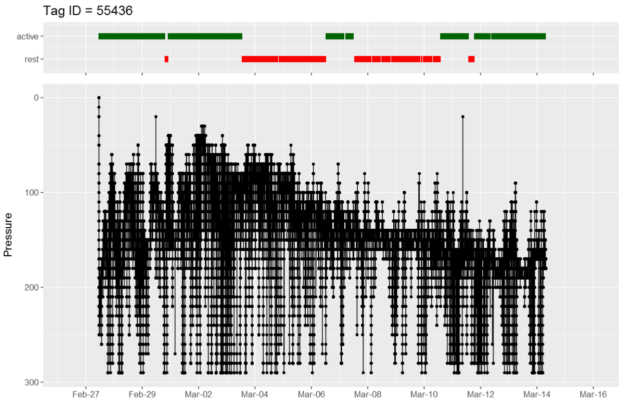

Tag ID = 55176
active
rest
Pressure
0
100
200
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

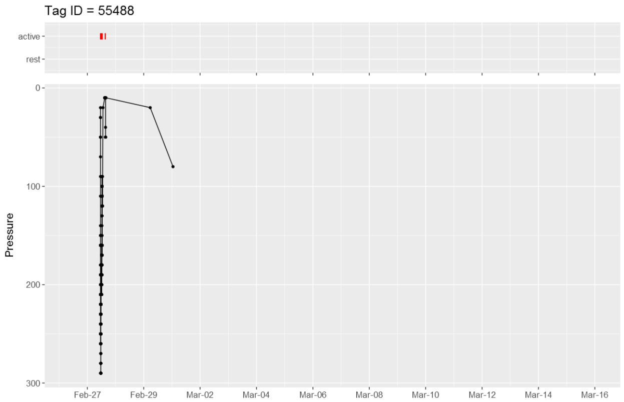

Tag ID = 55228
active
rest
Pressure
0
50
100
150
200
250
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

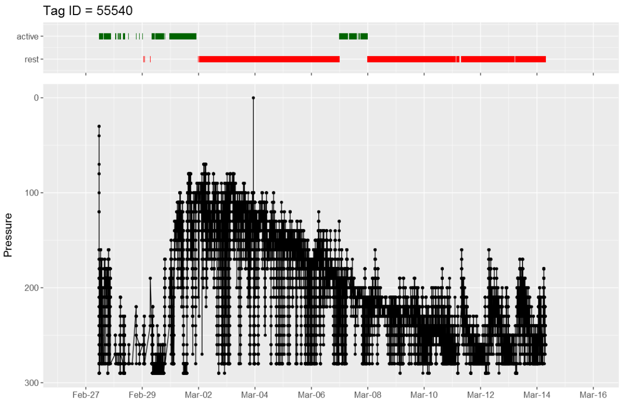

Tag ID = 55280
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

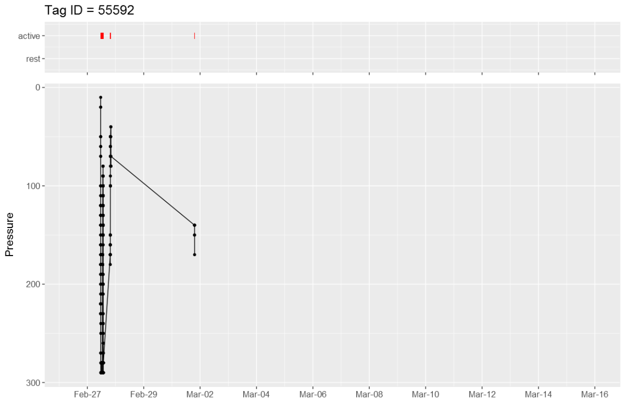

Tag ID = 55332
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

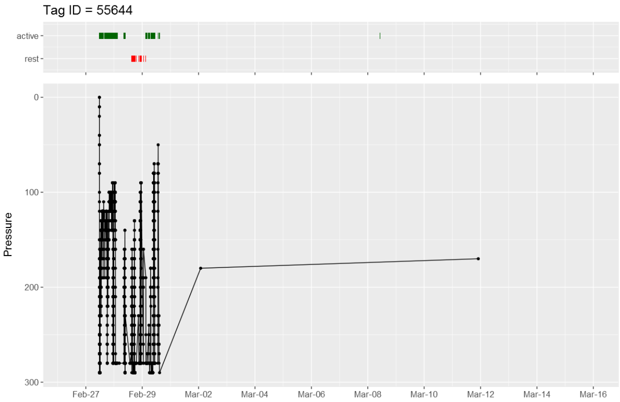

Tag ID = 55384
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

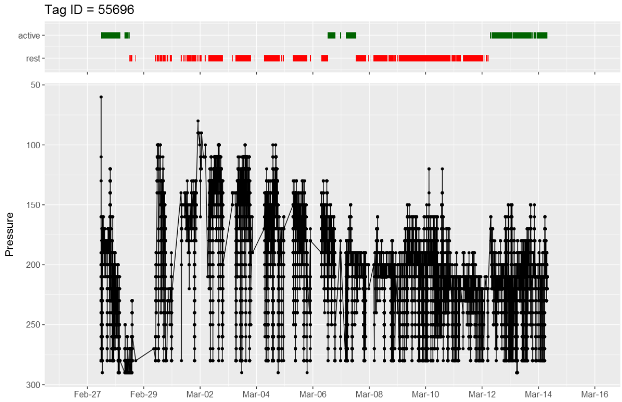

Tag ID = 55436
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

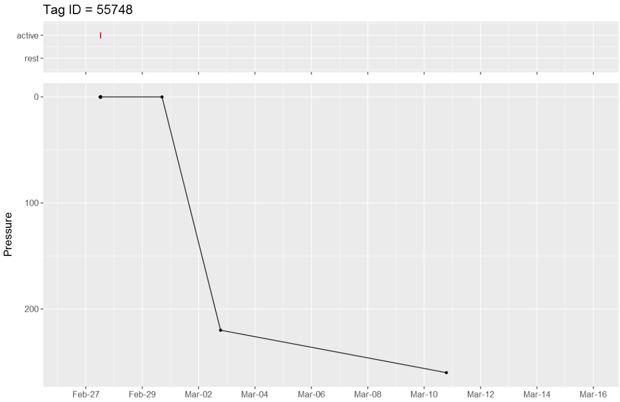

Tag ID = 55488
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

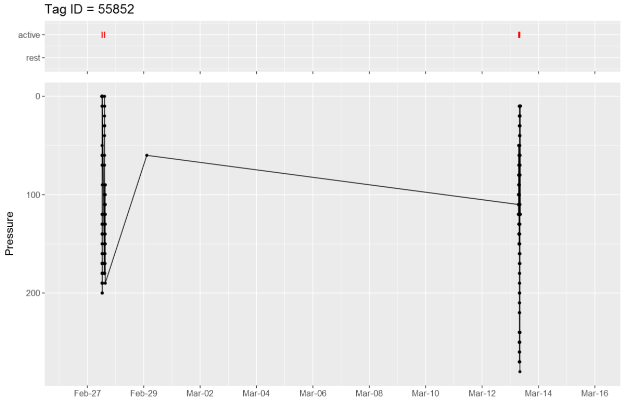

Tag ID = 55540
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

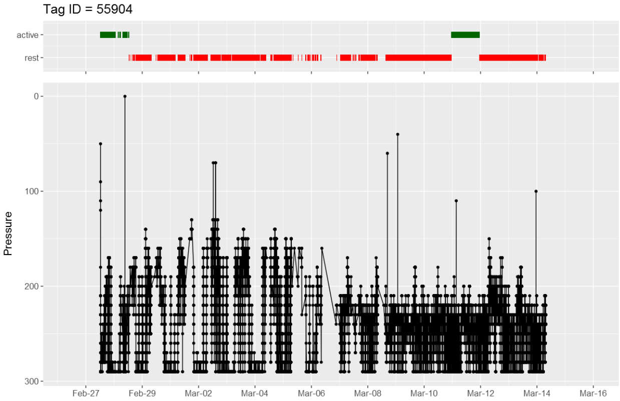

Tag ID = 55592
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

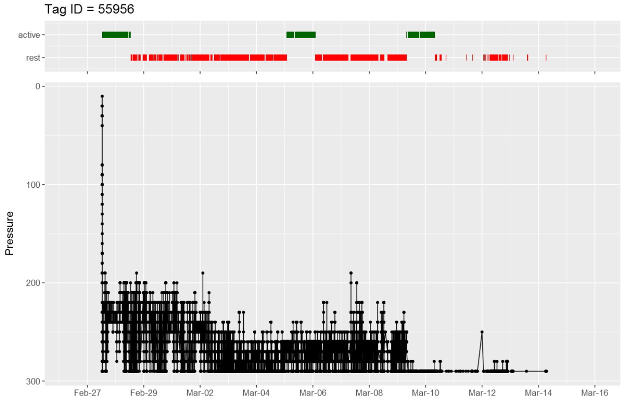

Tag ID = 55644
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

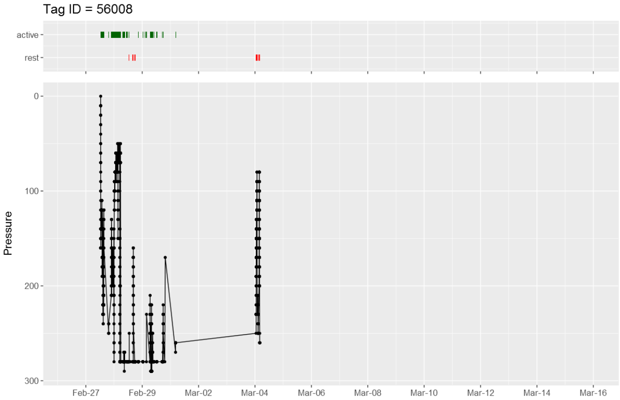

Tag ID = 55696
active
rest
Pressure
50
100
150
200
250
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

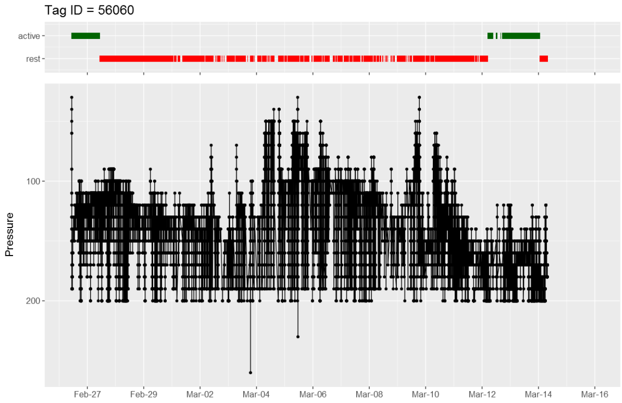

Tag ID = 55748
active
rest
Pressure
0
100
200
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

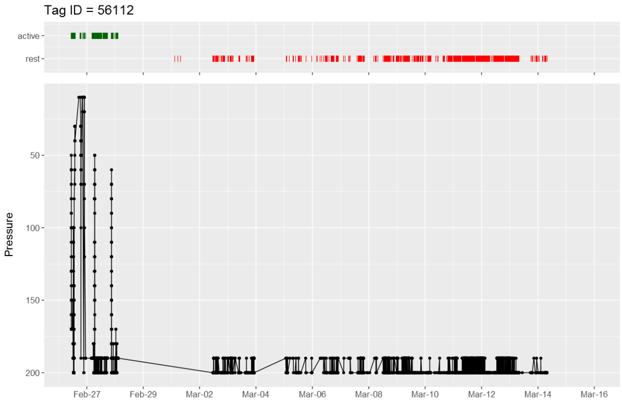

Tag ID = 55852
active
rest
Pressure
0
100
200
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

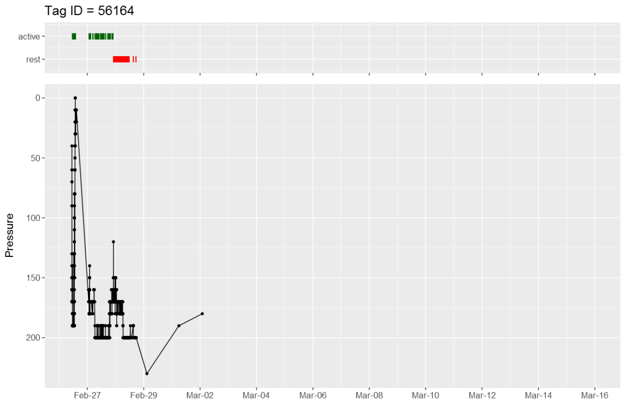

Tag ID = 55904
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

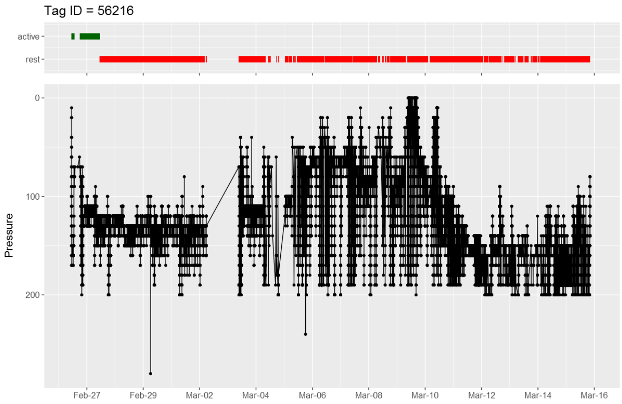

Tag ID = 55956
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

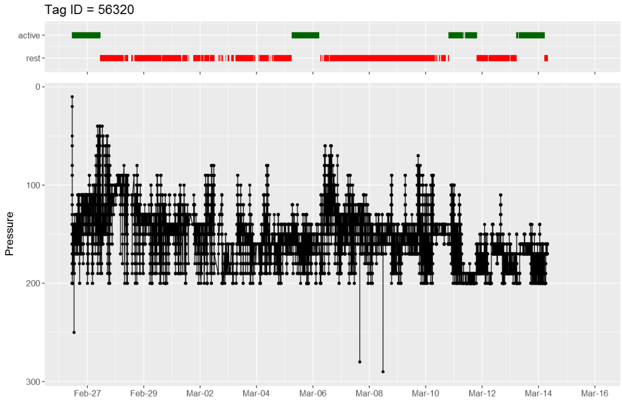

Tag ID = 56008
active
rest
Pressure
0
100
200
300
Feb-27
Feb-29
Mar-02
Mar-04
Mar-06
Mar-08
Mar-10
Mar-12
Mar-14
Mar-16

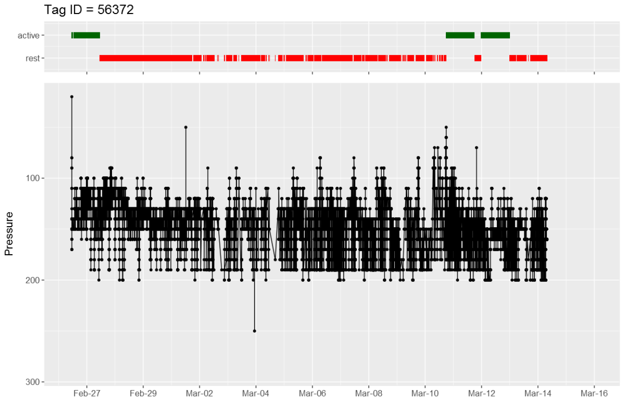

Tag ID = 56060

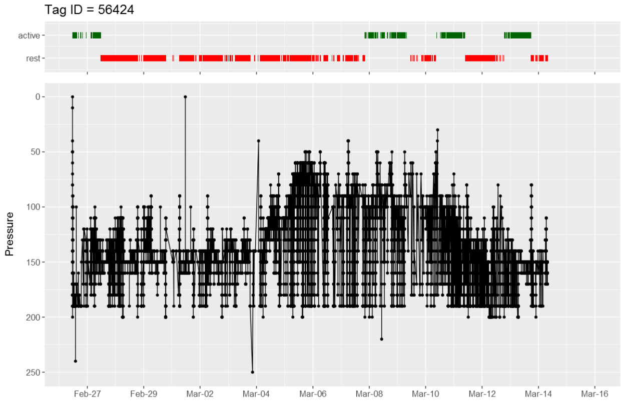

Tag ID = 56112

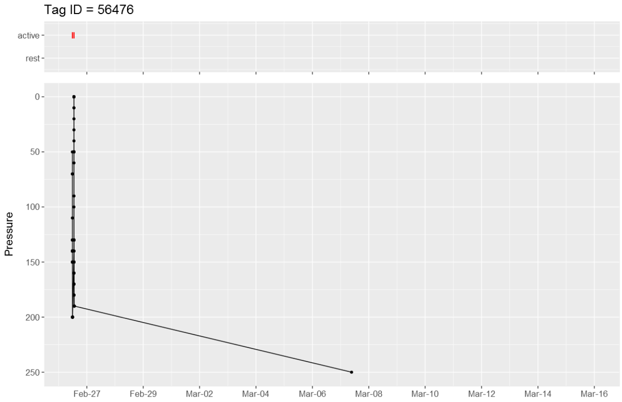

Tag ID = 56164

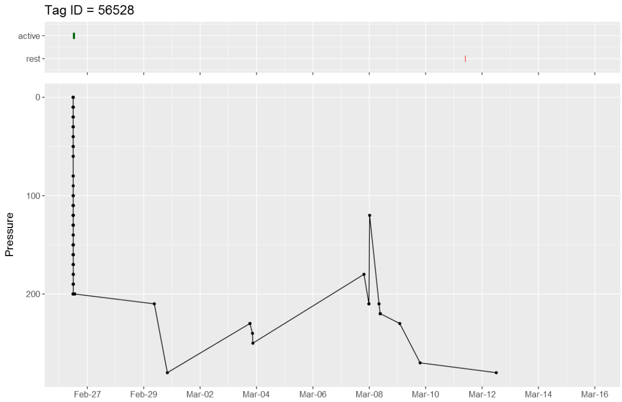

Tag ID = 56216

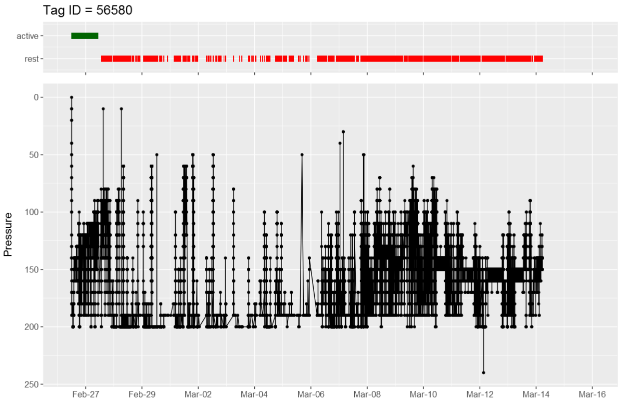

Tag ID = 56320

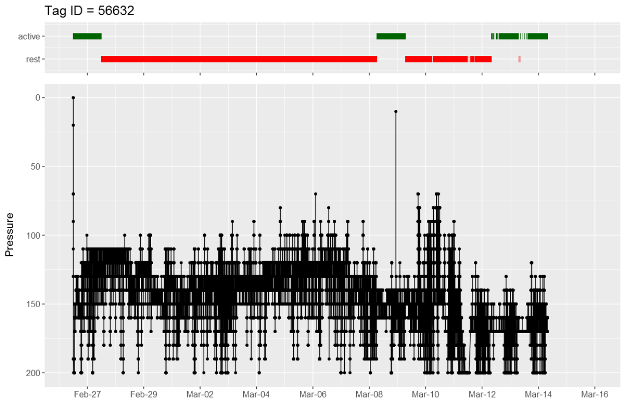

Tag ID = 56372

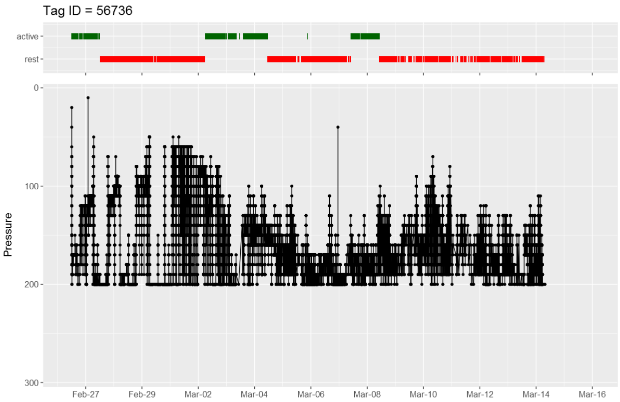

Tag ID = 56424

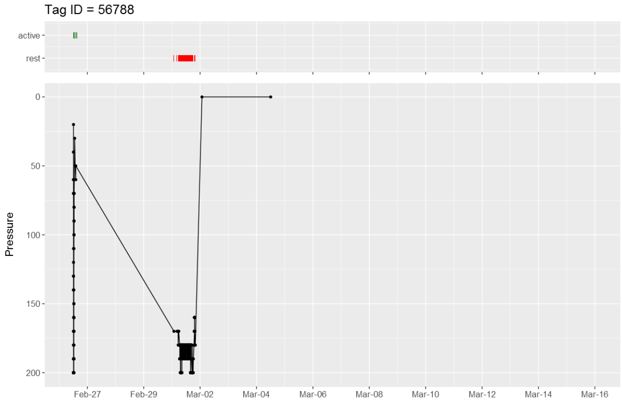

Tag ID = 56476

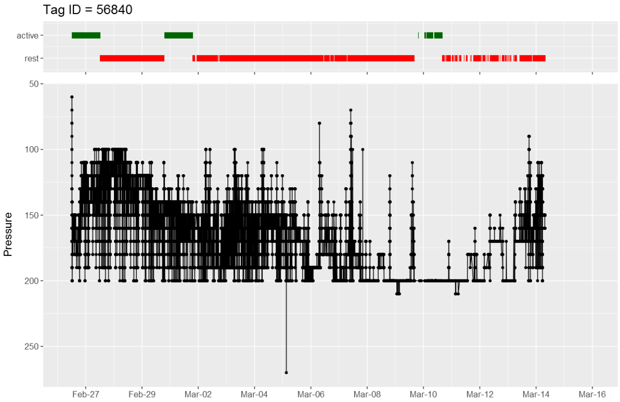

Tag ID = 56528

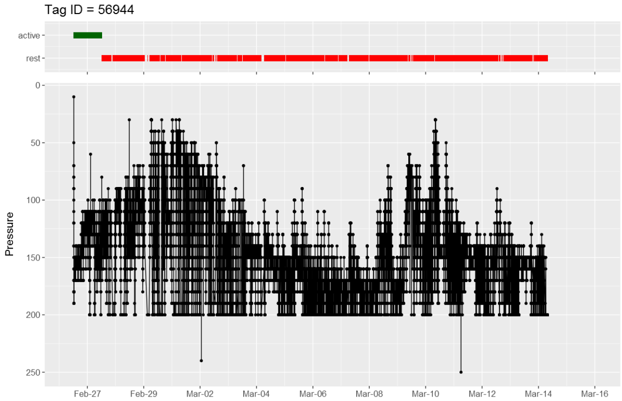

Tag ID = 56580

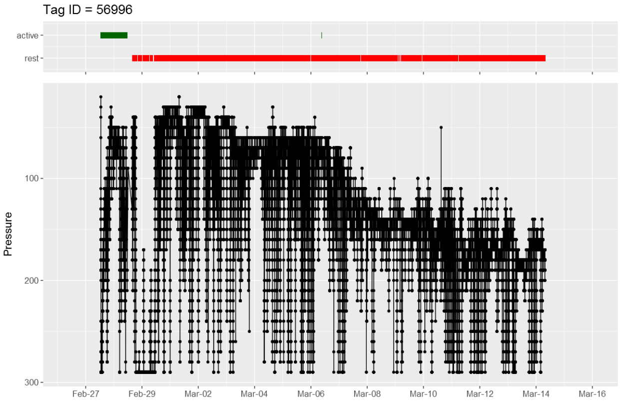

Tag ID = 56632


Tag ID = 56736

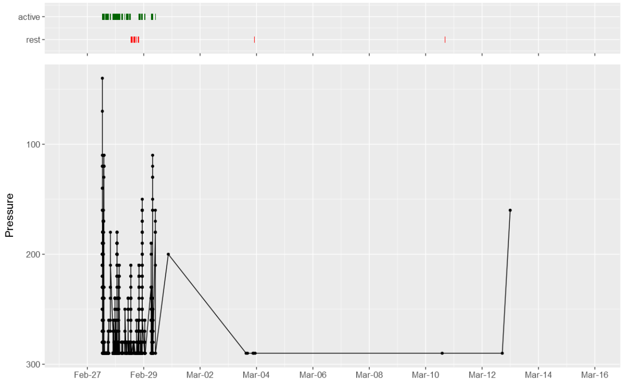

Tag ID = 56788


Tag ID = 56840

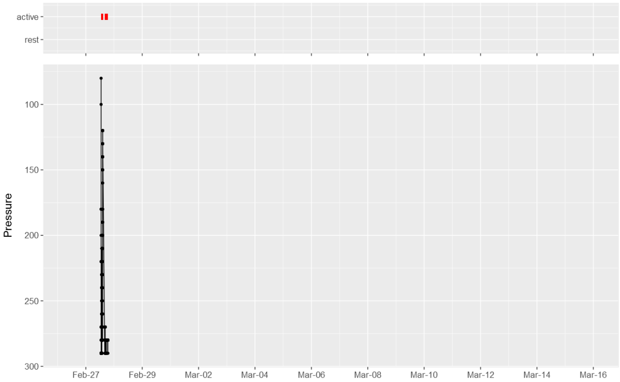

Tag ID = 56944


Tag ID = 56996

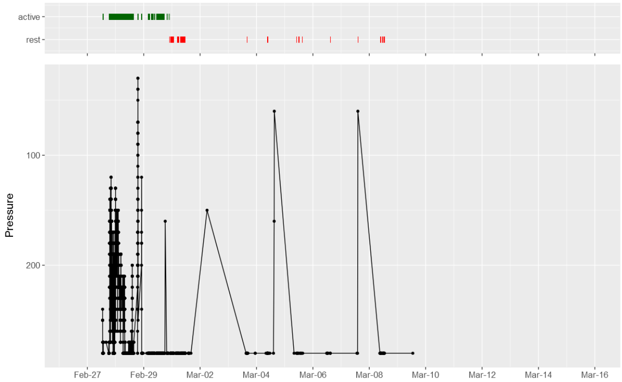
Tag ID = 57048



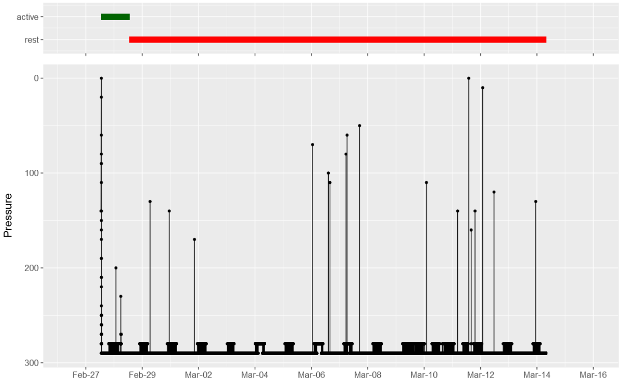
Tag ID = 57100



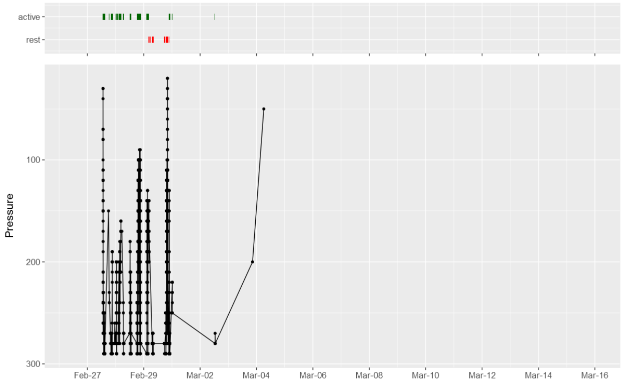
Tag ID = 57152



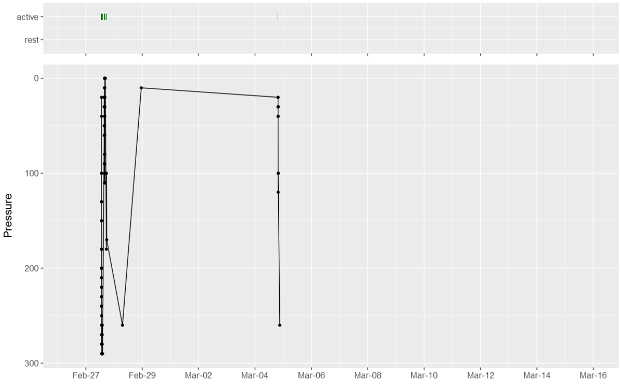
Tag ID = 57204



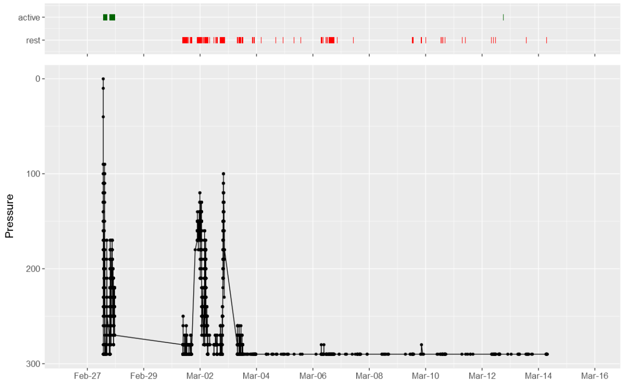
Tag ID = 57256



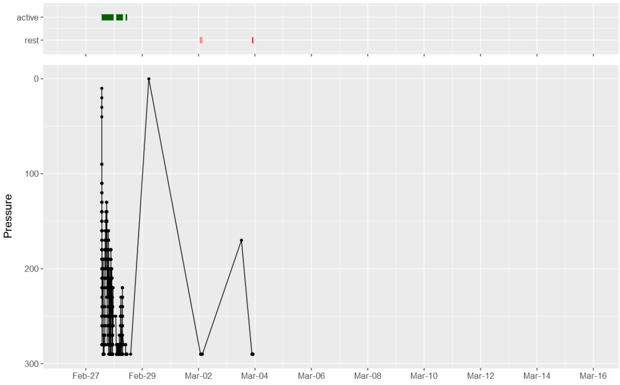
Tag ID = 57308



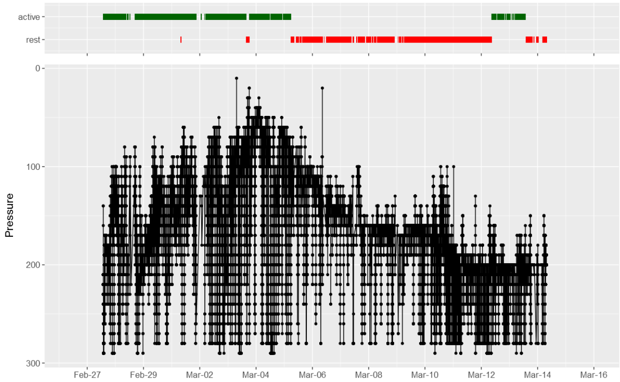
Tag ID = 57360



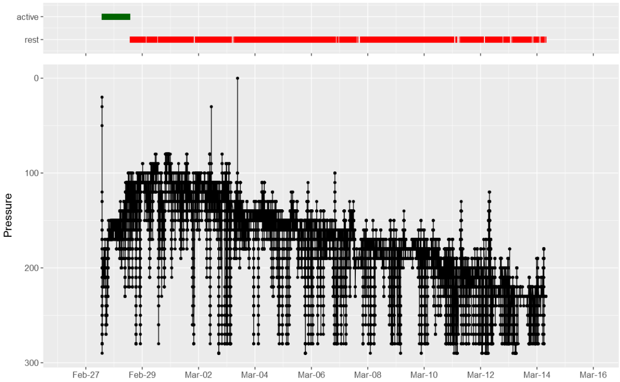
Tag ID = 57412



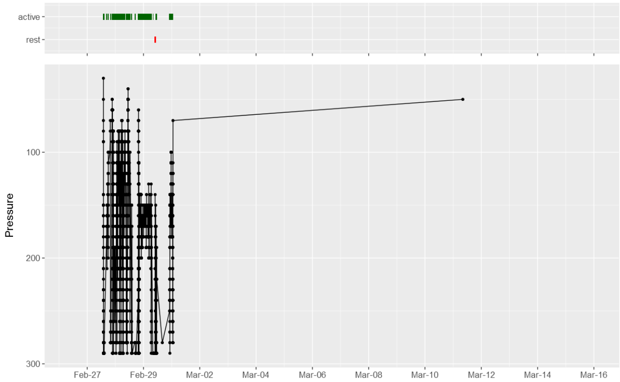
Tag ID = 57464



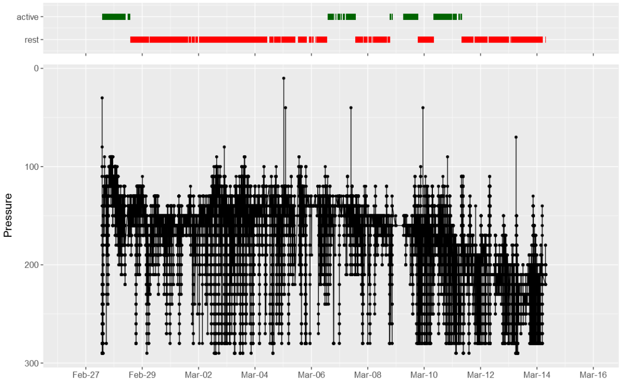
Tag ID = 57516



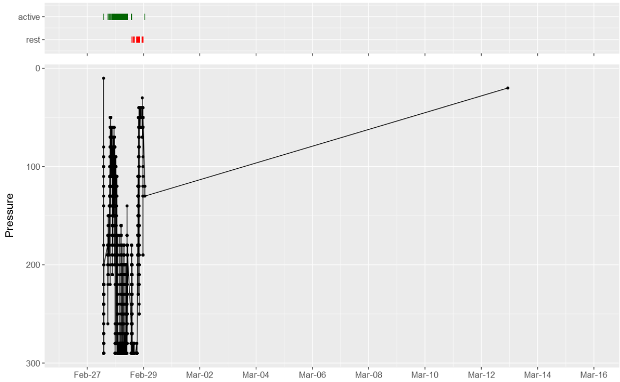
Tag ID = 57568



Tag ID = 57620



Tag ID = 57672



Appendix C: Recreational Angler Survey

Saltwater Fishing Participation Survey

Thank you for participating in this survey. Your contribution is an important part of effectively managing our fisheries resources along the Texas Coast. This survey is completely voluntary. There are no questions that will identify you as an individual and all responses are anonymous. The captain and crew of this vessel will not have access to the individual survey responses. This survey will take approximately 5 minutes to complete.

1. Are you male or female?

○ Female
○ Male

2. What is your age?

○ 18-21
○ 21-29
○ 30-39
○ 40-49
○ 50-59
○ 60-69
○ 70 or older

3. What is your race?

○ White
○ Hispanic
○ Black or African-American
○ American Indian or Alaskan Native
○ Asian
○ Native Hawaiian or other Pacific Islander
○ From multiple races

Some other race (please specify)

4. In what county do you currently live?

5. How many days did you fish offshore within the last 12 months?

6. What type of fishing vessel do you most commonly use when fishing offshore?

○ Private Fishing Vessel
○ Head-Boat
○ For-hire/Charter Boat

7. At what depth range do you commonly catch Red Snapper?

○ less than 75 ft
○ 75 - 125 ft
○ 125 - 175 ft
○ 175 - 225 ft
○ more than 225 ft

8. How frequently do you witness pressure-related injuries (barotrauma) in Red Snapper during fishing?

○ Always
○ Often
○ Sometimes
○ Rarely
○ Never

9. How much experience do you have using venting tools?

○ None ○ Very Little ○ Moderate ○ Quite a bit ○ Lots

10. How likely are you to use a venting tool prior to releasing Red Snapper?

○ Always
○ Very likely
○ Moderately likely
○ Slightly likely
○ Never

11. In your estimation, what percentage of Red Snapper that are vented will survive long-term?

○ 0 - 20 %
○ 20 - 40 %
○ 40 - 60 %
○ 60 - 80 %

○ 80 - 100%

12. How much experience do you have using fish descender devices?

○ None ○ Very Little ○ Moderate ○ Quite a bit ○ Lots

13. Which fish descender devices do you have experience using? (*Check all that apply.*)

☐ Shelton Fish Descender
☐ SeaQualizer
☐ Blacktip Catch & Release Recompression Tool
☐ RokLees Fish Descender
☐ Weighted Milk Crate
☐ None

Other (please specify) ☐

14. How likely are you to use a fish descender device prior to releasing Red Snapper?

○ Always
○ Very likely
○ Moderately likely
○ Slightly likely
○ Never

15. In your estimation, what percentage of Red Snapper released using a descender device will survive long-term?

○ 0 - 20 %
○ 20 - 40 %
○ 40 - 60 %
○ 60 - 80 %
○ 80 - 100%

16. Which factors do you perceive to be most beneficial for increasing survival in discarded Red Snapper? (*Check all that apply.*)

☐ Less Barotrauma Injury
☐ Reducing Fight Time
☐ Reducing Handling Time
☐ Smaller Fish Size
☐ Shallower Fishing Depth
☐ Cooler Water Temperature
☐ Using Descender Devices

☐ Using Venting Tools

Other (specify)

17. What are some of the challenges/difficulties in using fish descender devices?

18. What suggestions do you have for improving fish descender devices?

19. Other Comments?