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Observations of Visitation to Gray's Reef National Marine Sanctuary

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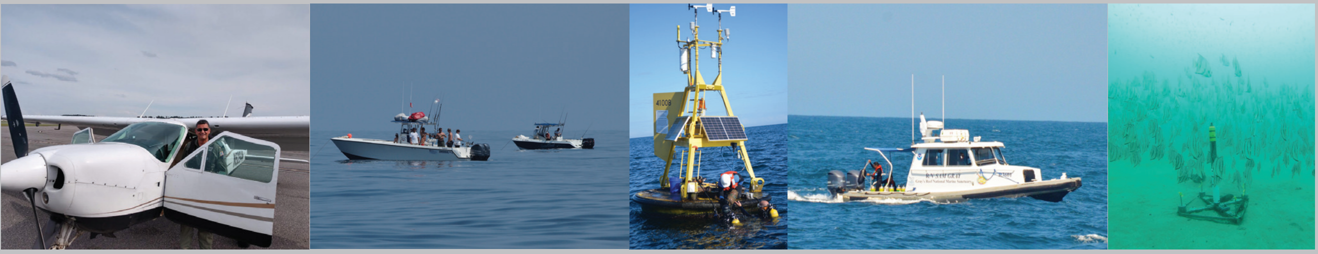

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Observations of Visitation to Gray's Reef National Marine Sanctuary

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September 2020

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Recreational fishing. Credit: Alison Soss.

Executive Summary

Basic information on the number and types of visitors to Gray's Reef National Marine Sanctuary (GRNMS) is needed to inform many management decisions. Despite this need, an understanding of visitor use has not progressed much beyond the anecdotal accounts compiled at the time of the sanctuary's designation in 1981. Recent technological advancements have resulted in three promising new datasets for assessing visitation. Commercially available satellite imagery, such as Maxar's WorldView constellation (www.digitalglobe.com), now provides a resolution (<1 m pixel size) and collection-revisit frequency (4-5 days) that may be sufficient to quantify visitation to offshore sites by small boats. Another potentially useful technology is a radial camera system on the weather buoy (buoy 41008) at Gray's Reef, which is operated by the National Data Buoy Center (www.ndbc.noaa.gov/). Although the camera is limited to viewing only visitors in the vicinity of the buoy, it makes digital photomosaics of its surroundings available on-line at 2 hour intervals every day. Lastly, hydrophones have been deployed in three locations within the sanctuary through the NOAA-Navy SanctSound project (https://sanctuaries.noaa.gov/science/monitoring/sound/). These instruments provide a continuous record of underwater sounds including vessel presence and behavior (e.g., transit, maneuvers).

Some boats in the sanctuary utilized Gray's Reef as a destination. Others were merely passing through on their way between destinations along the busy north/south transit corridor off the Atlantic seaboard. In this study, we quantify the proportion of those vessels merely passing through but focus on "visitation" defined as those boaters most likely to be deliberately targeting sanctuary resources.

We summarize several types of information made possible from these data including size, type, and number of boats seen or heard, daily and seasonal patterns of visitation, location of visitors within the sanctuary, and inferred activity (e.g., trolling, maneuvering) based on wake patterns and acoustic characteristics of vessel sounds. In addition to evaluating these novel datasets, we compile and summarize the smaller but still useful volume of information that is available from on-water or aerial surveys conducted by Georgia Department of Natural Resources, the U.S. Coast Guard Air Auxiliary, and GRNMS staff. Given the ever changing nature of use at Gray's Reef, and to focus this assessment on present day visitation patterns, only data from ~2015 onward is considered in detail for this report. Where appropriate however, older datasets are discussed to provide context on changes in monitoring or visitation.

These datasets included 1,228 discrete observations of surface waters as well as continuous underwater sound recordings for 2019 at Gray's Reef. There were 85 boats observed in the buoy camera images (out of 1,093 photomosaics), 34 in the Worldview satellite images (40 scenes), 527 in acoustic SoundTrap data (586 monitoring days at two sites), 63 in the Georgia DNR reports (66 patrol dates), 13 in the US Coast Guard Air Auxiliary surveys (18 overflights), and 22 in the GRNMS Research Vessel (R/V) field reports (11 dates).

Analysis of these diverse observational datasets enabled us to characterize the general patterns of visitation in several ways. Nearly all visitors (~90%) are arriving in small recreational fishing boats ~26 feet (8 m) long with outboard engines/center console design. There are typically 3 to 4 persons on those boats. A small percentage of boats observed in the sanctuary are yachts, sailboats, or sportfishers that appear to be merely passing through. Approximately 60% of visitors are bottom fishing, ~25% are trolling, and the remainder are most often just passing through. Tournament days for particular species such as king mackerel dramatically affect this ratio. Only two boats were engaged in suspicious looking activities in the Research Area based on satellite data, and only 1 has been cited with a fisheries violation in 5 years of Georgia DNR patrols. There are no doubt, other forms of visitation not captured in the data, such as charter fishing trips and scuba diving, however, their lack of appearance in data used here indicates their rarity.

Warmer months including May through September comprise the peak of visitation, but it is clear that boats can be found in any season of the year provided that weather conditions are suitable. The early days of the week, Monday-Thursday, are least likely to see visitors. Saturday is the most common day of the week for visitors (4 to 9 times more boats than Monday through Wednesday), with Friday and Sunday experiencing intermediate levels of use. Visitation can take place at any time of the day but is most common from 9 am to 1 pm (~90% of visitors).

From these analyses we are also able to evaluate the strengths and limitations of each technique or dataset for assessing visitor use. We describe the types of variables that each dataset can provide about boats (e.g., basic count, type, and size) and anglers (e.g., count per boat, specific activities such as bottom fishing or trolling). We also include information on sources of bias (e.g., weather, angler behavior, and spatial scope) and temporal aspects of each dataset (e.g., frequency of collection, time of day, season, and longevity of the dataset). Last, we provide recommendations for improvement during collection of each data type to enhance information on visitor use at Gray's Reef.

Use of multiple methods for counting visitors is advisable, especially when no single method provides all of the unbiased information needed. This is definitely the case for visitor use information at GRNMS. For future visitation monitoring, an effective combination of data can include: 1) the buoy camera which provides imagery at two hour intervals every day, and is largely unaffected by weather, but is limited in spatial scope, 2) hydrophones which provide continuous acoustic monitoring with automated vessel recognition, but limited range, 3) satellite and Coast Guard Air Auxiliary overflights which best document spatial aspects of usage not only within the sanctuary, but also relative to fishing sites elsewhere offshore from Georgia, 4) Georgia DNR enforcement patrols which provide needed information on regulatory compliance, species targeted, anglers per boat, and are focused primarily on weekends, and 5) GRNMS R/V observations which fill in the weekday scarcity in observations and can be done opportunistically as part of other research activities.

Recreational boats. Credit: GADNR

Offshore catch. Credit: Alison Soss.

1.0 INTRODUCTION

1.1 VISITATION AT GRAY'S REEF

Basic information on the number and types of visitors to Gray's Reef National Marine Sanctuary (GRNMS) is needed to inform sanctuary staff and the advisory council on many management decisions, especially those involving human use and their impacts. Any changes in access, regulations, promotion, or limitations of human use must carefully consider all consequences to the people who are affected. Despite this clear need, an understanding of visitor use at GRNMS has not progressed much beyond the anecdotal accounts compiled at the time the sanctuary was originally designated in 1981 (NOAA 1980).

> *"There are no comprehensive data available on the number of vessels which frequent Gray's Reef. Estimates are that 10 to 20 private boats fish the reef on weekends from April to September, assuming favorable weather conditions. Fishing activity is significantly less during the remainder of the week (Doss, 1979, pers. comm.; Fendig, 1979, pers. comm.)."*

The presence of game fish such as black sea bass (*Centropristis striata*), king mackerel (*Scomberomorus cavalla*), red snapper (*Lutjanus campechanus*), gag (*Mycteroperca microlepis*), and scamp grouper (*Mycteroperca phenax*) make Gray's Reef a popular site for recreational fishing (Bird et al. 2001, Kendall et al. 2008a, NOAA 2014 a, b). Although the dominant user group is known to be recreational anglers, the number and size of boats, number of individuals per boat, and frequency of visits remain poorly quantified (NOAA 2014 a, b). There is also not an adequate understanding of temporal aspects of visitation such as relative intensity of fishing activities among seasons, days of the week (e.g., weekend versus weekdays), or time of day. This lack of robust quantitative information about visitors has persisted for nearly four decades.

Once human use has been quantified, statistics can be used for a wide variety of applications, environmental impact assessments, and to decide among alternative management actions. Law enforcement can optimize their schedule of patrols to achieve the most benefit for the least cost. Natural resource managers can incorporate catch statistics and fisherman density into estimates of mortality to promote sustainable fisheries. Even the contribution of the sanctuary to the local economy can be estimated. Although compliance with regulations including the no-take Research Area are assumed to be satisfactory (NOAA 2014 a, b), definitive data do not exist. Ultimately, with information on visitation, the sanctuary can better facilitate compatible uses while ensuring that the resources are maintained for the enjoyment of future generations.

From the 2014 GRNMS Management Plan (NOAA 2014 a):

Objective SR-5: Facilitate compatible sanctuary uses over the next five years ensuring that the resources are being maintained at a level of good.

Activity SR-5B – Sanctuary use data: Collect and assess data on sanctuary users and uses.

Activity SR-5E – Law enforcement: Support and enhance enforcement of regulations in the sanctuary with partners NOAA Office of Law Enforcement, Georgia Department of Natural Resources Law Enforcement Division, NOAA Office of General Counsel Enforcement Section, and the U.S. Coast Guard.

Activity SR-5F – Sanctuary use programs evaluation: Synthesize and review results from user data, law enforcement and compliance, permitting, and regulatory changes for potential future management applications. Adapt programming as needed to protect sanctuary resources.

1.2 METHODS FOR COUNTING BOATS

There are several factors contributing to the ongoing challenge of counting visitors to Gray's Reef. This 58 km^2 sanctuary is located 30 km (19 mi) off the coast of Georgia, roughly one-third of the way from the shore to the edge of the continental shelf (Figure 1.1). The small size of the recreational boats (i.e., Class 1-2 or 20-30 feet long) suspected to be the primary visitors, as well as the sanctuary's distance from shore have meant that until recently, the only way to get observations of boaters at the sanctuary was to go there via boat or airplane and watch. Indeed, boat- or airplane-based observations have been conducted on a limited basis through deliberate or opportunistic counts by sanctuary staff as well as through partnerships with the

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Georgia Department of Natural Resources (GA DNR) and US Coast Guard Air Auxiliary from as long ago as 1979. Those data have never been formally compiled or published. Such an approach to counting visitors is however, prohibitively costly and time consuming for the sanctuary, GA DNR, or US Coast Guard to staff and conduct with the needed regularity (e.g., weekly).

Other techniques effectively used to assess visitation elsewhere have proven untenable at Gray's Reef. The Vessel Monitoring System (VMS) and Automatic Identification System (AIS) have been used for tracking the activities of larger commercial fishing fleets and other vessels (Shepperson et al. 2018), but rely upon boats equipped with satellite transponders. These systems are therefore effective at quantifying larger boats passing through the sanctuary, however, these data are not likely to include visitors that are actually stopping and using the sanctuary. Those users are presumed to be on small, privately owned, recreational boats that seldom have such positioning systems. Cell phones have been used in some areas to assess visitation (Barros et al. 2019), however, Gray's Reef is out of connection range for shore-based cell towers. Visitors typically turn their phones off while offshore, making that also an ineffective assessment tool. Shore-based camera systems mounted on coastal promontories (Parnell et al. 2010, Keller et al. 2016, Lancaster et al. 2017) or at boat ramps (Hartill et al. 2016, Flynn et al. 2018) have been successfully used to monitor recreational fishing activity in some marine areas, however, again the distance offshore and departure from private docks prevent those techniques from being effective in this setting. Even underwater surveys for marine debris such as fishing line have been used as an indirect way of measuring visitation (Bauer et al. 2008). Despite initial success at identifying relative intensity of fishing pressure across the sanctuary, and the establishment of regular survey locations and protocols to facilitate monitoring of accumulation rates (Bauer et al. 2010), even that has proven difficult to sustain by sanctuary staff constrained by limited resources. Satellite based approaches have also previously been used through partnerships with the US Government. While these met with some success (Kendall et al. 2008b), they are also severely impacted by constraints on accessibility and interpretation of the raw data.

Various methods from the fields of social science, human geography, and economics have also been effective for understanding aspects of visitation at GRNMS. Information from visitors and the general public about their knowledge and use of Gray's Reef has been gathered using in-person, telephone, and mail-based questionnaires. While they are too infrequent and expensive to implement for annual monitoring, these methods have served to develop an understanding of the uses and users of the sanctuary based on opinions and recollections of the people in coastal Georgia (Ehler and Leeworthy 2002, Loerzel et al. 2018). Information gathered has focused on specific types of anglers (Bird et al. 2001, Ehler 2008), those affected by particular rules or regulations (Ehler 2008, Ehler 2009), and participants in the general comment periods of sanctuary management plan revisions or public meetings (NOAA 2014 a, b). These studies have greatly informed various aspects of visitor use, such as general public awareness, user demographics, and attitudes about GRNMS regulations. While providing a wealth of information, these studies are reliant upon the willingness of participants to respond as well as the accuracy and honesty of their opinions. As a result, GRNMS managers have expressed an interest in exploring methods of quantifying visitation using observational data that are independent of subjective biases.

Recent technological advancements have resulted in three promising new datasets for assessing visitors to remote locations such as Gray's Reef. Commercially available satellite imagery such as Maxar's WorldView constellation (www.digitalglobe.com) now provides a resolution (<1 m pixel size) and flyover frequency (4-5 days) that may be sufficient to quantify visitation to offshore sites by small boats. Although only a single image is provided every few days and can be obscured by cloud cover, this satellite data potentially enables boat counting, measurement, and in some cases, identification of boat types throughout the sanctuary.

Another potentially useful technology for quantifying visitation is the presence of a radial camera system on the weather buoy at Gray's Reef which is operated by the National Data Buoy Center (NDBC Buoy 41008). Many visitors either capture baitfish that are attracted to the buoy or target bottom fish on nearby hardbottom and the boats can be observed in the cameras. Although the camera is limited to viewing only the area of the sanctuary around the buoy, it provides digital photomosaics of its surroundings publicly available online every 2 hours making it a potentially useful dataset for quantifying visitors.

Lastly, underwater sounds are continuously monitored at three locations within Gray's Reef as part of the NOAA-Navy SanctSound Project. Recent advancements in passive hydro-acoustic recorders and analysis techniques have made it possible to examine visitation based on the sounds made by boats (Simard et al. 2016). Although limited by a variable detection range of a few hundred meters, noises can be characterized to infer size, speed, behavior, and number of vessels as well as duration of activities.

1.3 OBJECTIVES

Our primary goal in this study was to evaluate the WorldView satellite imagery, buoy camera, and acoustic recordings for their potential to quantify visitation at Gray's Reef. We summarize several types of information made possible from these data including size, type, and number of boats, daily and seasonal patterns of visitation, location of visitors within the sanctuary, and inferred activity (e.g., trolling) based on wake patterns and acoustic characteristics.

Several types of boats can be observed in Gray's Reef. Some are specifically visiting the sanctuary and conducting activities such as fishing or diving. Others, particularly larger vessels, just happen to be passing through on their way between other destinations such as the ports of Savannah and Jacksonville or elsewhere. These vessels are not visiting Gray's Reef per se, but are observed there merely because of its position on the continental shelf in the busy north/south transit corridor along the Atlantic seaboard. In this study, we quantify the proportion of those vessels merely passing through but focus on "visitation" defined as those boaters most likely to be deliberately targeting sanctuary resources.

In addition to evaluating these novel datasets, we compile and summarize the smaller but still informative volume of information that is available from on-water or aerial surveys conducted from boats or aircraft by GA DNR, US Coast Guard and Air Auxiliary, and GRNMS staff. These surveys are useful for comparison to the observations made using satellites and the buoy camera. Furthermore, the on-water counts include unique aspects of visitor use not possible to determine from acoustics or satellite and buoy camera imagery. This includes topics such as targeted species or violations of regulations which are also summarized.

It should be noted that much of the data available to assess visitation was collected intermittently over nearly four decades. For most of those records, an explanation of methods and accompanying metadata are lacking. Older data are especially problematic for estimating visitation to Gray's Reef for several reasons beyond the lack of sufficient documentation. An anchoring ban enacted in 2006 (Department of Commerce 2006) and refined in 2014 (Department of Commerce 2014) changed the way some anglers target bottomfish in the sanctuary. Boats had to repeatedly drift or continuously adjust to maintain position over live bottom habitat where target species reside. In 2010, spearfishing was prohibited (Department of Commerce 2010). Although never a large segment of the user community, spearfishers were therefore displaced to undertake those activities elsewhere. Also, in 2011 the southern ~1/3 of the sanctuary was designated as a no-take, research-only area (Kendall et al. 2008b, Department of Commerce 2011). Although intentionally located in the least visited part of the sanctuary based on best available information at the time, closing it to fishing could have displaced some users. Collectively, these regulatory changes may have reduced the appeal of Gray's Reef as an offshore fishing destination.

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Developments outside the sanctuary have likely reduced visitation as well. The economic downturn and increase in gas prices around 2008 correlated with a reduction in offshore fishing (B. Shortland, G. McFall pers. comm.). In addition, the GA DNR Offshore Artificial Reef (OAR) Program has made enhancement of fishing opportunities an ongoing priority since the 1970's (https://coastalgadnr.org/HERU/offshore. Accessed April 2020) (Figure 1.1). A wide range of opportunistic materials (e.g., concrete telephone poles, subway cars, military tanks, bridge debris, and vessels) have been deployed all along the Georgia coast in offshore waters at depths similar to Gray's Reef. The accumulation of these artificial reefs has greatly increased the opportunities and convenience for offshore anglers all along the coast, potentially drawing them away from the sanctuary.

Technological advancements such as the now widespread use of acoustic fish finders and GPS may also contribute to a reduction in visitation at Gray's Reef. At one time, the data buoy at the sanctuary was among the only visible landmarks that anglers could use to reliably locate specific patches of hardbottom offshore. Now, site coordinates can be precisely visited without any surface reference. In fact, GA DNR offshore artificial reef sites are no longer marked with surface buoys for this reason.

Given the changing nature of use at Gray's Reef, and to focus this assessment on present day visitation, only data from ~2015 onward is considered in detail for this report. Where appropriate however, older datasets

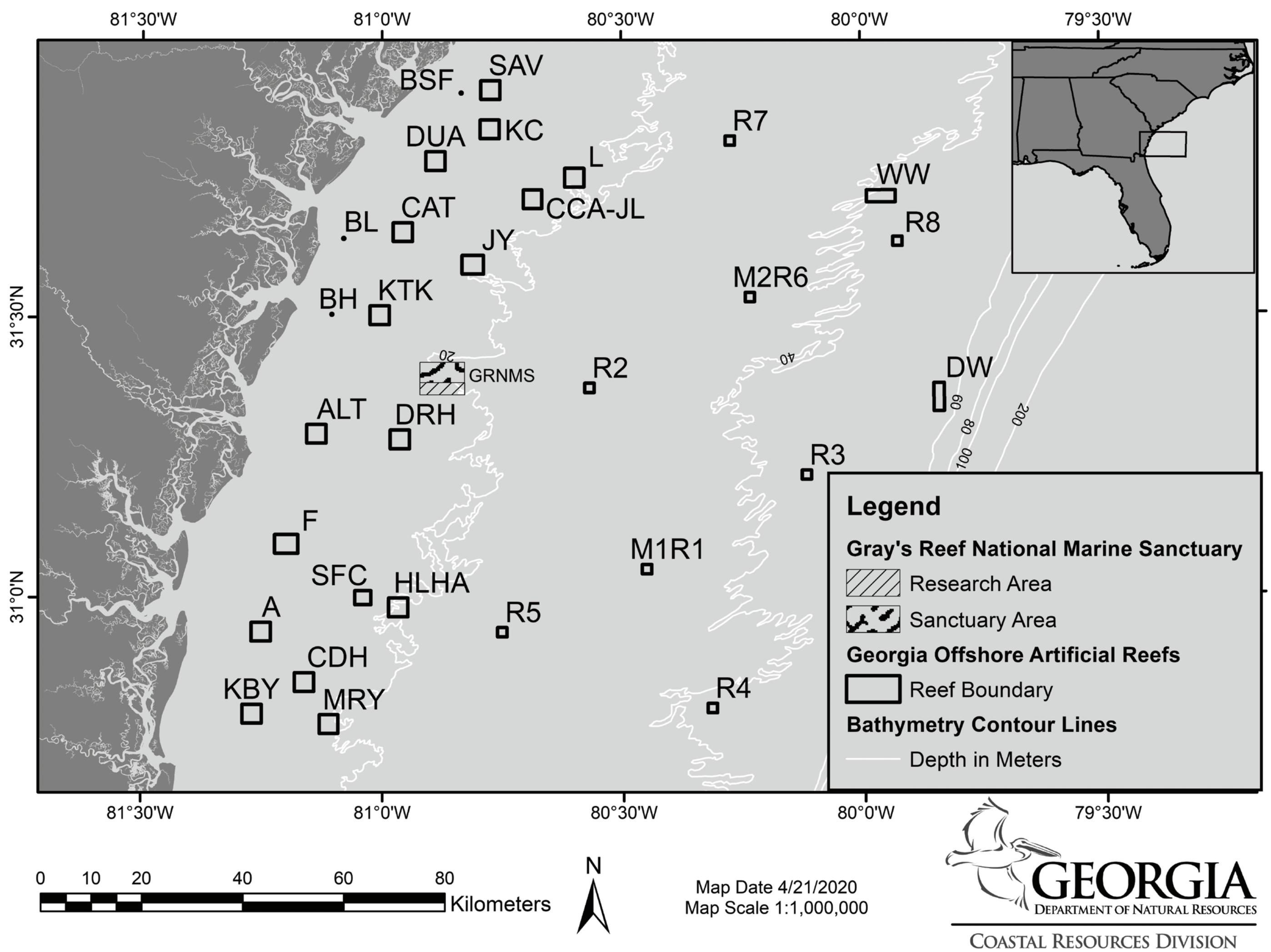
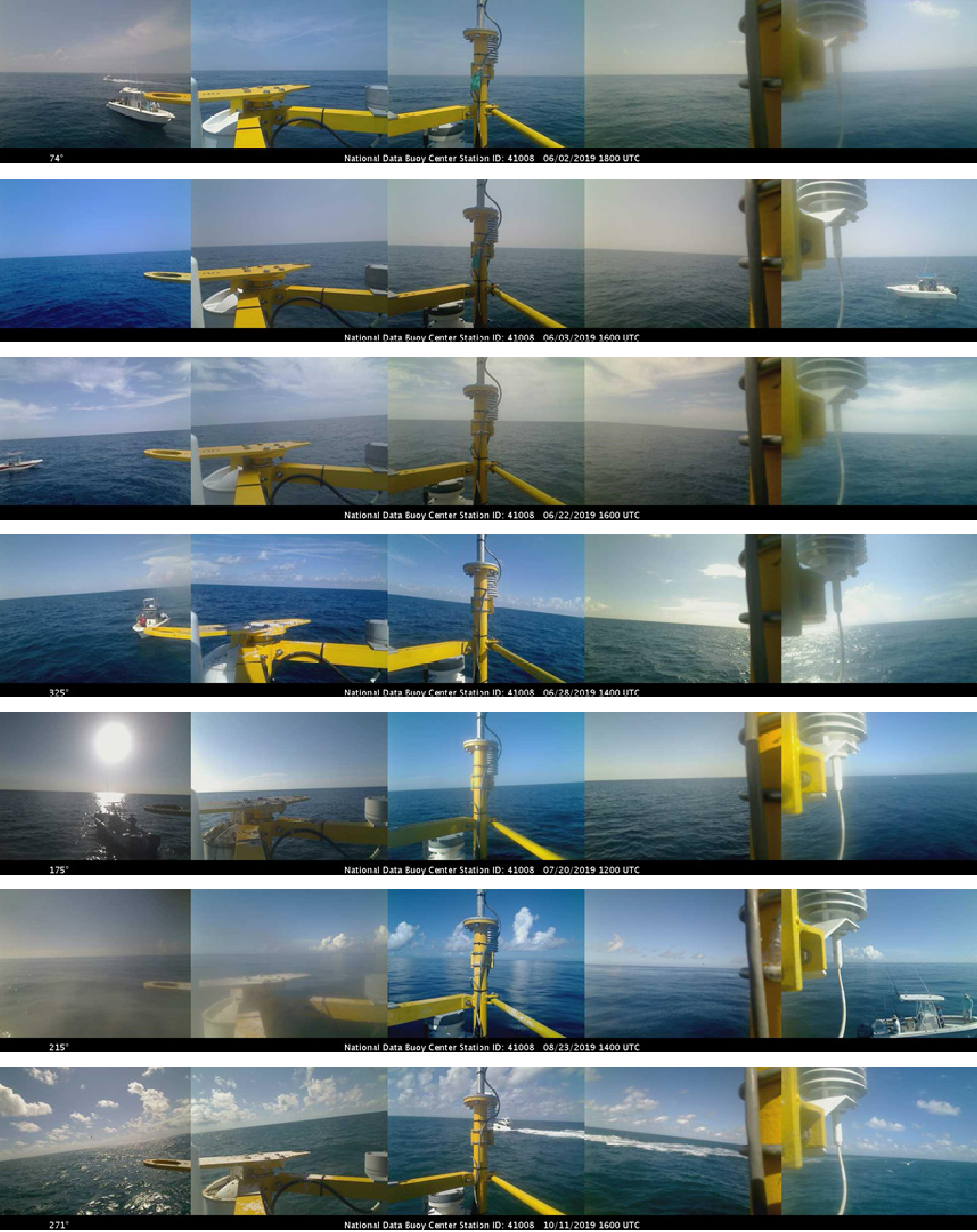


Figure 1.1. Location of GRNMS and artificial reefs off the coast of Georgia. Artificial reef sites are denoted by 1 to 4 digit alphanumeric codes. Source: C. Brinton, Georgia DNR Coastal Resources Division, Brunswick Georgia. 2020.

are discussed to provide context on changes in monitoring or visitation. To restrict the results to patterns of public visitation, instances of the research vessel NOAA Ship *Nancy Foster* or the sanctuary's R/V *Sam Gray* conducting research at the sanctuary have been noted or excluded in analysis.

Specifically, our goals were to:

1. Describe the observational datasets available for quantifying visitation at GRNMS, These include:
    - o Buoy 41008 Camera
    - o WorldView Satellites
    - o Passive acoustic recorders
    - o Georgia DNR law enforcement patrols
    - o Research Vessel (R/V) based observations
    - o US Coast Guard and Air Auxiliary patrols
2. Summarize the patterns of visitation based on each dataset
3. Discuss the strengths and weaknesses of each observational technique
4. Consider ways to enhance the value of each approach
5. Archive the available data at the National Centers for Environmental Information (NCEI) so that it is readily available for use by others
6. Prepare the observation data for developing a predictive model wherein visitation will be related to weather conditions and other variables



Example photo-mosaics from the buoy camera 41008 that included boats. The time (UTC) and date stamp's are included at the bottom of each mosaic. Credit: NDBC.

2.0 COUNTING BOATS FROM IMAGERY

2.1 NATIONAL DATA BUOY CENTER COASTAL WEATHER BUOY 41008 CAMERA

The National Data Buoy Center (NDBC) maintains a 3 meter discus buoy (WMO ID 41008) within GRNMS moored at 31.400 N, 80.868 W. This buoy is equipped with oceanographic and meteorological sensors to collect sea-surface temperature, directional waves, wind speed and direction, air temperature, relative humidity, and barometric pressure (for a complete description see https://www.ndbc.noaa.gov). In addition, the buoy is equipped with a camera system that was designed as a vandalism deterrent but also offers the potential for additional applications. This system is comprised of 5 cameras facing outward horizontally from the buoy. Each camera covers 60° of horizon for a total coverage of 300° with 12° gaps between cameras. Buoy instruments visible on 3 cameras block an additional 30° of the surrounding horizon, resulting in a clear view of ~270° around the buoy. Distance to the horizon is ~2.5 nautical miles based on camera height but varies significantly based on environmental conditions.

The system collects color images every 20 minutes during daylight hours at a resolution of 800 by 660 pixels for each camera and stores them to internal memory. To conserve power, the buoy transmits the most recent image every two hours. The image is transmitted at a reduced resolution (400 by 330 pixels) via Iridium satellite and posted on the NDBC website along with the *in-situ* data collected by the buoy instruments. All five camera images are provided on the station webpage as a horizontal mosaic. Upload times are automated to occur at 7 am, 9 am, 11 am, 1 pm, 3 pm, 5 pm, and 6:20 pm. The website uploads are less frequent than images stored internally on the buoy in order to extend battery life for a target of six months of operation. The data used for this assessment are based on the buoy deployment at GRNMS that began on May 29, 2019. Following a few days of preliminary monitoring, all of the publicly available imagery was compiled and evaluated as described below.

2.1.1 Methods

Image mosaics were viewed on a computer monitor and visually inspected for boats. When a boat was present, the type of vessel was categorized as one of the following: center console/small (<~10 m), sportfisher, sailboat, large (i.e., >50 m), R/V *Sam Gray* (11 m long), NOAA Ship *Nancy Foster* (57 m), or unknown. The *Sam Gray* and *Nancy Foster* were the only boats specifically identified based on visual appearance and were noted such that their presence could be excluded in analysis of public visitation. Most small boats were center console layout, however not all small craft could be confirmed as having that specific design due to their orientation to, or distance from, the buoy camera. Large boats appeared only as indistinct features on the horizon. In some cases, boats were merely identified as present, but of unknown type. This occurred when boats were far from the camera, on image seams, when viewed from directly in front or behind, or obscured due to lens interference (e.g., salt accumulation). Bearing to boats could not be reliably determined and was not recorded due to buoy spin and uncertainty in compass values (pers. comm. K. Grissom NDBC). When boat orientation and distance from the camera permitted, the number of people on board was noted for center console style boats (other boat types were not amenable to counting individuals due to enclosed helms or cabins).

Camera errors or lens obstructions were noted when they occurred. These included issues such as partial image upload, image failure (black), water droplets, sun glint, image saturation (white), and condensation/haze. Typically, only a portion of one of the five camera images were affected by any of these issues at one time. Unusual observations (e.g., banded birds) or special environmental conditions (e.g., hurricane Dorian Sept. 4, 2019) were also noted.

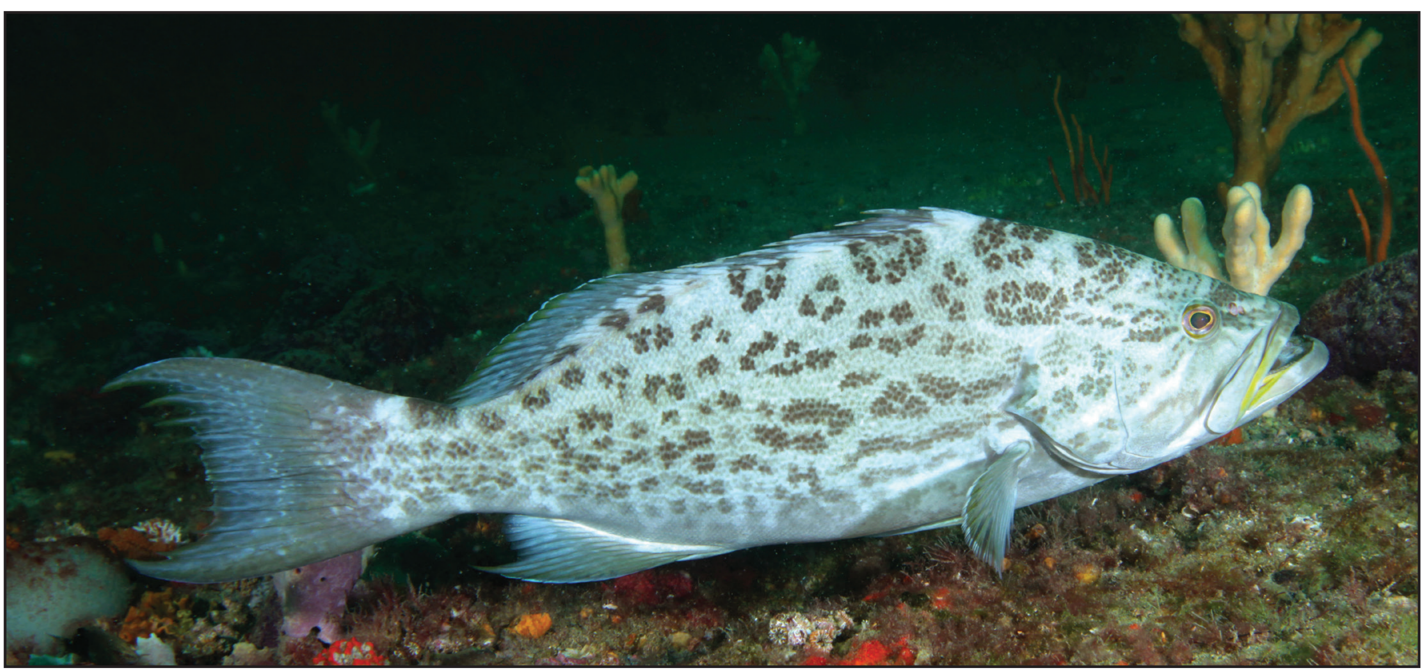
Counting Boats from Imagery

Sea-state was scored according to the Beaufort Wind Force Scale (National Meteorological Library and Archive 2010) based on the appearance of waves, white caps (if present), and camera tilt. Percent cloud-cover was categorized based on a visual assessment of the sky as it appeared across the entire mosaic. Categories were 'Clear' (0-10% cloud cover), 'Partly Cloudy' (10-90% cloud cover), and 'Overcast' (90-100% clouds). It was also possible to quantify sea birds appearing in the mosaics. Flying birds could not typically be identified taxonomically due to the combined effects of their rapid motion, low resolution of images, and distance from the cameras. Flying birds were therefore simply counted. Small black dots or smudges in the sky were not counted as flying birds unless they could be readily distinguished from distant aircraft. Perched birds were nearly always on the part of the buoy mast that straddles the field-of-view for cameras 1 and 2. These were identified to species level. These environmental and bird observations are not analyzed here, but are included in the data product archived at NCEI should they be useful for others. All images were evaluated twice for quality control. Based upon these observations, we summarized the number and types of boats observed by month, day of the week, and time of day.

2.1.2 Results and Discussion

From June 1 to December 6, 2019 the BuoyCam provided 1,093 (83%) out of a possible 1,323 day/time combinations (189 days and 7 images per day) of images usable for analysis. Upload malfunctions prevented access to 14% of images (n = 181). These occurred haphazardly during the time-series and were not suspected to systematically bias the visitation data. Another 3.8% (n = 50) were unusable due to darkness after mid-October when the 6:20 pm (local time or UTC -5) imagery was acquired after sunset. Beginning December 5 2019, the cameras experienced terminally low battery-power and sequentially ceased providing pictures such that no images were available by 12:00 UTC on December 7. It took an analyst a total of 26 hours to evaluate all the images and review them a second time for accuracy and consistency.

Among the best properties of this dataset is its equal sampling effort over time. Digital photographs are taken at the same time every day no matter the weather conditions. This means that it provides temporally unbiased sampling effort and can be used to understand the patterns of visitation at the sanctuary in ways many of the other datasets cannot. For example, the actual number of days that fishermen are travelling to the sanctuary while the system is deployed and the types of weather conditions conducive to visitation can be determined.



Scamp grouper. Credit: GRNMS.

Counting Boats from Imagery

There were a total of 85 boats observed. Of those, 3 instances were the R/V *Sam Gray* and another 21 were the NOAA Ship *Nancy Foster* during its July 29 –August 9, 2019 field mission. Another 13 were too far from the camera to be identified as particular boat types but were seen on the horizon and appeared to be large vessels. Of the remaining 48 boats that could be identified to type, the most common type was center console which comprised 94% (45) of identifiable boats (Figure 2.1). The remaining boats were sportfisher (2) or sailboat (1). None of the center console boats were on the AIS system. Subsequent analyses and figures will include only these small, center console boats.

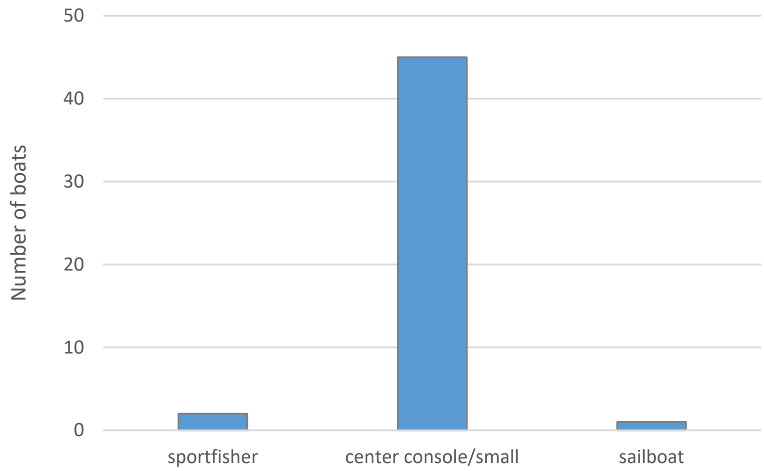


Figure 2.1. Number of boats observed in the buoy camera imagery.

It should be noted that consecutive boat observations on the same day may have been the same boat, provided that fishermen stayed at GRNMS for the two hour interval between images and remained close enough to the buoy to be seen. Interviews with fishermen indicate that they typically spend over 4 hours at Gray's Reef before moving on to another site (Bird et al. 2001). In addition, boats seen on multiple days were potentially repeat visitors. This could not be determined because the specific identity of individual boats could not be discerned. Other limitations of this dataset are its limited spatial scope around the buoy and the low resolution of the publicly available source imagery.

The seasonal distribution of fishing boats observed in the buoy camera imagery reveals that most visitation (40/44 or 91%) occurred in June – August (Figure 2.2). An important caveat is that the buoy camera was only deployed at the very end of May. It is likely that some visitation had commenced earlier in the Spring, but was not detected. Similarly, the buoy camera batteries expired in early December, and winter visitation rates (presumed to be low) could not be determined either.

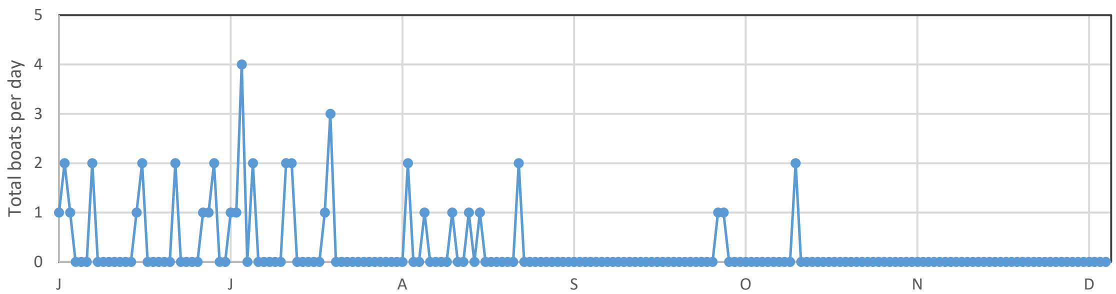


Figure 2.2. Number of center console/small boats observed in the buoy camera imagery by date.

The day of the week that fishing boats were observed in the buoy camera imagery reveals that most visitation occurs on Friday and Saturday (Figure 2.3). Of the 45 center console boats seen in the imagery, 27 (60%) occurred on just those two days of the week although at least some boats were seen on every day of the week. Sunday had more boats than weekdays, but not as many as Friday and Saturday as was expected.

Counting Boats from Imagery

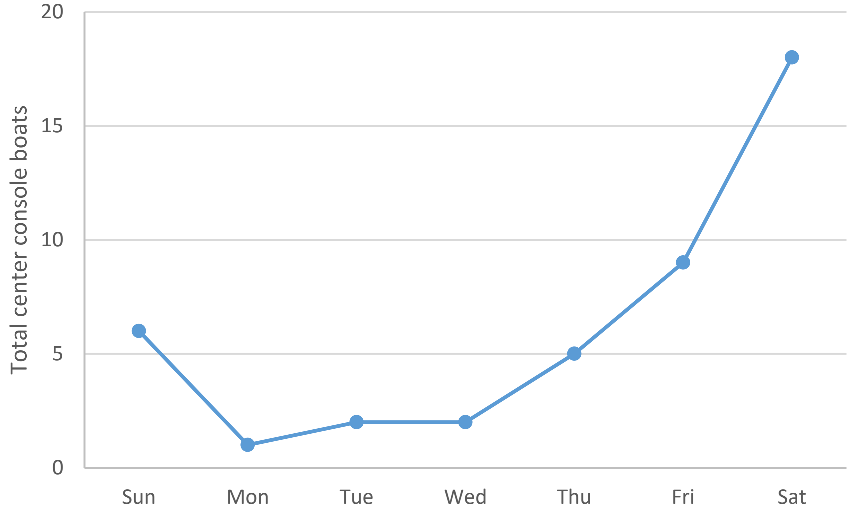


Figure 2.3. Total number of center console boats observed in the buoy camera imagery by day of the week.

The time of day that fishing boats were observed in the buoy camera imagery reveals that most visitation occurs mid-day (Figure 2.4). Of the 45 center console boats seen in the imagery, 38 (84%) occurred between ~9 am and 1 pm. Boats were seen as early as 7 am, and as late as 3 pm. None were observed in the last two images of each day at 5:00 and 6:20 pm.

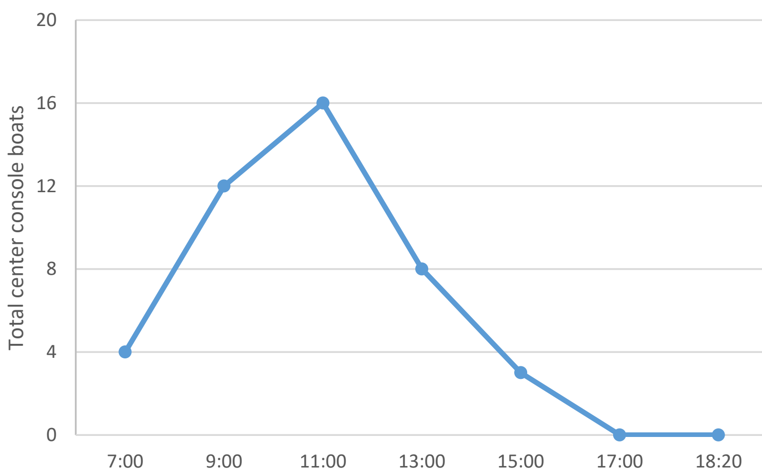


Figure 2.4. Total number of center console boats observed in the buoy camera by time of day that the images were collected.

People were difficult to distinguish and count even on boats with no cabin due to boat orientation (e.g., head on), low resolution of the cameras, or distance. Despite these challenges, the number of people could be counted on 10 of the 45 center console/small craft and always included 2 to 4 individuals (mean 2.9 people per boat +/- 0.28 SE).

2.2 WORLDVIEW SATELLITES

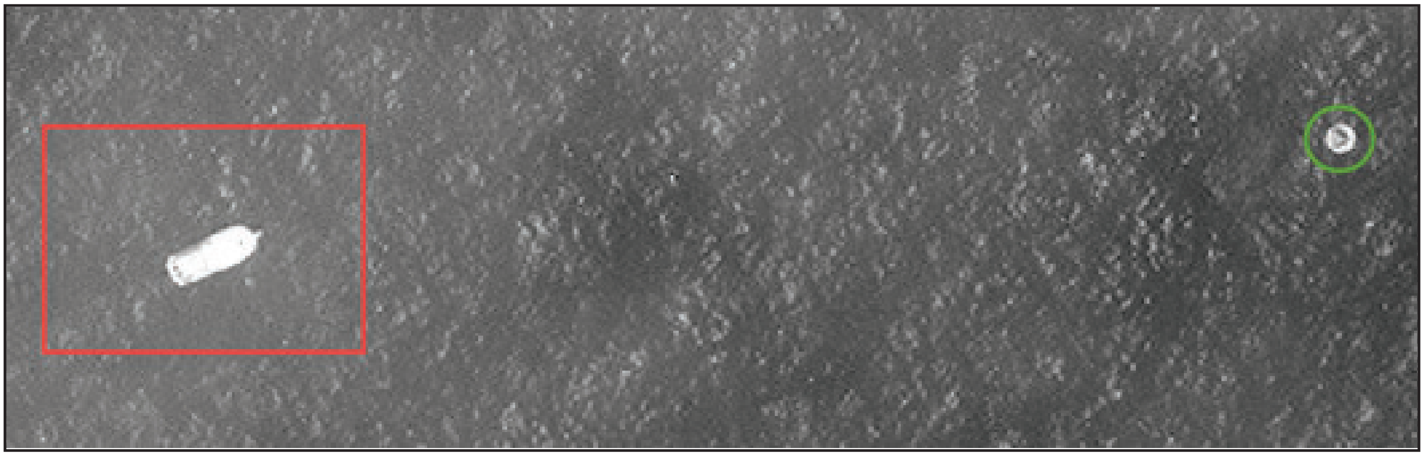
Digital Globe's World View (WV) 1-3 satellites are in sun-synchronous orbits such that they pass over a given point on the globe at the same time each day. The combined revisit frequency of these satellites results in an image of GRNMS every 4-5 days. Image acquisition times range from 11:04 am to 4:42 pm local time depending on the satellite and acquisition angle. For this project, we requested all possible images of the sanctuary regardless of cloud cover and atmospheric conditions so that we could apply custom processing, use partial images that included at least some of the sanctuary, and better understand the prevalence of cloud cover. Depending on the satellite and acquisition angle parameters, which varied for every collection, pixel resolution for the panchromatic (i.e., greyscale) imagery ranged from 32 to 89 cm. Positional accuracy of the raster imagery is <4.0m for all of these satellites.

2.1.2 Methods

When new satellite images were acquired, they were downloaded from Digital Globe's Enhanced View Web Hosting Service (EVWHS) for processing. Several custom optimization steps were performed on each image to discern multiple aspects of boats including size (edge contrast with boats and water), type (color and contrast within the boat), and cavitation/wake properties (contrast in water). Panchromatic (WV1) and multispectral/panchromatic-sharpened or multispectral/ortho natural color images (WV2-3) were enhanced via brightness, contrast, and gamma adjustments. All images were rendered using the cubic convolution algorithm, min-max stretch values, and other histogram and multispectral band adjustments to reduce sun glare and interference from thin clouds. Multispectral rasters were registered to the panchromatic raster using the Shift tool when necessary to improve alignment. Image processing was performed in ArcPro (v2.5).

For each satellite image the following metadata were recorded: satellite (i.e., WV1-3), date, time of day, percent clouds over the sanctuary, sea state (Beaufort scale), and acquisition parameters such as resolution, nadir angle, sun elevation, and azimuth.

The sanctuary and Research Area boundaries were overlaid on the images along with the coordinates of the weather buoy (NDBC 41008) as a spatial reference framework. Each image was visually inspected for the presence of boats, aircraft, the data buoy, and other objects by panning at a scale of 1:1000 on the computer monitor. We also evaluated DigitalGlobe's automated vessel detection options on the EVWHS platform as well as the potential for ArcPro's machine learning capacity to identify vessels automatically. The data generated here will be used to build a training dataset for automated detection of small vessels in the future. For each of the boats or other objects seen, the following data were recorded: boat type (e.g., center console, sail), class (e.g., Class 1: 16<26 feet, Class 2: 26<40 feet, Class 3: 40<65 feet; NOAA Office of Marine and Atmospheric Operations), coordinates, overall location within the sanctuary (i.e., inside the Research Area or not), presence in AIS, length, width, speed (e.g., adrift, slow, running), wake description (e.g., long, short, none), distance from buoy, direction from buoy, and other notes. Outboard engines were excluded in length measurements. A complete list of parameter choices can be found in Table 2.1. When boats were seen, a screen-shot of the adjusted image was saved at a scale of 1:200 to convey boat details and another at 1:500 or broader to show context and reveal cavitation/wake properties (Appendix A).



Example segment of a WorldView satellite image from GRNMS depicting a boat (red box) and the data buoy (green circle). The data buoy is ~10 feet in diameter for scale. Credit: Digital Globe, National Geospatial Agency, and the USGS/Civil Applications Center

Counting Boats from Imagery

Table 2.1. Variables for satellite image analysis.

Variable Name	Definition	Units/Text
Date	Date	DD/MM/YYYY
Local_time	Time in eastern USA standard time (UTC -5)	12 hour
Boat_type	Boat type visually interpreted from enhanced satellite imagery.	Center console/outboard, unknown, sportfisher, sail, R/V *Sam Gray*
Class	Boat classes defined as Class 1 = 16 to <26 feet, Class 2 =26 to <40, Class 3 = 40 to <65	Class 1, Class 2, Class 3
Length_m	Boat length from bow to stern, excluding outboard engines as measured on satellite image	meters and tenths (m.m)
Width_m	Boat width as measured on satellite image	meters and tenths (m.m)
Latitude	Latitude of the boat	Decimal degrees
Longitude	Longitude of the boat	Decimal degrees
Research_area	Is the boat inside the boundary of the GRNMS Research Area?	yes, no
Speed	Vessel speed inferred from wake characteristics	slow, drifting, running
Wake	Wake appearance on satellite image	none, short, long
Boat_heading	Direction of boat orientation in 16-point compass	e.g., NNE, WSW
AIS	Is the boat on the Automatic Identifcation System (AIS)?	yes, no
Clouds_%	Percent of the GRNMS area obscured by clouds in the satellite imagery	Percentage
Sea_state	Estimated sea state based on the Beaufort scale	Numeric, ordinal
Satellite_name	Name of the specific WorldView (WV) satellite that collected the image.	WV1, WV2, WV3
Resolution_cm	Pixel size of the panchromatic band of the satellite image	cm
OFF_NADIR_ANGLE	Viewing angle in degrees off straight down for the satellite image	degrees
SUN_ELEVATION	Angle of the sun off the horizon at the time of the image	degrees
SUN_AZIMUTH	Compass direction from which sunlight is coming at the time of the image	degrees
TARGET_AZIMUTH	Angle from the satellite to the image relative to north	degrees

2.2.2 Results and Discussion

A total of 40 satellite images were acquired from April 16 to October 12, 2019. Average collection time was 1:49 pm local time and average resolution was 61 cm (Table 2.2). Most images either had few clouds (0-20% cover in 23 images) or extensive cloud cover (>80% in 14 images) (Figure 2.5). Clouds prevented boat counts on consecutive collections in late April through early May and then again in early September.

Thirty four boats were observed visiting the sanctuary in the satellite images. None of them were on the AIS system. Boats appeared in the imagery beginning in mid-May and ending by September. It is important

Table 2.2. Number of acquisitions by satellite and the ranges in their resolution and time of acquisition.

	WorldView 1	WorldView 2	WorldView 3
Collects (n)	17	15	8
B&W Resolution (cm)	Mean 67 Min 50 Max 89	Mean 64 Min 50 Max 82	Mean 42 Min 32 Max 56
Acquisition Time (Eastern US)	2:22 pm to 3:54 pm	11:04 am to 3:57 pm	12:03 pm to 4:42 pm

to interpret these data in the context of the snapshot nature of the satellite images, multiple days between collections, and the limitations imposed by cloud cover on many images.

The largest number of boats (n = 9) was observed on July 20, coinciding with the end of red snapper season in 2019. Another date with several boats (n = 5) was June 10, which was during the Two-Way Sportfishing Club's kingfish tournament. Unfortunately, no other tournament dates coincided with satellite images.

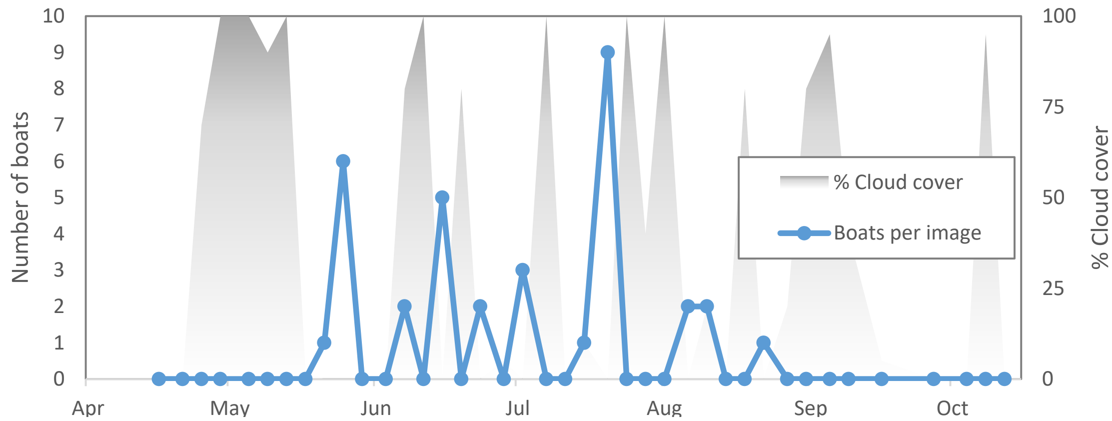


Figure 2.5. Number of boats observed and percent cloud cover in satellite images.

Two types of boats could be identified in the satellite images (Figure 2.6). The center console/outboard design was the dominant type observed (85% of all identifiable boats). The T-top, open bow, and outboard engine (s) of this boat type could often be discerned in the higher resolution Worldview 2 and 3 images. Three sportfisher style boats were also observed and were identified by their characteristic size, white and enclosed bow area, elevated bridge/cockpit, and in one case, deployed outriggers. An additional 14 small boats were seen but could not be confidently identified as specific types. Eleven of these were Class 1 (16 to <26 feet) and 3 were in Class 2 (26 to <40 feet) indicating that they were all small recreational boats.

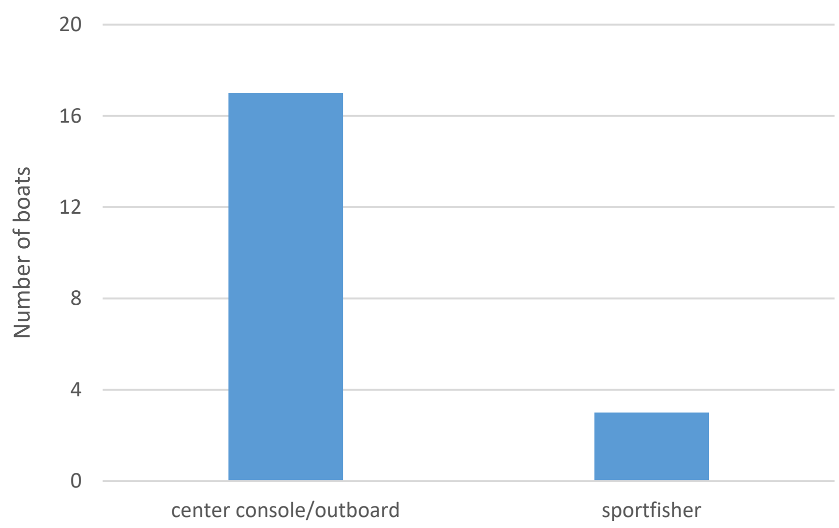


Figure 2.6. Number of boats observed by boat type.

Counting Boats from Imagery

Considering size alone, it is clear that most visitors use smaller boats in Class 1 (16 to <26 feet) (Figure 2.7). Average boat size was 7.9 m (+/- 0.3 SE) (26 feet). The smallest boat seen was 6 m (19.7 feet) and largest was a 13.8 m (45 feet) sportfisher.

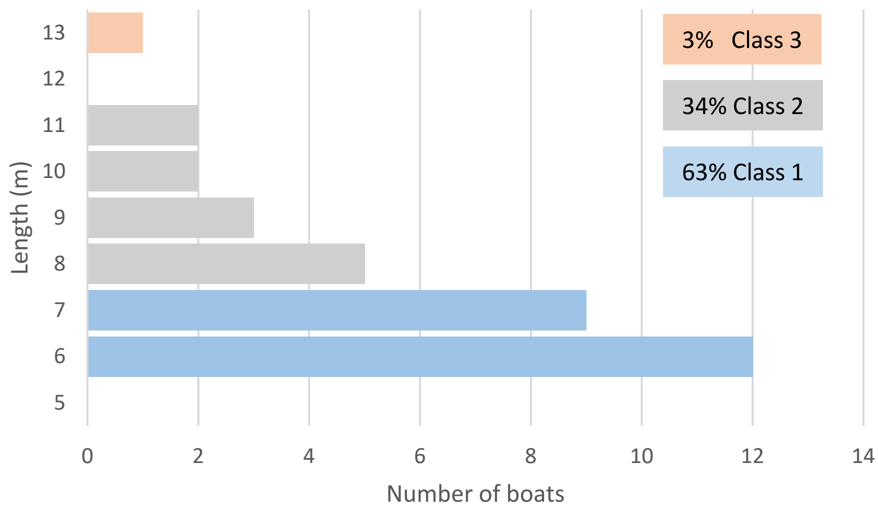


Figure 2.7. Size frequency of boats observed.

The satellite data also allow us to examine the position of boats in the sanctuary as well as to infer their activities (Figure 2.8). Of special concern is compliance with the Research Area's restriction on fishing and stopping. Only three (9%) of the boats observed in the satellite data were inside the Research Area. One was observed to have a long wake and was travelling at high speed, which is allowed. Another was observed to be merely drifting, which is consistent with bottom fishing, however, it was not over an area of especially high relief hard bottom (westernmost boat in the Research Area in Figure 2.8). The last boat observed in the Research Area had a wake pattern consistent with slow, steady, movement as is indicative of slow transit or trolling and was in an area with multiple high relief bottom features (easternmost boat in the Research Area in Figure 2.8). Of the boats outside the Research Area but still within the sanctuary, 74% (23) were within 1 km of the data buoy in an area with many high relief ledges (Figure 2.8) and nearly all were drifting. This pattern is consistent with what is known of usage patterns based on compilations of older data (Kendall et al. 2008b).

Red grouper. Credit: Justin Miyano.

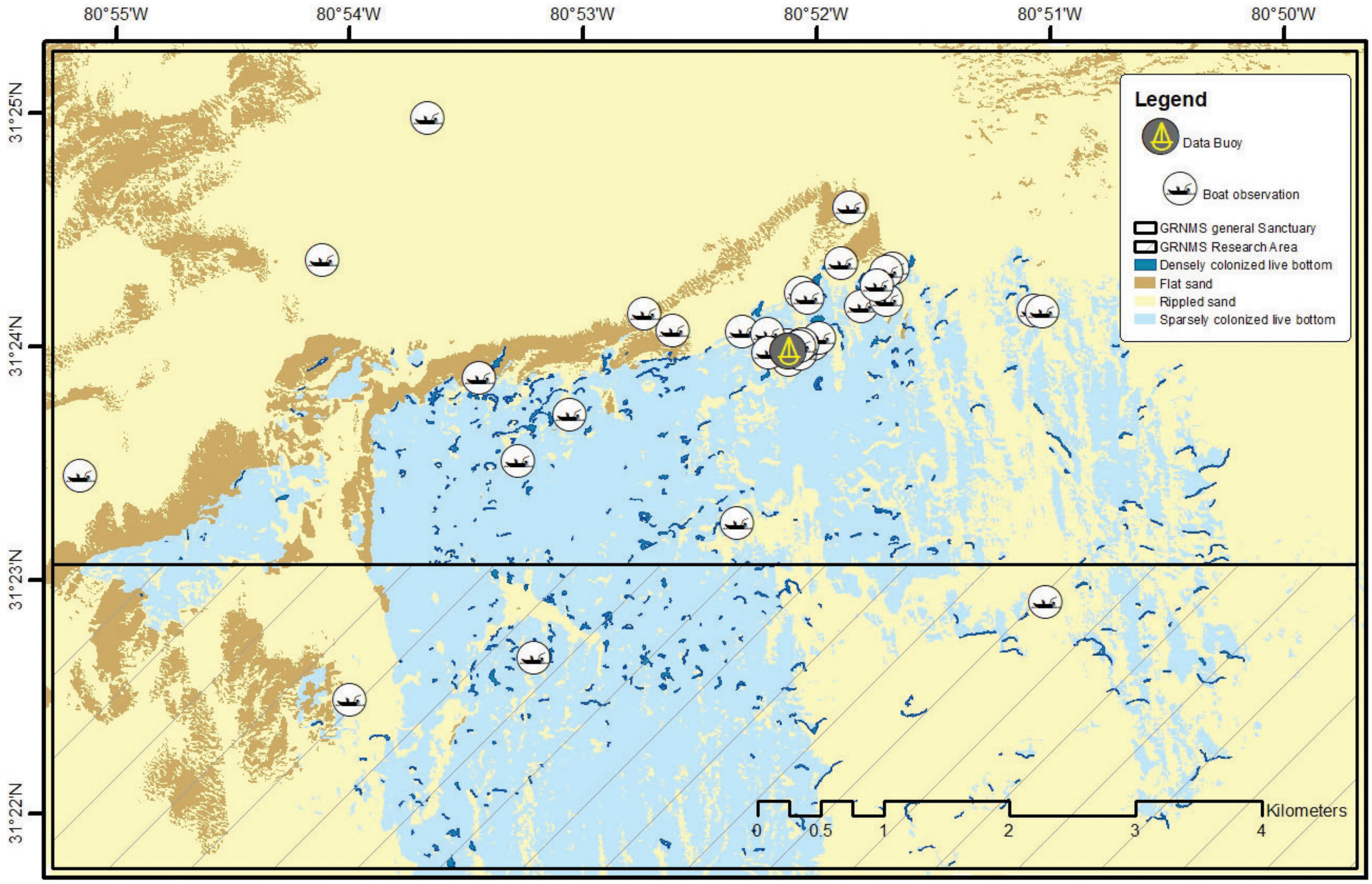
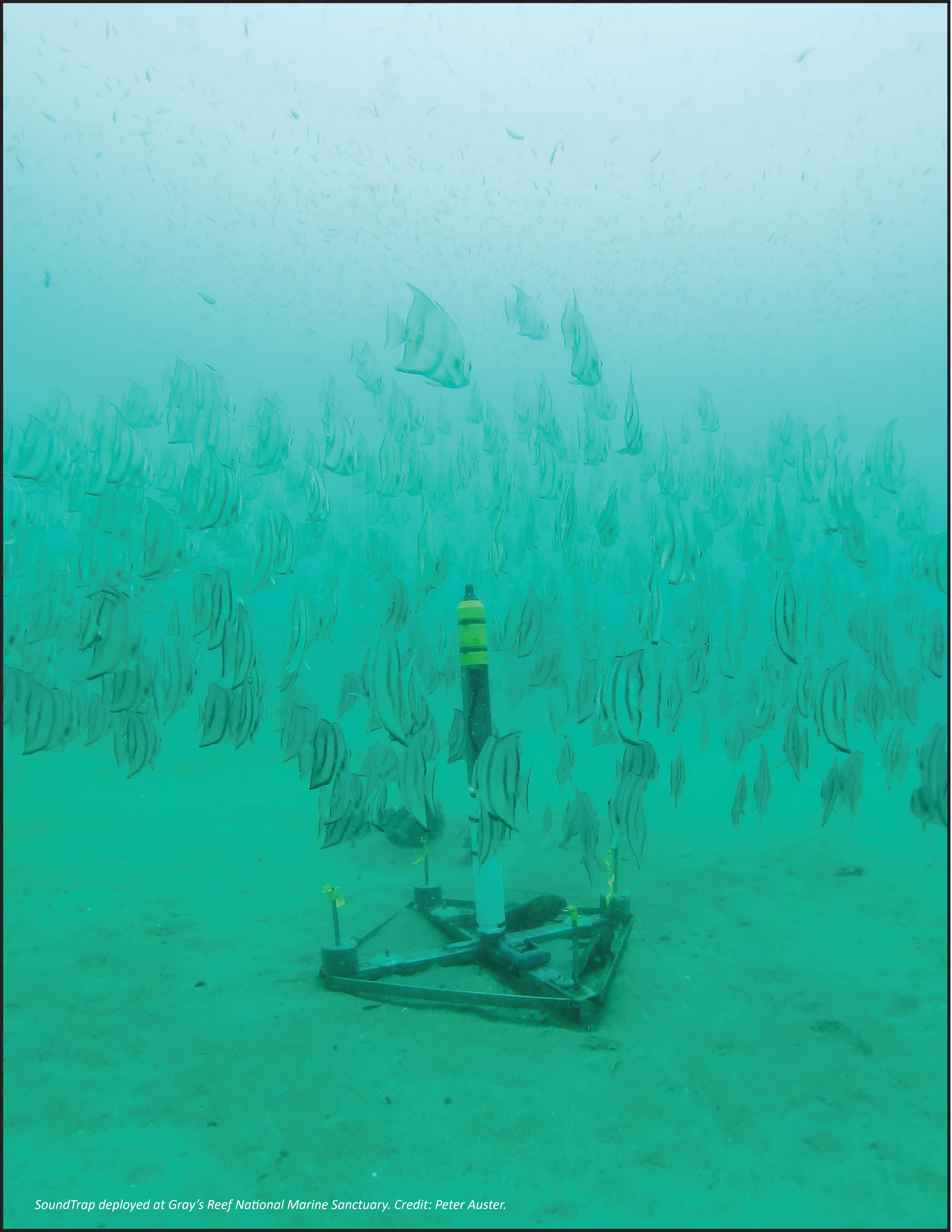


Figure 2.8. Position of boats observed in satellite imagery overlaid on bottom maps and sanctuary boundaries.

Other forms of satellite data have been used in the past to assess visitation at GRNMS. Most notably, on many weekends from 1998 to 2007, boats were counted using satellite data from the US Government's National Technical Means of Verification Program. Unfortunately, the imagery from this data source could only be processed by authorized staff in particular settings and critical metadata such as time of day, quality of imagery, and any bias in collection parameters were unavailable. For these reasons, any derived products from the program were difficult to interpret, could not be independently evaluated or shared, and the program was discontinued.



SoundTrap deployed at Gray's Reef National Marine Sanctuary. Credit: Peter Auster.

3.0 COUNTING BOATS FROM UNDERWATER SOUNDS

3.1 SOUNDTRAP ACOUSTIC RECORDERS

As part of a larger initiative to better understand 'baseline' acoustic conditions within multiple National Marine Sanctuary locations (SanctSound - https://sanctuaries.noaa.gov/science/monitoring/sound/), three sites within GRNMS boundaries are monitored using passive listening devices called SoundTraps (Figure 3.1). At these sites, acoustic sensors have been passively recording ambient underwater sounds since December 2018 (site GR01) and May 2019 (GR02-03). These data include sounds produced by marine animals (e.g., mammals, fishes, and invertebrates), physical processes (e.g., wind and waves), and human activities (e.g., boat noise).

Unlike other data types such as imagery and visual surveys, these acoustic recordings allow for continuous monitoring of an area for sounds of interest, in this case the engine noise created by boats. However, similar to visual methods to assess visitation from the buoy camera, acoustic detection of boats is limited by the range of sound transmission at each site. Stationary and non-stationary environmental variables at each site such as depth, bathymetry, salinity, temperature, bottom type, sea surface roughness, and background noise levels, coupled with the frequency and amplitude of sounds emitted from a source, often dictate how far away a sound can be detected. Given the environment at Gray's Reef and initial results from acoustic propagation modeling (numerically modeled detection range), it is estimated that individual sites monitor a surrounding radius of ~1 – 4 km for small vessels with the exact detection range dependent on environmental conditions at the time of recording as well as boat speed, engine size, and amplitude of sounds generated by boat operation (pers. comm. T. Margolina Naval Postgraduate School). Larger boats, such as tugs and container ships, can be detected at greater ranges due to "loud" acoustic source levels, but are not associated with visitation in this analysis.

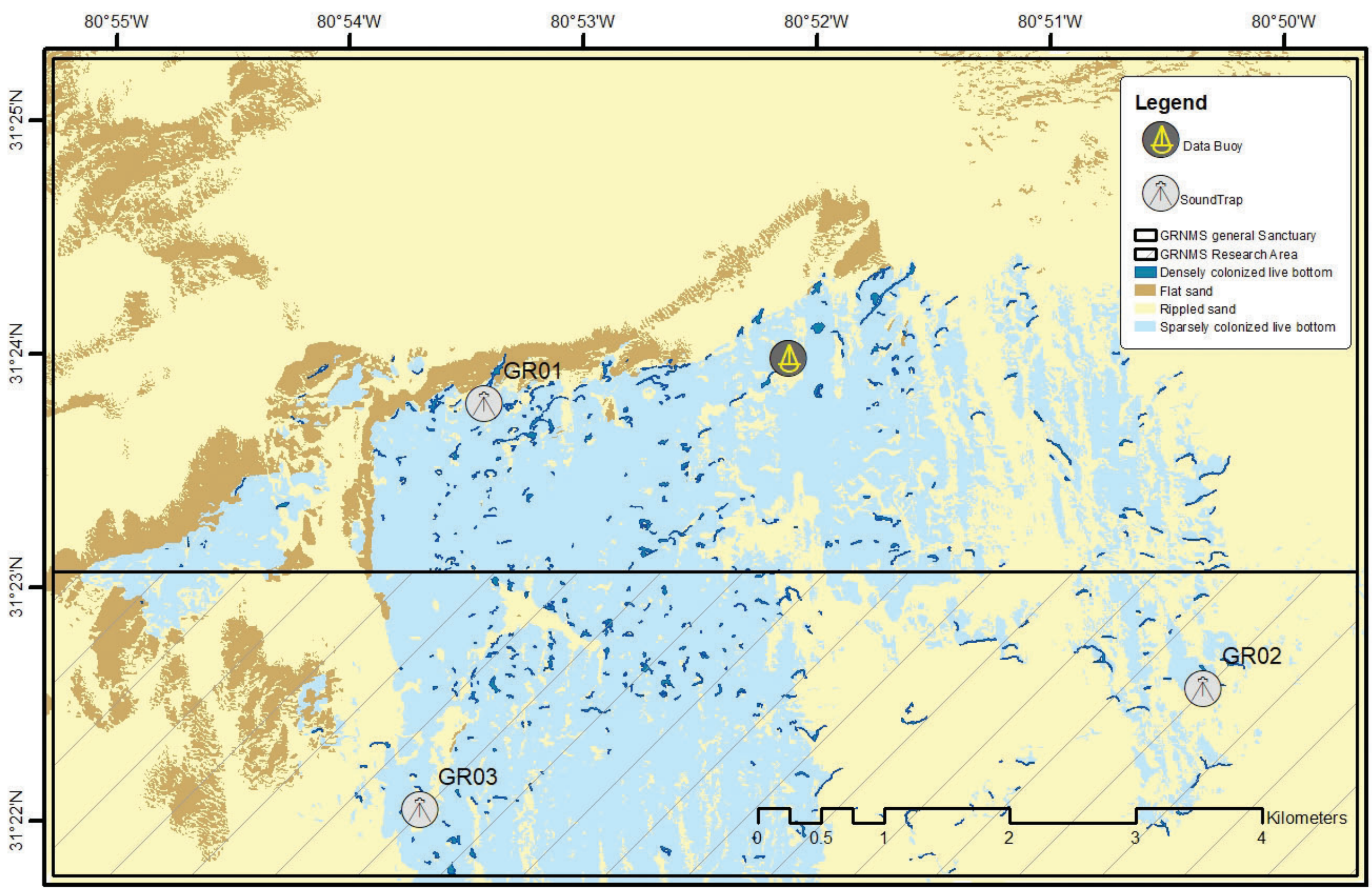


Figure 3.1. Locations of SoundTrap sites.

Counting Boats from Underwater Sounds

3.1.1 Methods

3.1.1.1 Passive Acoustic Monitoring

All acoustic recordings were made using SoundTrap ST500 STD Long Term Recorders (Ocean Instruments Inc., Auckland, New Zealand). Each SoundTrap was calibrated by the manufacturer to record unbiased and accurate representations at the frequencies of boat sounds. Ambient sound was continuously recorded at a rate of 48,000 samples per second (i.e. 48 kHz). This effectively sampled the range of 0 – 24 kHz and encompasses the frequencies of boat sounds. SoundTraps were powered by 9 D-cell batteries, and data were saved on removable microSD memory cards.

Diver above algae and live bottom at Gray's Reef. Credit: Greg McFall.

At each of the three sites, SoundTraps and a temperature logger (HOBO TidbiT v2 - Onset, Borne, MA) were secured to a custom mooring stand engineered to minimize noise interference. The hydrophone element was optimally positioned ~1 m from the seafloor which reduced the noise created by sediment moving along the bottom as well as noise from current flow higher in the water column. SoundTraps were retrieved by divers every 4-5 months to swap out batteries, switch memory cards, and remove accumulated biofouling. When possible, instruments were redeployed on the same day as retrieval. After successful retrieval of data stored on the memory card, the digitized acoustic recordings (.wav files) were downloaded by GRNMS staff using the SoundTrap host software and sent to SanctSound researchers for analysis.

Acoustic data have been recorded at all three locations within GRNMS (Figure 3.1), however only site GR01 was deployed for all of 2019 (with the exception of a 9 day gap the first week of September due to battery limits). This site was located within the open access area of the sanctuary near ledge habitats with higher visitation relative to elsewhere in the sanctuary (Kendall et al. 2008 a, b, Bauer et al. 2008). The other two SoundTrap sites were located in the RA. These were deployed beginning May 15, 2019 and remained through the rest of the year. Data for site GR02 was also processed and made available for analysis in this report. All sound data have been archived for public use at the National Center for Environmental Information (NOAA National Marine Sanctuaries 2020).

3.1.1.2 Analysis of Acoustic Data for Boat Sounds

Two approaches were used to extract evidence of visitor use from the sound records. First, data were evaluated using the Triton (v1.93) acoustic processing software's automated ship-detection add-on (Ship-Detector Remora, Triton v1.93). This software quickly identifies the presence of acoustic signals produced by vessels, but it cannot provide detailed information about the characteristics of individual boat sounds such as frequency content, signal strength, total duration of intermittent sounds, or inferred boat activity (e.g., transiting, maneuvering), which are important for characterizing visitation. Additionally, as with most automated algorithms that rely on quantitative criteria and specific thresholds for detection, some boat sounds may be missed and others perceived as multiple visitation events when sounds are intermittent. These issues can skew estimated rates of visitation. Therefore, to evaluate and overcome these potential limitations, data were also manually reviewed. Boat sounds were annotated with start and end times as well as other descriptors of their characteristics, as mentioned above. The results of both the automated ship-detector and manual analyses were compared to evaluate the more time-efficient, automated ship-detector for future analyses of large acoustic datasets.

3.1.1.3 Automated Boat Detections

To identify vessels using the ship-detector, a single, long-term spectral average (LTSA) file was created from the acoustic data at GR01 and GR02 respectively. The process of generating LTSAs included concatenating all acoustic data for each deployment and calculating sound levels (dB re 1 $\mu Pa^2\ Hz^{-1}$) as a function of time (5 s increments) within different frequency ranges (0 – 24 kHz; 48 Hz increments). This process resulted in a matrix of calibrated measurements of sound levels within each frequency range for every 5 s of data that could be examined statistically by the ship-detector for boat sounds. LTSAs could also be plotted as an image for inspection of detected boat sounds by reviewers during post-processing.

Table 3.1. Adjustable detector settings used to optimize the automated detection of boat sounds using the Triton Ship-Detector Remora.

Parameter	
Low Band Limit (Hz)	Min: 100; Max: 2000
Medium Band Limit (Hz)	Min: 2000; Max: 3000
High Band Limit (Hz)	Min: 3000; Max: 4000
Close Passage Duration Threshold (s)	40
Distant Passage Duration Threshold (s)	45
Received Level Threshold (%)	0.03
Time Between Passages (h)	0.1
Buffer Time (min)	4
Window Size (h)	1
Sliding Time Overlapping Windows (h)	0.5

Settings within the ship-detector can be optimized for different vessel types and environments. Preliminary sensitivity analyses were conducted with the software's built-in Interactive Detector interface to select settings that maximized the automated detection of boat sounds at GRNMS (Table 3.1). With optimized settings selected, the LTSA file was passed through the Batch Detector function, which searched 1-h windows of measurements for acoustic events louder than background noise. Once encountered, the detector then classified these events as either "Ship" or "Ambient" (e.g., storms, fish chorusing) based on the measured relationship between sound levels in various frequencies. "Ship" and "Ambient" events along with their approximate start and end times were then saved to a .csv file. Each event was then manually reviewed using the Evaluator tool of the ship-detector. The Evaluator tool presents a reviewer with zoomed in portions of the LTSA containing "Ship" and "Ambient" events for visual inspection. Each event was viewed to determine whether they had been correctly classified. Detections wrongly classified as "Ambient" were edited to "Ship" (false negatives) and vice versa (false positives). Corrections were saved in an updated .csv file. Importantly, the correction of falsely classified events only pertained to events identified by the automated detector as either "Ship" or "Ambient." Therefore, boat sounds that did not meet the criteria for automated detection (additional false negatives) could not be assessed for prevalence or corrected for inclusion in results.

3.1.1.4 Manual Boat Detections

Given the potential limitations of the automated ship-detector noted above, and to ensure that all boat sounds were included in an analysis of visitation, boat sounds were also manually identified in a separate process performed independently on data from site GR01. The LTSAs generated in the first step of the automated ship-detector were plotted as images and viewed without the automated annotation. LTSAs were viewed as 5-hr windows over a frequency range of 0 to 15 kHz (Figure 3.2). While boat sounds can extend from low frequencies to frequencies greater than 15 kHz, the selection of a maximum viewing frequency of 15 kHz enhanced the ability of the reviewer to see boat sounds isolated within lower frequencies. An analyst scanned though each 5-hr window for sounds produced by boats, whose appearance can vary from brief vertical spikes that extend into high frequencies to long-duration harmonic bands within low-medium frequencies (Figure 3.2). Upon encountering a boat sound, the start and end time of the event was saved to a text file. For each boat detection, the reviewer also categorized information about the sound's frequency (Low: <2 kHz; Medium: 2 – 5 kHz; High: > 5kHz), relative distance from the recording location based on signal amplitude and frequency (Near; Far), and a behavioral classifier (Transit; Maneuver). Vessels were classified as "Transit" if the sound maintained its characteristics throughout a detection event. Vessels were classified as "Maneuver" if there were indicators of speed change, changing gears, and/or starting and stopping within the event. When it was difficult to classify range and behavior within the LTSAs alone, vessel events were examined at a higher temporal and frequency resolution in another analysis software (Raven Pro v2.0). During this step, the analyst also listened to the audio to aid in classification.

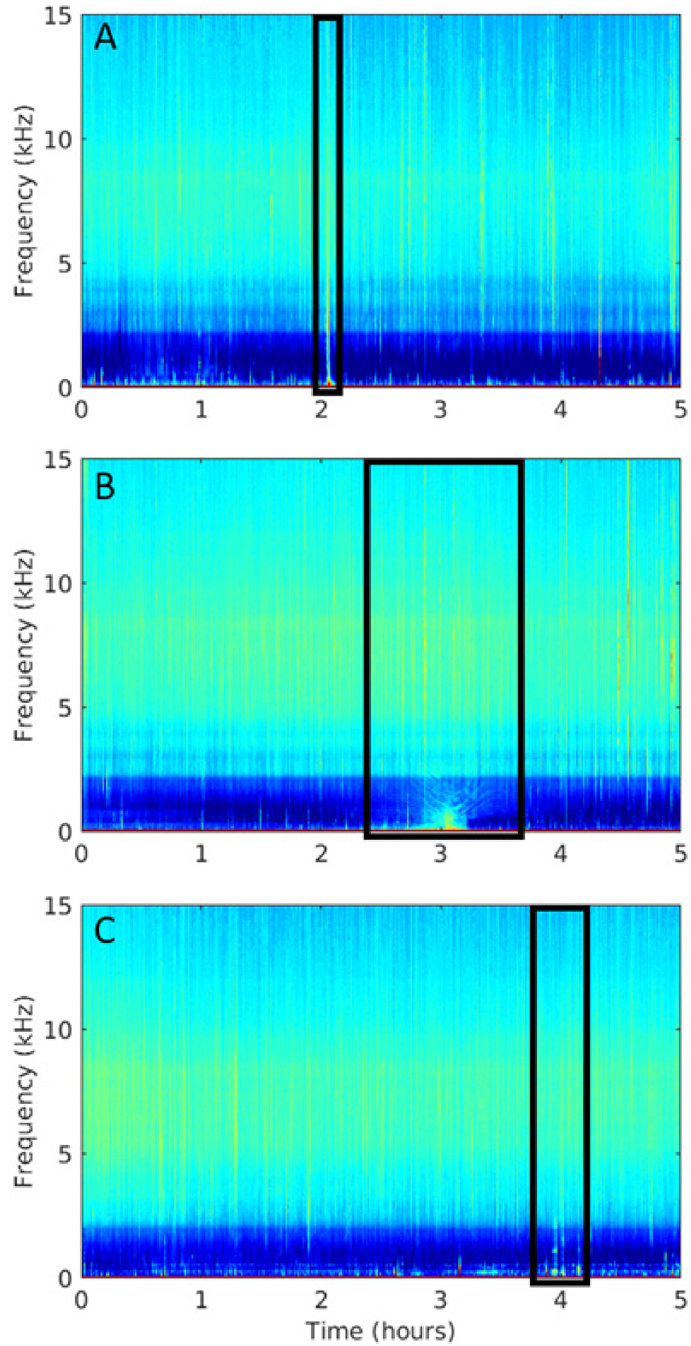


Figure 3.2. Black boxes indicate examples of LTSAs showing (a) high frequency sound of a boat transiting at high speed, (b) a medium frequency sound of a boat transiting at slow speed, and (c) a series of medium frequency sounds of a boat starting and stopping (maneuvering). High amplitude spectral averages are depicted in red; low amplitude spectral averages are depicted in blue.

3.1.1.5 Manual Boat Detections

The boat events from both the automated and manual processes were further classified based on ancillary data and filtering to better understand their likely source. The timestamps of boat detections were cross-referenced with timestamps of AIS data points generated from vessels within a 10 km radius of the recording location. This enabled us to identify large transiting vessels as well as research vessels such as the R/V *Sam Gray* and NOAA Ship *Nancy Foster* in the sound data. AIS track lines were imported into ArcMap (v10.7 ESRI) and selected if they coincided with an acoustic boat detection. If the frequency, amplitude, and estimated range of acoustic boat detection agreed with the range of an AIS track line from the acoustic recorder, then information about the vessel type and length were appended to the detection results (personally identifiable information such as vessel name is available from AIS but was excluded here for privacy purposes).

An additional step was taken to refine the estimated count of visiting boats. Preliminary evaluation revealed a cyclical pattern to many boat events. Boat noise would occur for 3-5 minutes, often classified as maneuvering, then a quiet period of 10-20 minutes, followed by another cycle of 3-5 minutes of activity. This cycle was repeated as many as 6 times in 44 different incidences. Observations of boater behavior and consultation with anglers indicate that this sort of repeated acoustic signal is expected if the same boat were drift fishing over the same ledge over and over. Repeatedly trolling over the same ledge system could also produce this acoustic pattern. For this reason, temporal filtering was used to convert multiple sound events with similar characteristics that occurred in a short period of time into a single event. When the same signal was repeated in less than 30 minute intervals, it was assumed to be the same boat and combined into a single event.

3.1.1.6 Boat Count Summaries

The data from sites GR01 (automated and manual interpretation processes) and GR02 (automated only) were summarized in several ways to understand the effectiveness of the two approaches and the temporal patterns of visitation as suggested by boat sounds inside (GR02) and outside (GR01) the RA. Here we summarize the number of boats observed by date, day of the week, and time of day (Eastern Standard Time; EST) for each dataset. The SoundTrap at GR02 was deployed mid-May, 2019 and therefore only included the latter 63% of 2019. To enable comparisons with GR01 in some analyses, the number of boat events at GR02 were increased by the proportion that would have been recorded had the SoundTrap there been deployed the whole year. This was done using the simplifying assumption that visitation in the first half of the year is roughly proportional to that observed in the second half of the year, an observation supported by seasonal visitation patterns in other datasets. In addition, because SoundTraps provide continuous recordings, it is possible to calculate the duration of each boat detection event. Because duration of visits is closely tied to boat behavior (i.e., transit vs. maneuver) this analysis focused on the manual interpretation of data from GR01 in which behavior was assigned and durations were better estimated. Histograms depicting the duration of sound events and boat behaviors were used to summarize those aspects of visitation.

3.2 RESULTS AND DISCUSSION

The two sites and various processing approaches in the SoundTrap data included 714 sound events that had the characteristics of boats. At GR01, a total of 349 and 241 boat events were identified in the manual and automated process, respectively, during 2019. A total of 124 boat events were detected at GR02 from May – December 2019 using the automated process. An unknown number of these were potentially the same boat, especially at GR01 as identified through the manual versus automated processes. One hundred and ninety of these events (26% of the total 714; 95 manual and 95 automated) were linked to vessels in the AIS database. The vast majority of AIS-linked boats, whose behaviors were classified manually at GR01, were transiting (98%). AIS-linked boats occurred evenly in all hours of the day and night and comprised the largest share of the observations (75%) between the hours of 8pm and 5am (75% of manual detections and 74% of automated detections). Because these boats were documented in AIS as passing through, rather than visiting the sanctuary as defined here, they were excluded from further analyses.

Compared to the manual process, the automated ship-detector identified 40% fewer non-AIS-associated boat noise events at GR01 overall (154 out of 254 manually identified events) (Table 3.2), which indicates that like most statistical detectors, the automated detector is not entirely successful in identifying all boats. However, given the efficiency of the automated detector compared to manually identifying boat sounds, a 40% reduction in detections may still be useful

Table 3.2. Summary of (A) the manually detected events that were also detected by the automated process, and (B) automated detections that were also detected by the manual process. Excludes AIS equipped boats.

A.	Events
Manual	254
Automated	154
Difference:	100

B.	Events
Automated	201
Manual	168
Difference:	33

Counting Boats from Underwater Sounds

in terms of being able to quickly identify patterns of boat presence and visitation in long-term acoustic datasets that otherwise might not be analyzed due to personnel and time constraints. This may be applicable to quickly examine time series for trends since the bias would be consistent among time periods. In general, there was good agreement of most results from the two methods (Figure 3.3). Of note however, there is additional complexity in the different observations from these two techniques. The duration of events differed among the two methods as the ship detector determines duration mathematically and not based on the true start and end of a boat sound. The manual approach also did not detect some events (n = 33) perceived by the automated detector (168 out of 201 events detected by the automated process) (Table 3.2). This is likely due to an inability to visually detect some brief and/or low amplitude (i.e. "quiet") and low frequency boat events within the 5-hr window spectrogram that was viewed manually. If the acoustic data were viewed at a higher resolution, e.g., 1-hr windows, it is expected that this discrepancy could be reduced. However, viewing shorter windows of data would increase manual processing time and may prove unfeasible in long-term or large datasets. Although not a 1:1 match, the results suggest that identification of boat sounds can be done manually, or more efficiently with an automated detector, as long as the limitations of the detector are understood.

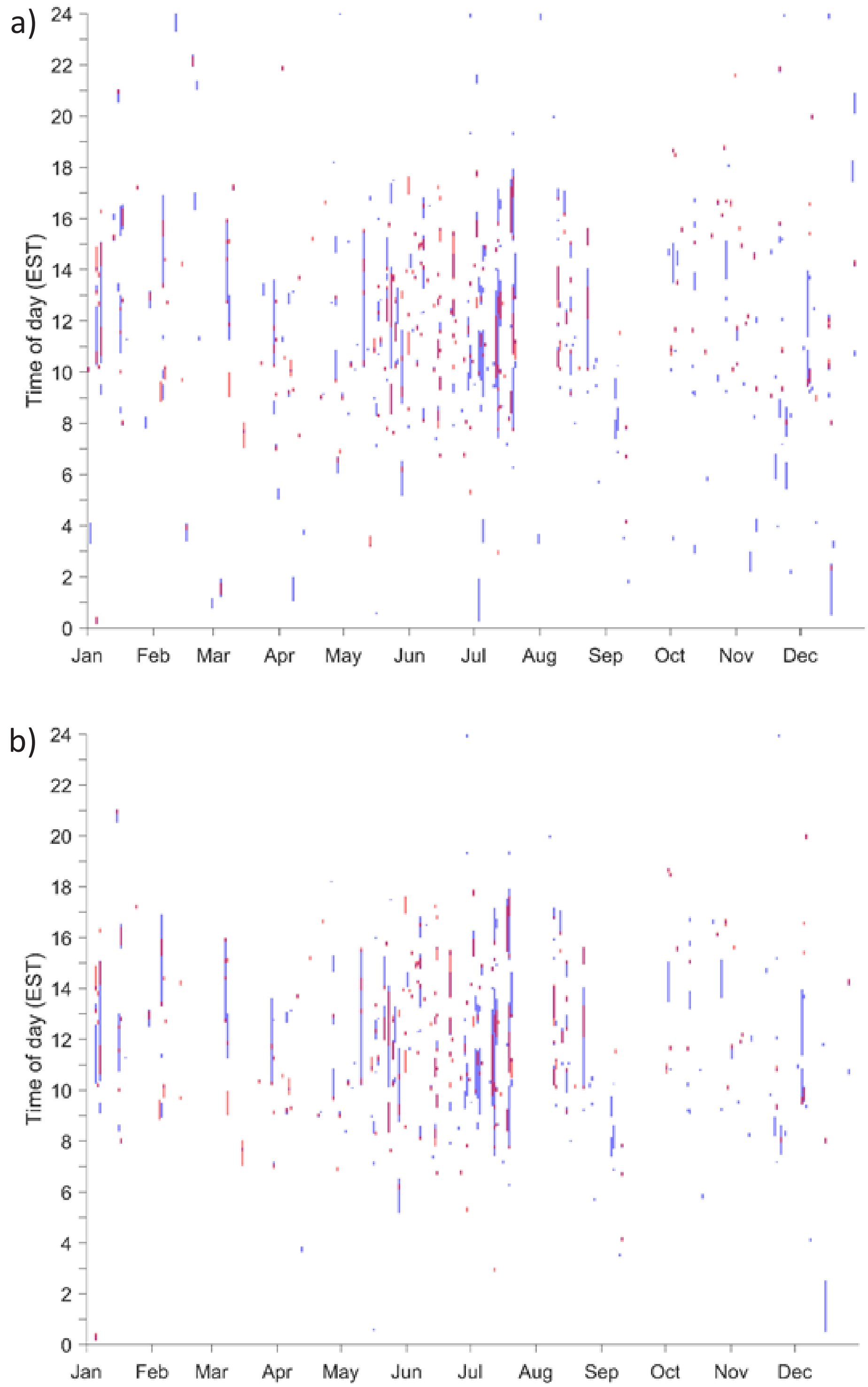


Figure 3.3a-b. Boat events and their durations detected at GR01 manually (blue) and with the automated detector (red). (a) includes all AIS and non-AIS boat events. (b) only includes non-AIS boat events.

Boats were detected in the sanctuary in all months of the year, but were most common June-August (Figure 3.4). These three months accounted for 46 to 63% of all boat events (46% at GR01 based on manual detections, 47% at GR01 based on automated detections, and 63% at GR02 based on automated detections). The largest number of boat detection events per day occurred in summer months in all three datasets. At GR01 using the manual process, 6 boats were observed on June 16, 22, and August 10 all of which were weekend days. Seven other dates with several boats (n = 5) were all on weekend days except for Friday, August 16 which was during the Golden Isles fishing tournament (Figure 3.4a). Similarly, 7 boats were detected on June 16 at GR01 using the automated process and 8 boats on July 13, both weekend days with July 13 coinciding with the Sapelo Open Kingfish Tournament (Figure 3.4b). Detections in the RA included a maximum of four possible boats on each of three days in June and July, all of which were on Saturdays (Figure 3.4c).

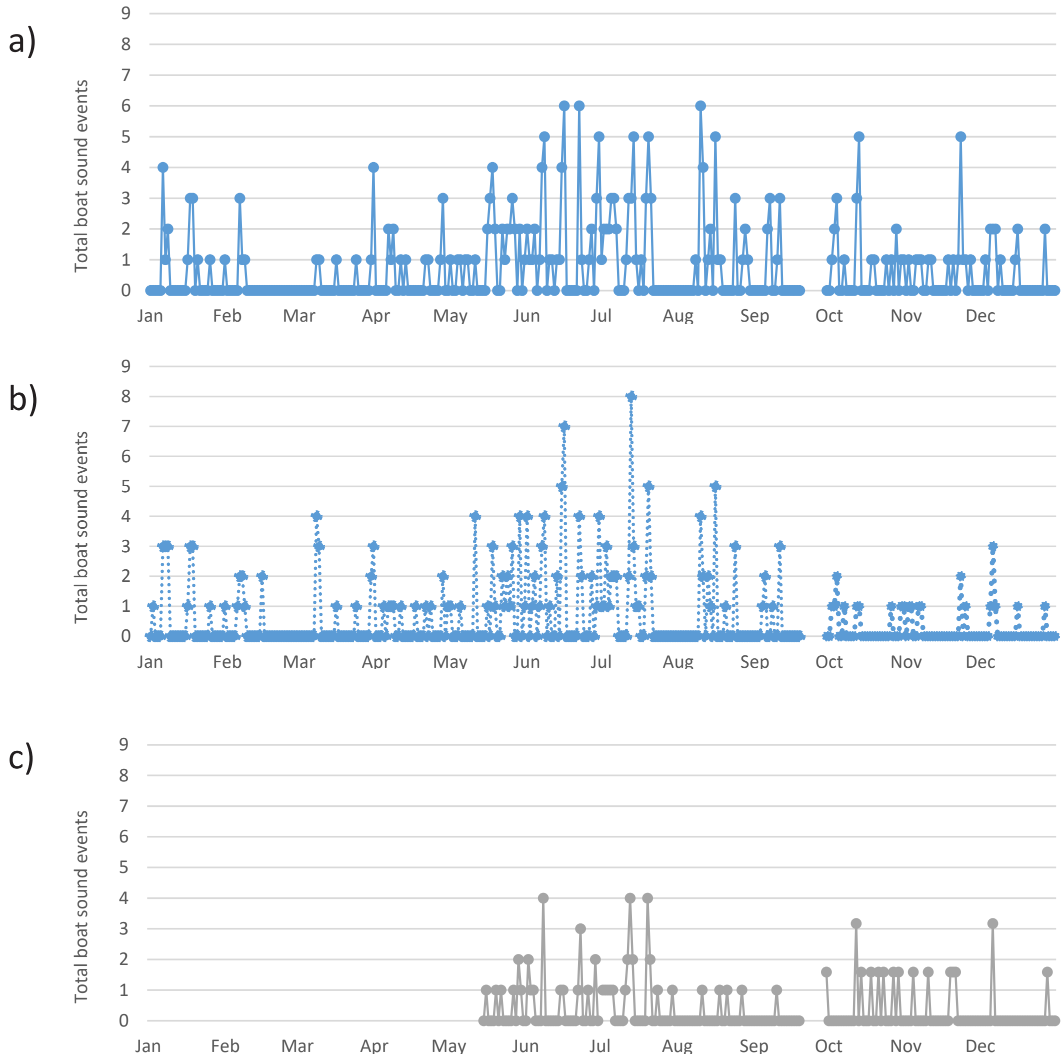


Figure 3.4a-c. Total number of boat sound events observed in the SoundTrap data by day of the year at: a) GR01 manual process, b) GR01 automated process, and c) GR02 automated process. Note that the SoundTrap at GR02 was not deployed until mid May and there is a data gap from September 21 to 28 at both sites when the receivers underwent download and maintenance.

A conspicuous drop in daily visitation events occurred from 30 July to 8 August in these plots (Figure 3.4). Boats were detected during this period of time however, these detections were excluded because the R/V *Nancy Foster* was present at GRNMS during those days. Insufficient AIS data did not allow for sounds to be attributed to the *Nancy Foster* or other boats visiting Gray's Reef at that time. Therefore, the results likely underrepresent true visitation during those dates.

The day of the week that boat sound events were observed reveals that most visitation occurs on Friday, Saturday, and Sunday regardless of location or type of data processing used to detect boats (Figure 3.5). Of the 527 boat events detected in total, 266 (50%) occurred on just Saturday and Sunday. At least a few boats were

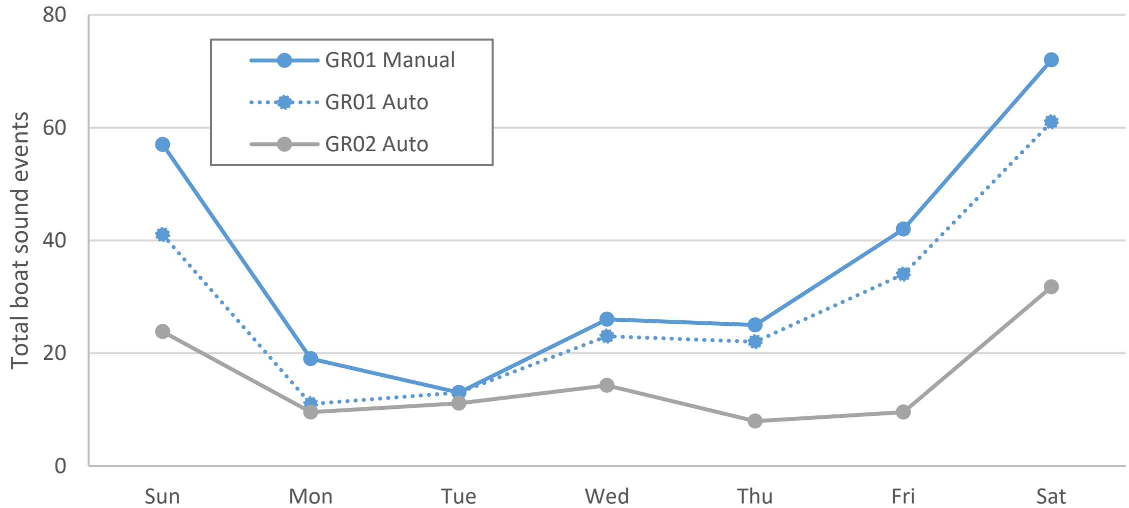


Figure 3.5. Total number of boat sound events observed in the SoundTrap data by day of the week at GR01 (manual and automated processes) and GR02 (automated process extrapolated to full year of deployment).

heard on every day of the week but least commonly occurred on Monday and Tuesday. Friday had more boats than other weekdays at GR01, but not as many as Saturday and Sunday.

The time of day that boats were heard in the SoundTrap data reveals that most visitation occurs late-morning and mid-day (Figure 3.6). Of the 527 boats detected, 381 (72%) occurred between ~9 am and 3 pm. Boats were detected at nearly all hours of the day and night including after midnight (12 am) and as early as 3 am. Boat sounds during darkness hours (~8 pm to 4 am) were especially curious to observers and were always interpreted as transiting based on their acoustic characteristics analyzed during manual processing.

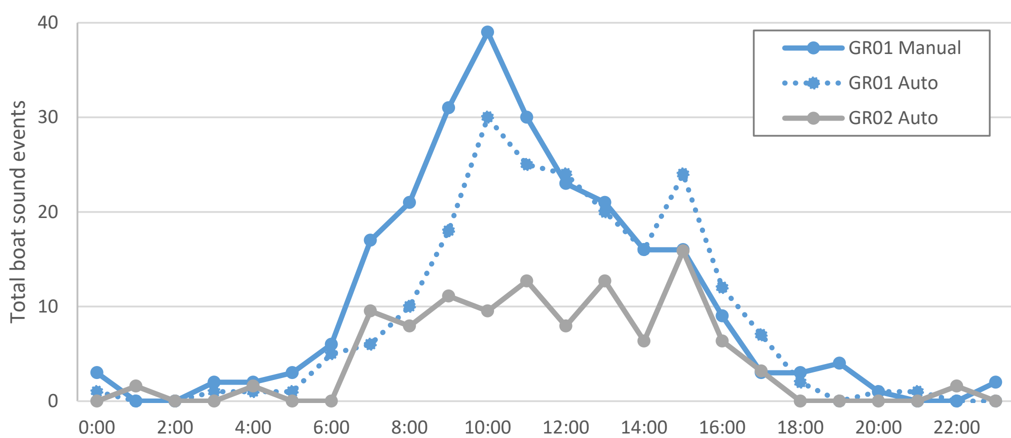


Figure 3.6. Total number of boat sound events observed in the SoundTrap data by hour of the day (EST) at GR01 (manual and automated processes) and GR02 (automated process extrapolated to full year of deployment).

Although they only infer activity within the detection range of the hydrophone (1-4 km), the SoundTrap recordings are the only dataset that provides more than a snap shot of activity. Most boat sounds lasted only a few minutes (Figure 3.7). Half of the boat sound events were less than 10 minutes long and another 17% lasted only 10-20 minutes. These shorter duration events were dominated by sounds that suggested the boats were transiting (78%). This makes sense since boats on the move will tend to drive out of the detection range of the receiver in a matter of minutes. It is unknown if these boats were going to a location inside the sanctuary or elsewhere. As sound events increased in their duration (>20 minutes), this pattern was reversed such that maneuvering took on a greater proportion of the inferred boat behaviors (71%). Again, this matches expectations as boaters likely maneuver to remain in an area and fish ledges.

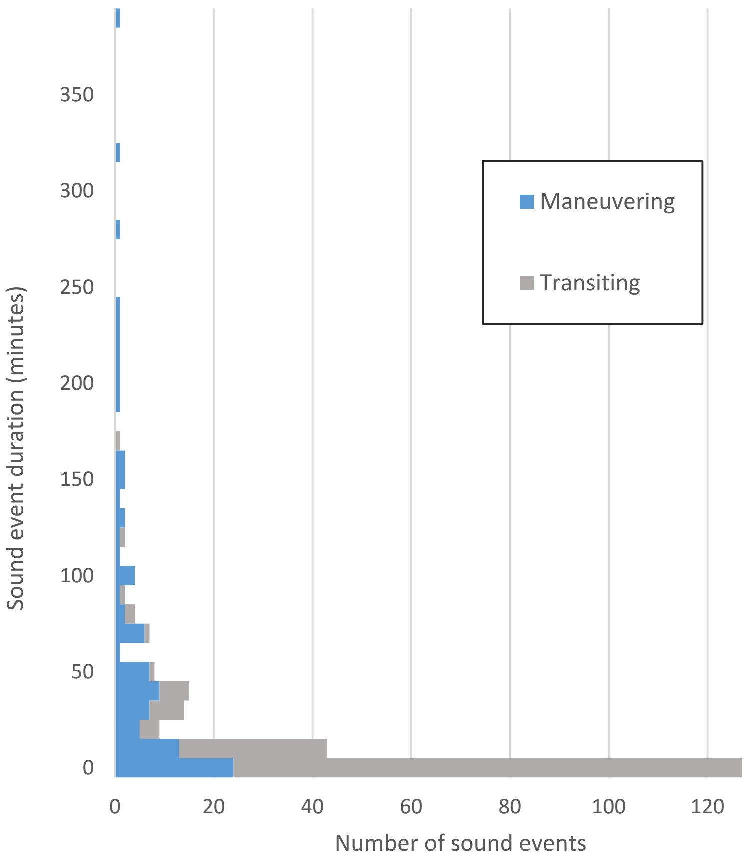


Figure 3.7. Histogram of the number of boat sound events observed in the SoundTrap data by duration of the event in 10 minute increments (site GR01 manual processing only).

R/V Sam Gray. *Credit: GRNMS.*


Overflight. Credit: U.S. Coast Guard Air Auxiliary Savannah.

4.0 COUNTING BOATS FROM BOATS AND AIRPLANES

4.1 GEORGIA DEPARTMENT OF NATURAL RESOURCES LAW ENFORCEMENT

Enforcement officers from the Georgia Department of Natural Resources (GA DNR) monitor fishing activity several times annually at GRNMS as permitted by their other enforcement priorities, available staff, and weather conditions. Patrols are primarily conducted mid-day to give fishermen some time to undertake fishing activities and potentially have some catch for the officers to inspect. Patrols can however, occur at any time of the day or night so that enforcement activities are not entirely predictable. En route to a patrol at Gray's Reef, the enforcement boat also stops all vessels observed returning toward shore and asks if fishing at Gray's Reef was conducted that day. When conducting a vessel stop, the enforcement boat typically ties up alongside and one of the three officers on the enforcement boat boards the vessel to conduct the inspection. Relevant aspects of the inspection and questions asked by the officers for this study include number of people on board, types of fishing conducted, allowable gear, compliance with fish size, season, and bag limits, and location of fishing activities if not conducted at the location of boarding. Duration of patrols is variable due to multiple activities planned on patrol days and level of fishing activity at the sanctuary. If no boats are at the sanctuary at the time of arrival, the enforcement boat typically waits for ~2 hours at the data buoy before moving to patrol at another location.

4.1.1 Methods

Only general descriptive statistics of relevant variables are provided due to the semi-quantitative nature of the patrols, haphazard periodicity in date and time of the patrols, low sample size, and unequal effort among time periods. It is important to recognize that the patrol data achieve an enforcement objective and are not designed to evaluate visitation per se. Despite these limitations, the patrol data provide useful inference on several topics. Here we summarize the number of patrols conducted by year, month, day of the week, and time of day. Mean number and standard error of boats encountered per survey by month and time of day are calculated along with the mean and standard error of the number of fishermen on each boat. Species caught or targeted are also summarized to provide additional insight into visitor use.

4.1.2 Results and Discussion

Patrols were conducted at Gray's Reef on 66 dates from 2014 to 2019. Most years had 9-11 patrols but as few as 7 (2016) or as many as 18 (2019) occurred during a given year. The vast majority of boats encountered fishing at Gray's Reef are outboard engine(s)/center console design in the 16-26 foot size class according to GA DNR (pers. comm. Sgt. M. Carson) although boat type data are not recorded. Strengths of this dataset include the highest precision of information on number of people per boat and fish species caught or targeted. Limitations of this dataset include the low number of patrols, low encounter rates with boats, variable patrol duration, and behavioral bias of boaters since the GA DNR enforcement boat is clearly marked. Important sources of bias influencing when patrols are conducted include weather conditions, time of day, and day of the week.

For all months and years combined, GA DNR encounters 0.97 (+/- 0.16 SE) boats per patrol. Zero boats were encountered on 54% of the patrols (37/69). The largest number of boats encountered on a single patrol was five. This occurred twice, both on weekend days during summer months.

There was no clear seasonal pattern in patrol frequency and patrols occurred in all months (Figure 4.1). June was the least common month to include a patrol (n = 2 from 2014 to 2019) and August was the most common (n = 11). Three dates were reported to have had multiple patrols.

Counting Boats from Boats and Airplanes

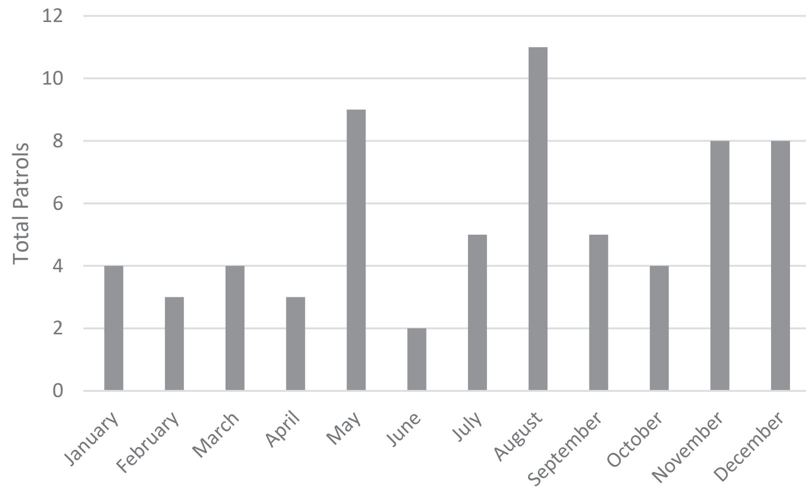


Figure 4.1. Number of patrols by month.

The number of boats encountered per patrol plotted by month indicates that anglers likely visit Gray's Reef during all months of the year but may be more common in summer months (Figure 4.2). June had only 2 patrols in the 5 year dataset and no boats were found. This is likely anomalous due to the low patrol effort in that month. June is the least patrolled month (but still has been patrolled) due to the transition in the GA DNR fiscal year and other monitoring priorities of enforcement staff in that month. Unfortunately, June is precisely when the number of patrols would benefit most from being increased as visitation ramps up into the busier summer months.

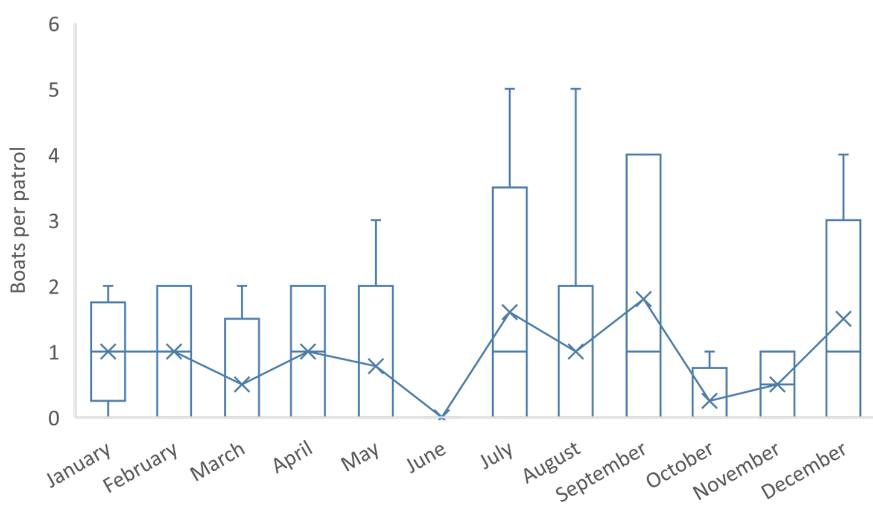


Figure 4.2. Number of boats encountered per patrol by month. Means are denoted by 'x' and connected by lines between months. Boxes denote median (center line) and interquartile range (top and bottom of boxes). Whiskers denote values 1.5 times above or below the interquartile range.

Patrols occurred on all days of the week, however, weekend days received most of the patrol effort. Nearly 60% of the patrols occurred on weekend days including Friday, and over 25% of all patrols occurred on Sundays alone (Figure 4.3). Thursday was the least common day of the week to conduct patrols (only 6% of patrol effort on each).

The number of boats encountered per patrol plotted by day of the week indicates that fishermen visit Gray's Reef primarily on Friday, Saturday, and Sunday (Figure 4.4). For all years combined, average number of boats encountered Friday-Sunday was 1.1 – 1.8 per survey, whereas Monday through Thursday the average number encountered was 0 – 0.5 per survey. No boats were encountered on Tuesday patrols, however only 6 patrols were conducted on Tuesdays.

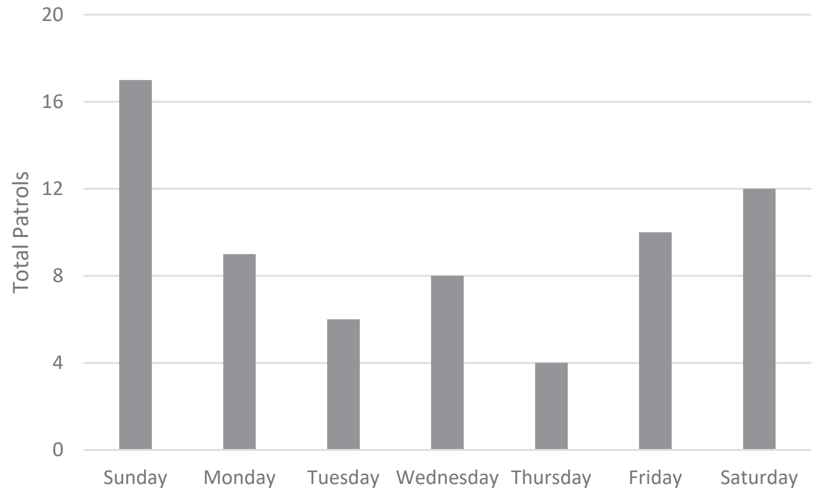


Figure 4.3. Number of patrols by day of the week.

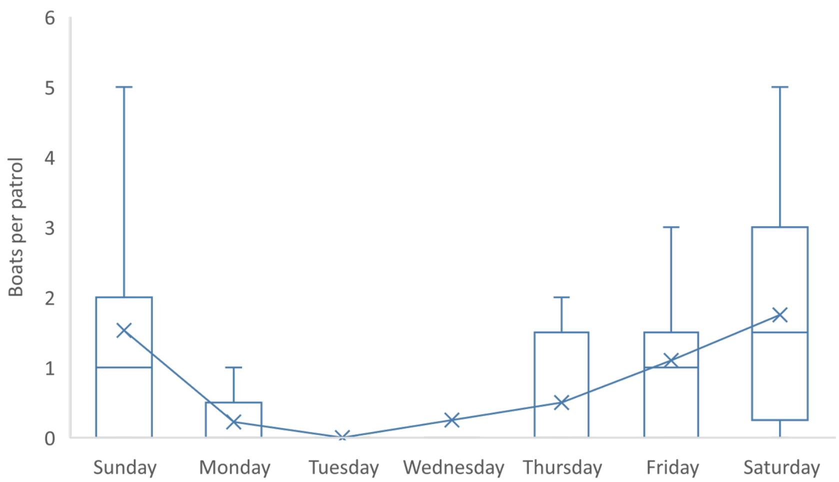


Figure 4.4. Number of boats encountered per patrol by day of the week (2014-2019). Means are denoted by 'x' and connected by the line between days. Boxes denote median (center line) and interquartile range (top and bottom of boxes). Whiskers denote values 1.5 times above or below the interquartile range.

Time of day that patrols began and ended, as well as the time that each boat was stopped were included for most patrols (90%) and are needed to calculate encounter rates. Start times ranged from 5:30 am to 3:30 pm. The average start time was 9:26 am (+/- 12 minutes SE). Nearly 75% of patrols began between 8 am and 11 am. End times for patrols ranged from 9:30 am to 8:30 pm. The average end time was 2:45 pm (+/- 14 minutes SE). Nearly 75% of patrols ended between 2 pm and 5pm. The duration of patrols ranged from 2 to 8 hours. Average duration was 5.5 hours (+/- 11 minutes SE). Nearly 75% of patrols were from 5 to 7 hours long.

Time of day when visiting boats were actually observed and stopped during patrols ranged from 9:21 am to 6:26 pm. Average time of boat inspections was 11:58 am (+/- 13 minutes SE). The total number of boats stopped steadily increases from 9 am until noon then drops off quickly thereafter (Figure 4.5).

It was also useful to standardize the number of boat encounters based on the amount of patrol effort at different times of the day. This reveals which time intervals may be the most efficient for achieving the greatest number of boat encounters (Figure 4.6). The 6 pm time slot had the highest encounter rate, however, this was likely an anomaly. Only two hours of patrols have occurred at that time and two boats happen to be seen. Considering only those time slots with a large number of patrol hours (>30) that occurred from 9 am to 3 pm (Figure 4.5), it

Counting Boats from Boats and Airplanes

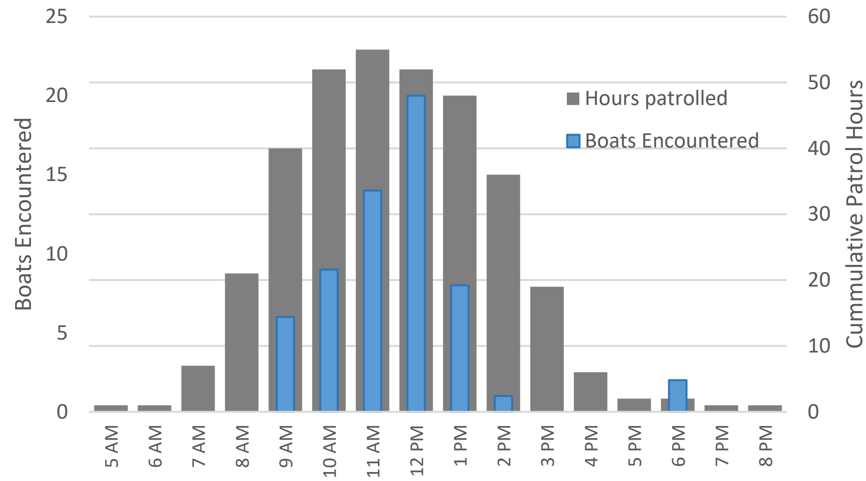


Figure 4.5. Cumulative number of patrol hours and visiting boats encountered by time of day.

can be observed that the greatest encounter rate occurs in the Noon hour (Figure 4.6). The encounter rate at that time was 0.38 visitors per patrol hour. In other words, 1 boat is encountered for every 2.6 hours of patrols conducted from noon to 1 pm. Encounter rates drop off dramatically after that, with 0.03 boats per hour from 2-3 pm (only 1 boat in 36 hours of patrols).

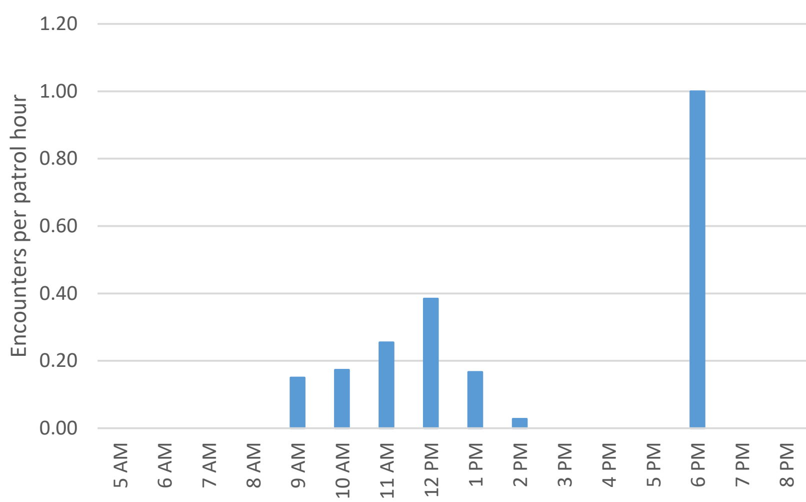


Figure 4.6. Boat encounters per patrol hour by time of day.

Number of fishermen per boat was recorded for 63 boats with the range being 1 to 15 people on board. Nearly 75% of boats had 2 to 4 people. Mean number of fishermen per boat is 3.7 (+/- 0.27 SE). Only 2 boats had a single person on board. One boat had 15 but the next highest was 8 occupants.

Georgia DNR provides the only dataset with information on which fish species are targeted. Anglers are obviously motivated to only show catch or claim targeting legal sizes and species during law enforcement stops, so results must be interpreted accordingly. Out of 63 boats inspected, 44 (70%) either had catch on board or told officers which species they were targeting. The most commonly caught or reportedly targeted species were black sea bass (*Centropristis striata*) (n = 25 boats, or 57% of boats with known target species) and king mackerel (*Scomberomorus cavalla*) (n = 11 boats, or 25% of boats with known target species) with only two boats reportedly targeting both. Black sea bass were targeted all year, whereas king mackerel were targeted primarily during July and August, but also as late as December. Other species less commonly observed caught or reportedly targeted at Gray's Reef were groupers, barracuda (*Sphyraena barracuda*), sheepshead (*Archosargus probatocephalus*), and spottail pinfish (*Diplodus holbrookii*). Two boats were merely transiting through Gray's Reef while returning with dolphinfish (*Coryphaena hippurus*) or tuna species from the Gulf Stream. In this six years of enforcement data (2014-2019), only 1 violation out of 63 vessel inspections was noted, which was for possession of undersized black sea bass.

These statistics can be useful for further optimizing the time and duration of patrol activities. If there is a target encounter rate desired by GADNR to achieve enforcement goals (e.g., 1 boat every three hours) these data can be used reduce the time spent patrolling at GRNMS and shift resources elsewhere. Of course, these data are biased toward the environmental conditions, seasons, and days of the week that were patrolled. Therefore it is advisable to examine the daily and seasonal encounter rates reported from other datasets when optimizing patrol schedules. Other logistical decisions may supersede trying to maximize efficiency based on encounter rates alone, such as travel time to and from GRNMS or other patrol destinations. Once at GRNMS, it may be deemed worthwhile to continue patrolling there despite low encounter rates, rather than transit to other locations.

Some older GA DNR data are available from 2003-2007, however they were not analyzed here. Those patrols were conducted before important changes in sanctuary regulations including the anchoring (2006) and spearfishing prohibitions (2010) and designation of the Research Area (2011). Of note however, is that patrols at GRNMS were conducted much more frequently, as many as 35 per year. Out of 143 vessel inspections from 2005 to 2007, there were 3 violations, one for possession of undersized fish and two given as warnings for anchoring in the sanctuary. This suggests that compliance with regulations has been generally good over time.

4.2 GRNMS RESEARCH VESSELS

Researchers conduct field operations at the sanctuary aboard GRNMS research vessels (R/Vs) several times monthly during the spring, summer, and fall field seasons. During these field operations they conduct boat counts as permitted by their task schedule. The protocol for collecting this supplemental information was designed with brevity and simplicity in mind given that the staff are at the sanctuary for another purpose and the boat counts cannot interfere with those priorities. At regular times each day (11:30 and 13:30), or as soon as practical around that time, the boat captain or designee is tasked with scanning the horizon for any boats and recording information on boat type, size, speed, activity, AIS presence, and when possible, number of people on board. Depending on the position of the observer boat in the sanctuary, it is possible that all boats may not be visible since estimated visibility for the R/V *Sam Gray* is ~4 nautical miles.

Instructions for on-water boat survey by GRNMS Staff

1. *Data should be recorded using the customized datasheet kept on the R/V (Figure 4.7 below as part of side bar).*
2. *An alarm at 11:30 am and 1:30 pm is the cue to conduct the assessment. If the assessment is conducted earlier due to anticipated activities at 11:30 and 1:30, or delayed due to priority activity, the actual time of the assessment is recorded.*
3. *Latitude/longitude of the R/V are recorded*
4. *Operational status of AIS is noted (Y/N)*
5. *Binoculars are used to scan the horizon in 360 degrees and observe boats.*
6. *For each boat seen record: direction from R/V (e.g., N, NE), estimated distance (km), suspected zone (outside the sanctuary, inside the sanctuary but outside the Research Area, inside the Research Area), boat type (i.e. outboard fishing, inboard fishing, sail, cabin cruiser, yacht, other), size class (<16, 16-26, 26-40, 40-65 feet), speed (anchored, adrift, idle, undersail, running), activity (transit, bottom fishing, scuba, trolling, other), presence on AIS (Y/N), number of people visible, and boat name. Fields should be left blank when unsure (e.g., too far to tell zone or number of people). Record all other data (time and position) even if no boats are present.*

Counting Boats from Boats and Airplanes

GRNMS Boat Count Protocol-

1. Set an alarm for 11:30 and 1:30 as your cue to look around. If delayed due to priority activity, record the actual time as soon as you are able to conduct the boat count after 11:30 and 1:30.
2. Take a waypoint and record your lat/long
3. Use binoculars to scan the horizon in 360 degrees
4. Fill out the fields for each boat seen, if no boats- enter "0" for boat number
5. Note that all values will be interpreted as "best visual estimates" (e.g. at distance it can be difficult to tell if a boat is in/out of the RA)

Date	Obs. Time	Sam Gray Location		Boat no.	Dir.	Dist.	On AIS?	Suspected Zone	Boat Type	Class	Speed	Activity	People visible	Vessel name
MM/DD/YY	• 11:30 AM • 1:30 PM or • Time ASAP afterwards	Latitude DD	Longitude DD	Numeric (0 to N)	• N • NE • E • SE • S • SW • W • NW	~ km	Y/N	• GRNMS • RA • outside	• outboard fishing • inboard fishing • sail • cabin cruiser • yacht • other	• <16 ft • 16 - 26 ft • 26 - 40ft • 40 - 65 ft	• anchored • adrift • idle • undersail • running	• transit • bottom fishing • trolling • scuba • other	Numeric	Text
5/1/2019	11:30	31.39650	80.89030	0	-	-	-	-	-	-	-	-	-	-
5/1/2019	1:30	31.37613	80.8913	0	-	-	-	-	-	-	-	-	-	-
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Figure 4.7. Data sheet for counts of visitor boats conducted by GRNMS staff during regular field operations.

4.2.1 Methods

Due to the low sample size and small number of boats observed, as well as inconsistencies and lack of information recorded in several fields, the data from these observations must be considered semi-quantitative and therefore only general descriptive values are reported. Despite these limitations, this information adds to the diversity of data available to assess important aspects of visitation, especially on weekdays when GA DNR patrols are less common. Here we describe the boat types, position in the sanctuary, type of activities, and number of people on board as observed from the GRNMS R/V *Sam Gray* during 2019 field operations. Some important but older observational data were collected during fishing tournaments, and are addressed in section 5.0 Conclusions.

4.2.2 Results and Discussion

Field operations using the GRNMS R/V were conducted at the sanctuary on 11 dates from May through November 2019. A total of 22 boats were observed. The number of boats seen per day ranged from 0 to 6. Position estimates suggested that 23% of observed boats (5/22) were inside the RA, and the remainder were inside the sanctuary but not in the RA. All five boats estimated to be in the RA were in transit. Outboard fishing boats (n = 8), all in the 16-26 foot class, comprised 33% of the boats seen with another 38% classified as yachts, mostly in the 40-65 foot class. In addition, 2 cabin cruisers, 2 sportfishers, and 1 sailboat were observed. Only 1 out of the 22 boats observed was on AIS (yacht in the 40 – 60 foot size class). The only boats classified as actively fishing (n = 8) were outboard in the 16-26 foot size class. Of these, 3 were observed trolling and 5 were bottom fishing. Only outboard fishing boats have open decks that enabled regular counts of the number of people on board. Number of people on that boat type ranged from 2 to 4 with an average of 3.0 (+/-0.29 SE) per boat.

Strengths of this dataset include the ability to record boat type, number of people, and specific fishing activities. Limitations of this dataset include low sample size, low encounter rates with boats, weekday bias, good weather bias, and behavior bias of boaters since the GRNMS R/V is clearly marked as a sanctuary vessel. Despite these challenges, it is recommended that this activity be continued whenever GRNMS staff are in the field. Much like the GA DNR dataset, records of visitation when compiled gradually but in consistent format over time, can grow into valuable sources of information.

Now that this datasheet and protocol have been tested for one field season, several modifications have been identified that will further simplify and streamline its use in the field. For example, we recommend discontinuing collection of observer coordinates as well as direction and distance to the observed boat. These variables were difficult to estimate or provided less important types of data. We also recommend combining the columns for speed and activity since these attributes are often correlated. We suggest the options for this column include “trolling at idle speed”, “bottom fishing while adrift”, “transiting while running”, and “at data buoy”. These changes reduce the number of variables collected while retaining the most critical aspects of visitor use including boat type, location within the sanctuary (in or out of the RA), and type of activity.

4.3 U.S. COAST GUARD AND AIR AUXILIARY

As another partner in law enforcement at GRNMS, the U.S. Coast Guard and Air Auxiliary conduct two additional activities that can contribute to an understanding of visitation. First, Coast Guard cutters from District 7 stop at GRNMS to make observations during their transits along the Georgia coast. The timing of these ~1 hour stops is dependent upon the higher-priority operations of the vessel. Stops can occur at any time of day or night, however, most records do not have time information.

The second type of data is from volunteer pilots with the Air Auxiliary and consists of overflights from a variety of small, privately-owned aircraft. Flights are conducted on a volunteer basis as part of the Auxiliary’s maritime observation mission and can only occur during good weather conditions and visual flight rules. Aerial patrols are typically conducted at an altitude of 1,000 feet and last only a few minutes at Gray’s Reef, or long enough to complete a loop or two over the sanctuary. These flights have provided insight into visitation at Gray’s Reef intermittently as far back a 1979.

4.3.1 Methods

Due to the low sample size and small number of boats observed, these data must be considered semi-quantitative and therefore only general descriptive values are reported. Like other small datasets, this information adds to the diversity of data available to assess important aspects of visitation. Here we describe the boat types, sizes, and type of activities to the extent practicable during the most recent 5 years of data. Some older survey data are discussed for context.

4.3.2 Results and Discussion

Records were available for a total of only 15 patrols by US Coast Guard cutters at the sanctuary from March 2015 to March 2020. All but three of these occurred in the months of January through March, and only one was on a weekend. No boats were seen on any stops. Due to this low number of observation times and winter bias, these data will not be considered further for assessing visitation at this time.

Counting Boats from Boats and Airplanes

Air Auxiliary overflights also have a limited number of occurrences. From November 2015 to June 2019, a total of only 18 aerial patrols were reported for the sanctuary. They occurred in all seasons but only 3 took place on weekends. Average patrol start time was 12:20 pm and all took place between 9:55 am to 5:24 pm. No boats were seen on 10 out of the 18 patrols. A total of 13 boats were observed. Average number of boats observed per patrol was 0.7 and the range was 0 to 4. This included 2 sailboats, 1 boat in the 40-50 foot size class, and the remaining 10 were described as 18-30 feet long. Eight of the boats were observed to be stationary or drifting and 2 were actively trolling. Two were described as being located near the weather buoy. No other information on location, number of persons onboard, or boat types was provided.

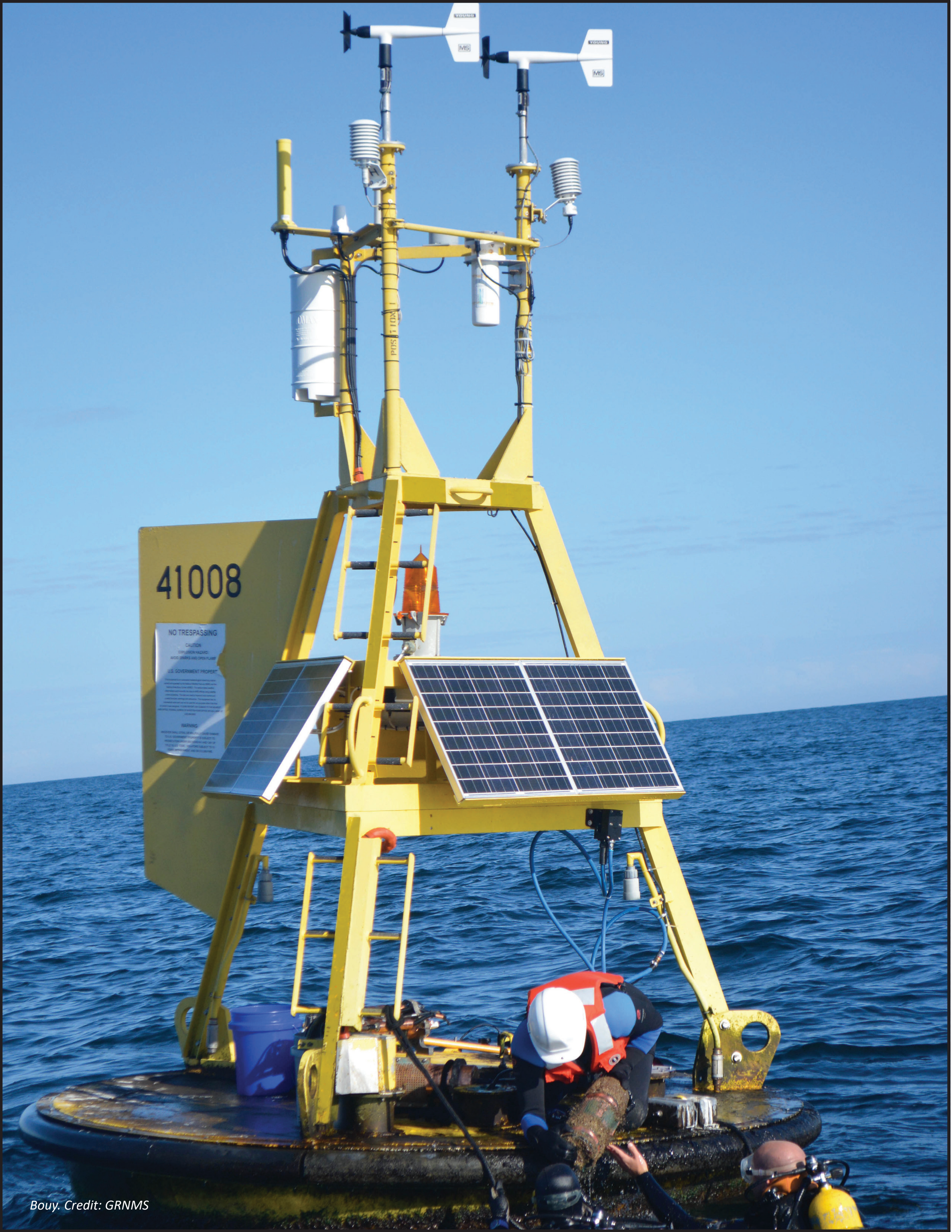
Archival summaries of overflights at GRNMS are available as far back as 1983 although metadata and collection specifications are not always available. This earlier era of overflights also recorded a limited variety of observed vessel activities. In data from 1983 to 2002, 87% of boats were classified as undertaking some type of fishing (26% trolling, 31% anchored and therefore likely bottom fishing, and 30% unspecified). Another 11% were described as in-transit. Small percentages were seen scuba diving or conducting research. These earlier overflights were much more frequent, with 41 in 1983 alone, and an average of 39 in each year from 1998 to 2002. This time period also had a much greater emphasis on weekends (70% of all surveys). The number of boats seen per survey ranged from 1.2 (1983) to 8.9 (2001) although these values do not account for day of the week, have large seasonal biases in effort, and don't include time of day.

Georgia Department of Natural Resources patrolboat. Credit: GADNR

Counting Boats from Boats and Airplanes

A small but important subset of these historical surveys occurred during fishing tournaments. The record number of boats observed fishing at GRNMS on a single survey was an incredible 150 from an overflight on June 23, 2001 during the Golden Isles Kingfish Classic tournament. The data from fishing tournaments are addressed in greater detail in section 5.0 Conclusions.

Neither of these types of observations take place very frequently, especially in recent years, and the types of data available from them are limited to counts of boats and irregular notes on boat type or activity. Additional limitations of this dataset include low encounter rates with boats, weekday bias, good weather bias, and possible behavior bias of boaters since the Coast Guard cutters are unmistakable. These constraints in understanding visitation do not however, diminish the importance of the U.S. Coast Guards periodic appearance at the sanctuary and their role in law enforcement.



Bouy. Credit: GRNMS

5.0 CONCLUSIONS

Despite the clear need, there has not been a quantitative assessment of visitation to Gray's Reef since its designation as a National Marine Sanctuary in 1981. With this report we sought to expand the understanding of visitation by evaluating three new approaches for counting visitors and summarizing some of the existing sources of visitor data. Analysis of recent records (< 5 years) from the 5 datasets examined here enabled us to characterize the general patterns of visitation at GRNMS in several ways.

Who is visiting the sanctuary? Nearly all visitors (~90%) arrive in small recreational fishing boats around 26 feet (8 m) in length with center console/outboard engine design. These craft are ideal for accessing offshore waters. There are on average 3 to 3.5 persons per boat. This occupancy is not surprising given the size and type of boats used. Center console fishing boats can comfortably accommodate 2-4 anglers with their fishing gear, beverages, coolers, and other equipment on a typical day-trip offshore. A small percentage of boats observed in the sanctuary were yachts, sailboats, or sportfishers that appear to have been merely passing through.

What are visitors doing at the sanctuary? Based on non-tournament days we estimate that ~60% are bottom fishing, ~25% are trolling, and the remainder are passing through. Obviously, tournaments for particular species such as king mackerel will affect this ratio on those days. We can also report that visitors are largely compliant with sanctuary regulations. Only two boats were engaged in suspicious looking activities in the Research Area based on satellite data, and only one has been cited with a fisheries violation in the six years of GA DNR patrols available for this report. One additional violation occurred at GRNMS on March 1, 2020 in which a red snapper was taken out of season although comprehensive data for 2020 were not available for analysis here. There are no doubt, other forms of visitation not captured in the data used here such as charter fishing trips and scuba diving, however, their lack of appearance in data used here suggests that such events are rare.

When are visitors using the sanctuary? We can address this in three different time frames; seasonal, day of the week, and time of the day. Warmer months including June through September comprise the core of visitation, but it is clear that boats can be found in any season of the year provided that weather conditions are suitable. Saturday is the most common day of the week for visitors, followed by Sunday and Friday. The early days of the week, Monday-Wednesday, are least likely to see visitors (4 to 9 times fewer than Saturdays). Visitation can take place at any time of the day but is most common from 9 am to 1 pm (~90% of visitors).

5.1 STRENGTHS AND LIMITATIONS OF THE DATASETS

From these analyses we are also able to provide a general description of the strengths and limitations of each technique or dataset for assessing visitor use (Table 5.1). We include the types of variables that each dataset can provide about boats (e.g., basic count, type, and size) and anglers (e.g., count per boat, specific activities such as bottom fishing or trolling). We also include information on sources of bias (e.g., weather, angler behavior, and spatial scope) and temporal aspects of each dataset (e.g., frequency of collection, time of day, season, and longevity of the dataset). Last, we provide recommendations for improvement of each dataset to enhance information on visitor use at Gray's Reef.

All of the techniques included here are capable of counting recreational boats. Each of them may also determine boat types in at least some situations. The buoy camera and satellite images do not always have the needed resolution to conclusively determine boat type, whereas the GA DNR and GRNMS R/V observations as well as the USCG Air Auxiliary overflights could all determine boat types if that were part of the observation protocol. Acoustics can only infer boat type based on engine noise. Boat length can be measured from satellite data provided that imagery is sufficiently resolved. All other data types can at least classify boats into size categories (i.e., Class 1, 16 to <26 feet) provided that staff are trained and datasheets call for this information. It may be

Conclusions

Table 5.1. Strengths and limitations of each monitoring technique.

	Buoy Camera	WorldView Satellites	SoundTrap	Georgia DNR Patrols	Gray's Reef NMS R/Vs	USCG Air Auxiliary
Boat Count	Yes	Yes	Yes	Yes	Yes	Yes
Boat Type	Yes, if close enough	Yes, if resolution is adequate	Possible, but not analyzed	Possible, but not recorded	Yes	Possible, but not recorded
Boat Length	Possible, if calibrated	Yes	No	Possible, but not recorded	Yes, within classes	Yes, within classes
Angler Activities	No	Inferred by wake pattern	Inferred by sound pattern	Yes	Yes	Yes
Passenger Count	Yes, if close enough	No	No	Yes	Yes, if close enough	No
Angler Behavior Bias	Unlikely	No	No	Yes	Yes	Unlikely
Species Targeted	No	Yes, by inference	No	Yes	Yes, by inference	No
Weather Bias	Low	Yes, due to clouds only	Low	Yes, only during good conditions	Yes, only during good conditions	Yes, only during good conditions
Spatial Scope	Vicinity of data buoy	Entire sanctuary	Vicinity of soundtrap	Vicinity of operations	Vicinity of operations	Entire sanctuary
Research Area Compliance	No	Yes	Yes	Yes	Yes	Yes
Acquisition Interval	Every 2 hours during daylight	Once every 4-5 days	Continuous	~1 per month	A few times per month	A few times per year
Acquisition Time of Day	Every 2 hours during daylight	Average is 2 pm (+/- ~3 hours)	Continuous	Mostly between 9 am and 2 pm	11:30 am and 1:30 pm or as practical	Average is 12:30 pm (+/- ~3 hours)

possible to get size class information from the buoy camera in the future provided that calibration images such as photographs of boats of known size at known distances from the buoy can be created. Acoustics can only generally infer boat size based on engine noise.

Information on number of passengers can be recorded most accurately by GA DNR, because they actually board each fishing boat. The buoy camera and GRNMS R/V staff can also count passengers provided that boats are within reasonable proximity. Satellites and overflights generally lack the viewing angle to see under boat canopies as well as the resolution needed to count passengers. No information on passenger numbers can be inferred from acoustics.

Another key aspect of angler activity to understand is the types of fishing taking place and the fish species they are targeting. The GA DNR likely provides the best information on these topics because they conduct a visual inspection of the catch, examine any fishing gear onboard, and discuss fishing directly with the passengers of each boat. Satellite data, GRNMS R/V observations, and to some degree the overflights can often infer what fishing techniques are being used and therefore what they are targeting. Anglers often target bottomfish such as black sea bass, grouper, or snapper by drifting over ledges or trying to maintain position over favorable bottom types. This behavior can be detected as repeated maneuvering sounds in acoustic data. Anglers target pelagic fishes such as king mackerel by trolling which produces cavitation bubbles and distinctive wake characteristics viewable even from satellite imagery.

Some techniques are more likely to induce behavior bias by anglers. Both the GA DNR and GRNMS R/V are clearly marked and likely induce anglers to be on their best behavior. Anglers are likely unaware of the buoy camera and USCG Air Auxiliary overflights, and satellites and acoustic recorders are least likely to induce any bias in angler behavior.

Another source of bias is weather conditions. On-water activities by GA DNR and R/V *Sam Gray* are only likely to take place during good, or at least safe, boating conditions. Atmospheric conditions can limit the utility of overflights (sea fog and safe flying conditions) and satellite data (clouds). For example, in the satellite data acquired here, 14 out of 40 images had >80% cloud cover making them unusable to assess visitation. The buoy camera and SoundTrap systems are least impacted by the weather, transmitting images and recording sounds even during the passage of hurricanes. However, they too experience reduced range and effectiveness by factors such as wave and rain noise in the case of acoustics, or rain, sun glint, and fog in the case of buoy camera images.

The spatial scope of the satellite data encompasses the entire sanctuary and can be accurately overlaid on boundaries to determine compliance with the Research Area. Boat based observations are limited to a few kilometers around the boats, and depending on their position can also be used to evaluate compliance. It is more challenging to establish position of boats from overflights, and the buoy camera and SoundTrap can only be used to assess the area for a few hundred meters around those instruments

Acquisition interval and timing are other aspects of evaluating the capability of each dataset to quantify visitation. SoundTrap acoustic recorders provide the most comprehensive understanding of temporal aspects of visitation through continuous monitoring of sounds in the sanctuary. The buoy camera is next with images every two hours, every day, regardless of weather, until the camera batteries expire. The frequency of the other data types drops off rapidly with satellites providing images every 4-5 days, GA DNR patrols and GRNMS R/V observations being conducted on average only a few times per month, and USCG Auxiliary overflights taking place only a few times each year. Most activities (except the SoundTrap and buoy camera) have monitoring effort focused in the middle of the day (~10 am to 2 pm) during peak visitation hours.

5.2 RECOMMENDATIONS FOR IMPROVED MONITORING

Having considered the types of information that each dataset can provide, we offer recommendations for improving the quality of the information available to assess visitation at Gray's Reef. Some of the buoy camera's limitations should be addressed with the installation of the next generation camera scheduled for 2020. This system will include a higher resolution camera and utilize solar panels to recharge the power supply extending the operational deployment from six months to well over one year. In addition, the sampling and telemetry frequency will double, images will be collected every 10 minutes and transmitted once per hour. Accurate compass readings would be beneficial. Calibrating the images using targets of known length and distance from the cameras would be another important improvement in using that technology understanding visitation.

The satellite images and overflights are also capable of efficiently addressing another important question for sanctuary and natural resource managers. How much time do anglers spend at Gray's Reef versus other offshore fishing sites that harbor similar species? When possible, both of these methods should broaden the area surveyed to include artificial reefs and hardbottom areas throughout the offshore areas of Georgia (Figure 1.1). It is also especially useful for overflights to monitor multiple offshore destinations during tournaments. These flights provide excellent training opportunities for volunteer pilots and can be scheduled in advance.

SoundTrap recorders are the only technology capable of providing 24/7 (hours per day/days per week) monitoring. Additional acoustic recorders within the sanctuary and elsewhere would broaden the scope of visitor information. Calibration of sound signatures from various boat engine sizes, types, and behaviors as well as the influence of distance, background noise, and water column properties will all enhance the ability to glean information on visitors from boat noise. Furthermore, the tuning of the automated detector to perform optimally will allow for larger datasets to be processed with increased efficiency.

For on-water observations by GRNMS, it is recommended that the datasheet and protocol be further simplified to streamline data acquisition. This will promote standardization among observers and completion of datasheets. This dataset is one of the few that is focused on weekdays and importantly, can be conducted during the course of other operations already underway at Gray's Reef. Gradually building sample size will provide a valuable addition to understanding long-term patterns of visitation.

Patrols by GA DNR provide not only a valuable enforcement presence but also the most accurate measures of anglers per boat, species targeted, and fishing techniques. Increasing the frequency of patrols to previous levels (e.g., 3/month versus the 1/month occurring in recent years) would be very beneficial for understanding current patterns of visitation. Enforcement agencies can optimize the efficiency of their patrols by scheduling based on the time-standardized encounter rates from multiple sources shown here including month, day of the week, and time of the day. Allocating more effort to the peak times and proportionally less in the off peak times would be effective at increasing encounter rates while still ensuring that anglers can't anticipate law enforcement activity.

Use of multiple, independent methods for counting visitors is advisable when data are available, especially when no single method provides all of the unbiased information needed (Fraidenburg and Bargmann 1982, McCluskey and Lewison 2008). This is definitely the case for visitor use information at GRNMS.

For future visitation monitoring, an effective combination of data can include: 1) the buoy camera and SoundTrap systems which provide data all day, every day, and are relatively unaffected by weather, but limited in spatial scope, 2) satellite and Coast Guard Auxiliary overflights which best document spatial aspects of usage not only within the sanctuary, but also relative to fishing sites elsewhere offshore from Georgia, 3) GA DNR enforcement patrols which provide needed information on regulatory compliance, species targeted, and anglers per boat, and is focused primarily on weekends, and 4) GRNMS R/V observations which fill in the weekday scarcity in on-water observations and can be done opportunistically as part of other research activities.

5.3 A BRIEF HISTORICAL PERSPECTIVE

Records greater than 5 years old were used sparingly in this report in order to focus on present-day patterns of visitor use. Not only do older records lack rigorous metadata, but it is suspected that older data do not reflect current visitation due to several factors such as changes in the regulations at the sanctuary and the ongoing increases in availability of fishing opportunities at nearby artificial reefs. Indeed, the earlier anecdotal estimate of 10 – 20 boats visiting the sanctuary on weekends (NOAA 1980) is not borne out in the more recent data analyzed here which suggests lower visitation rates in the present era.

Despite its limitations, archival data do provide an especially important perspective on changes in visitation during fishing tournaments. Although descriptions of the methods, timing, and duration of surveys are lacking, it is clear that visitation at GRNMS during such events could be much higher than anything observed in the more recent data. Boat counts from 12 tournament days between 1992 and 2004 were available in sanctuary records (Table 5.2). These tournaments were all focused on king mackerel. An average of 53 boats (+/- 11.5 SEM) were observed on tournament days and two counts included over 100 boats with most being clustered in the vicinity of the data buoy and the nearby hardbottom. For comparison, in 2019 a total of just 12 boats were observed from the buoy camera and 23 were heard at the 2 SoundTrap sites over all 7 tournament days (Table 5.2). All tournament days in 2019 had good weather as observed in the buoy camera, so that is not suspected to be a cause of the reduced counts. Although the buoy camera, satellite, and acoustic detections all have temporal or spatial limitations for comprehensively counting anglers, these observations represent a dramatic drop off in the visitation rates that were documented 15-20 years ago during tournaments.

Table 5.2. Boat counts at GRNMS during tournaments chronologically from 1992 to 2004 and then 2019. Aerial overflights were primarily conducted by the US Coast Guard Auxiliary. On-water counts were conducted by GRNMS staff. Buoy camera images and boat sounds were analyzed as part of this study.

Date	Tournament Name	Boats	Observation type
23 May 1992	Sapelo Open Kingfish Tourn.	43	Overflight
10 Jul 1992	Golden Isles Kingfish Classic	47	Overflight
28 May 1994	Sapelo Open Kingfish Tourn.	23	Overflight
11 Jun 1994	Two-Way Sportfishing Club Kingfish Tourn.	37	Overflight
9 Jul 1994	Golden Isles Kingfish Classic	20	Overflight
23 Jun 2001	Golden Isles Kingfish Classic	150	Overflight
22 Aug 2003	Golden Isles Kingfish Classic	53	On-Water
23 Aug 2003	Golden Isles Kingfish Classic	103	On-Water
29 May 2004	Sapelo Open Kingfish Tourn.	30	On-Water
10 Jul 2004	Boaters World Tourn. of Champions	49	On-Water
12 Jul 2004	Bell South Greater Jacksonville Kingfish Tourn.	7	On-Water
23 Jul 2004	Bell South Greater Jacksonville Kingfish Tourn.	79	On-Water
14 Jun 2019	Two-Way Sportfishing Club Kingfish Tourn.	0	Buoy Camera
14 Jun 2019	Two-Way Sportfishing Club Kingfish Tourn.	1	SoundTrap
15 Jun 2019	Two-Way Sportfishing Club Kingfish Tourn.	1	Buoy Camera
15 Jun 2019	Two-Way Sportfishing Club Kingfish Tourn.	1-5	SoundTrap
15 Jun 2019	Two-Way Sportfishing Club Kingfish Tourn.	5	Satellite
12 Jul 2019	Sapelo Open Kingfish Tourn.	2	Buoy Camera
12 Jul 2019	Sapelo Open Kingfish Tourn.	2-3	SoundTrap
13 Jul 2019	Sapelo Open Kingfish Tourn.	2	Buoy Camera
13 Jul 2019	Sapelo Open Kingfish Tourn.	3-8	SoundTrap
15 Aug 2019	Golden Isles King Mac Attack	0	Buoy Camera
15 Aug 2019	Golden Isles King Mac Attack	0	SoundTrap
16 Aug 2019	Golden Isles King Mac Attack	2	Buoy Camera
16 Aug 2019	Golden Isles King Mac Attack	5	SoundTrap
17 Aug 2019	Golden Isles King Mac Attack	0	Buoy Camera
17 Aug 2019	Golden Isles King Mac Attack	1	SoundTrap

Also useful from the archival data and on-water boat counts by sanctuary staff during tournaments is the observation that there were 3.38 (+/- 0.07 SEM) persons per boat based on n = 182 boats in 2004. This is comparable to the three different estimates of boat occupancy from the more recent sources compiled here (2.9 people on-board based on the buoy camera, 3.0 observed from R/V *Sam Gray*, and 3.7 counted by GA DNR).

Overflight photo. Credit: U.S. Coast Guard Air Auxiliary Savannah.

Overflight photo. Credit: U.S. Coast Guard Air Auxiliary Savannah.

6.0 NEXT STEPS

The ultimate goal for compiling these boat observation data is to create a predictive model of daily visitation. An appropriate statistical framework such as generalized linear modeling will be used to evaluate the relationship between the number of boats present at the sanctuary and a suite of predictor variables including environmental factors such as measured and forecasted wind speed and wave height, as well as temporal variables such as day of the week, holidays, and fishing tournaments. The model will be used to predict visitation at the sanctuary throughout the year, based on weather and temporal variables. We will also run scenarios with and without each of these boat count methods to determine how predictions change depending on which input variables are used. This can help sanctuary staff and others determine which boat count methods to promote in the future.

Many sites in the National Marine Sanctuary system lack robust assessments of visitor use. This has led to a conceptualized National Marine Sanctuary Visitor Counting Process (NMS-COUNT) through which resource managers can obtain reliable data, methodologies, and predictions on visitation (Burns et al. 2020). The data summarized here were identified and compiled in consultation with the original providers as well as staff from the GRNMS Advisory Council, Science Advisory Group, Law Enforcement Working Group, and sanctuary management. This compilation of data, and ultimately the predictive model, will advance the NMS- COUNT conceptual process and future visitation studies at Gray's Reef and other locations.

References

Barros, C., B. Moya-Gómez, and J.C. García-Palomares. 2019. Identifying Temporal Patterns of Visitors to National Parks through Geotagged Photographs. Sustainability. 11(24)6983. https://doi.org/10.3390/su11246983

Bauer, L. J., M.S. Kendall, and C.J. Jeffrey. 2008. Incidence of marine debris and its relationships with benthic features in Gray's Reef National Marine Sanctuary, Southeast USA. Mar Poll Bull. 56(3):402-13. DOI: 10.1016/j.marpolbul.2007.11.001

Bauer, L.J., M.S. Kendall, and G. McFall. 2010. Assessment and monitoring of marine debris in Gray's Reef National Marine Sanctuary. Prepared by National Centers for Coastal Ocean Science (NCCOS) Biogeography Branch and Gray's Reef National Marine Sanctuary (GRNMS). Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 113. 40 pp.

Bird, C., B. Hooker, G. Moretti, L. Nojek, and D. Wusinich. 2001. An analysis of recreational fishers' activities and attitudes at Gray's Reef National Marine Sanctuary. Master's Thesis. Duke University, Nicholas School of the Environment, Durham NC, USA. 36 pp.

Burns, R.C., G.A. Ross, M.E. Allen, D. Schwarzmann, and J.C. Moreira. 2020. Conceptualizing the National marine sanctuary visitor counting process for marine protected areas, Journal of Ecotourism, DOI: 10.1080/14724049.2020.1746794

Department of Commerce. 2006. Gray's Reef National Marine Sanctuary Regulations. 15 CFR Part 922. Federal Register 71(197):60055-60064.

Department of Commerce. 2010. Gray's Reef National Marine Sanctuary Regulations. 15 CFR Part 922. Federal Register 75(33):7361-7367.

Department of Commerce. 2011. Gray's Reef National Marine Sanctuary Regulations. 15 CFR Part 922. Federal Register 76(240):77670.

Department of Commerce. 2014. Gray's Reef National Marine Sanctuary Regulations. 15 CFR Part 922. Federal Register 79(138):41879-41881.

Ehler, R., and V.R. Leeworthy. 2002. A Socioeconomic Overview of Georgia's Marine Related Industries and Activities. NOAA NOS ONMS. Silver Spring, MD. 33 pp.

Ehler, R. 2008. Socioeconomic Assessment of Georgia Offshore Spearfishing. NOAA NOS ONMS. Silver Spring, MD. 4 pp.

Ehler, R. 2009. Economic analysis of recreational fishing in the proposed Gray's Reef National Marine Sanctuary Research Area. NOAA NOS ONMS. Silver Spring, MD. 10 pp.

Flynn, D.J.H., T.P. Lynch, N.S. Barrett, L.S.C. Wong, C. Devine, and D. Hughes. 2018. Gigapixel big data movies provide cost-effective seascape scale direct measurements of open-access coastal human use such as recreational fisheries. Ecology and Evolution. 8:9372-9383. DOI: 10.1002/ece3.4301

Fraidenburg, M.F., and G.G. Bargmann. 1982. Estimating boat-based fishing effort in a marine recreational fishery. North American Journal of Fisheries Management 4:351-358.

Hartill, B.W., G.W. Payne, N. Rush, and R. Bian. 2016. Bridging the temporal gap: continuous and cost-effective monitoring of dynamic recreational fisheries by web cameras and creel surveys. Fisheries Research. 183:488-497. http://dx.doi.org/10.1016/j.fishres.2016.06.002

Keller, K., A.S. Steffe, M. Lowry, J.J. Murphy, and I.M. Suthers. 2016. Monitoring boat-based recreational fishing effort at a nearshore artificial reef with a shore-based camera. Fisheries Research. 181:84-92. http://dx.doi.org/10.1016/j.fishres.2016.03.025

Kendall, M.S., L.J. Bauer, and C.F.G. Jeffrey. 2008a. Influence of benthic features and fishing pressure on size and distribution of three exploited reef fishes from the Southeastern United States. Transactions of the American Fisheries Society. 137: 1134-1146.

Kendall, M.S., K.A. Eschelbach, G. McFall, J. Sullivan, and L.J. Bauer. 2008b. MPA design using sliding windows: Case study designating a research area. Ocean and Coastal Management. 51: 815–825.

References

Lancaster, D., P. Dearden, D.R. Haggarty, J.P. Volpe, and N.C. Ban. 2017. Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas. Aquatic Conservation: Marine and Freshwater Ecosystems. 27:804-813. DOI: 10.1002/aqc.2736

Loerzel, J., C.S. Fleming, and M. Gorstein. 2018. Ecosystem Services Valuation of the Central Georgia Coast, including Sapelo Island National Estuarine Research Reserve and Gray's Reef National Marine Sanctuary. NOAA Technical Memorandum NOS NCCOS 248. Silver Spring, MD. 85 pp. https://doi.org/10.25923/r522-xv78

McCluskey, S.M. and R.L. Lewison. 2008. Quantifying fishing effort: a synthesis of current methods and their applications. Fish and Fisheries. 9:188-200.

National Meteorological Library and Archive. 2010. Fact Sheet 6 – The Beaufort Scale. Met Office, Exeter, United Kingdom. 22 pp.

NOAA. 1980. Final Environmental Impact statement on the proposed Gray's Reef Marine Sanctuary. NOAA Office of Coastal Zone Management. Washington DC, USA. 286 pp.

NOAA. 2014a. Gray's Reef National Marine Sanctuary: Final Management Plan. July 2014. Savannah, GA, USA. 32 pp.

NOAA. 2014b. Gray's Reef National Marine Sanctuary Final Environmental Assessment for Implementation of the Sanctuary Management Plan and New Regulations. NOAA NOS ONMS, Savannah, GA.

NOAA Office of National Marine Sanctuaries and U.S. Navy. 2020. SanctSound Raw Passive Acoustic Data. NOAA National Centers for Environmental Information. https://doi.org/10.25921/saca-sp25

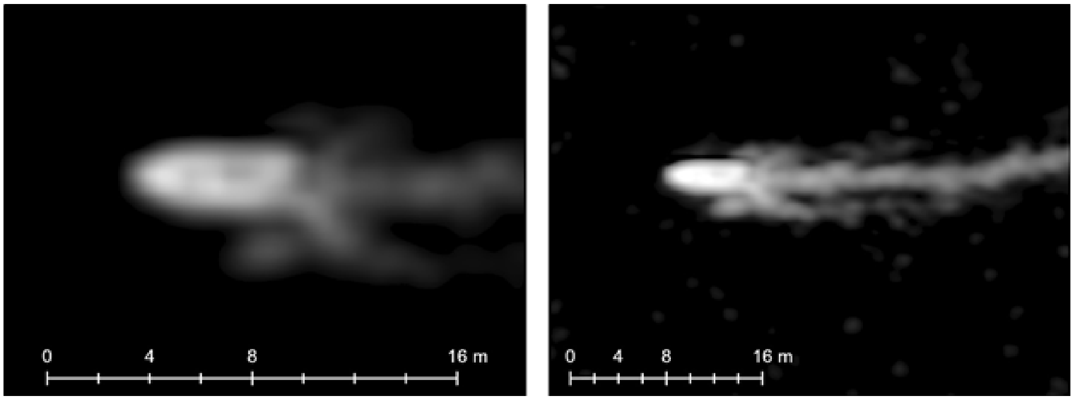
Parnell, P.E., P.K. Dayton, R.A. Fisher, C.C. Loarie, and R.D. Darrow. 2010. Spatial patterns of fishing effort off San Diego: implications for zonal management and ecosystem function. Ecological Applications. 20(8):2203-2222.

Shepperson, J.L., N.T. Hintzen, C.L. Szostek, E. Bell, L.G. Murray, and M.J. Kaiser. 2018. A comparison of VMS and AIS data: the effect of data coverage and vessel position recording frequency on estimates of fishing footprints. ICES Journal of Marine Science. 75(3): 988–998. https://doi.org/10.1093/icesjms/fsx230

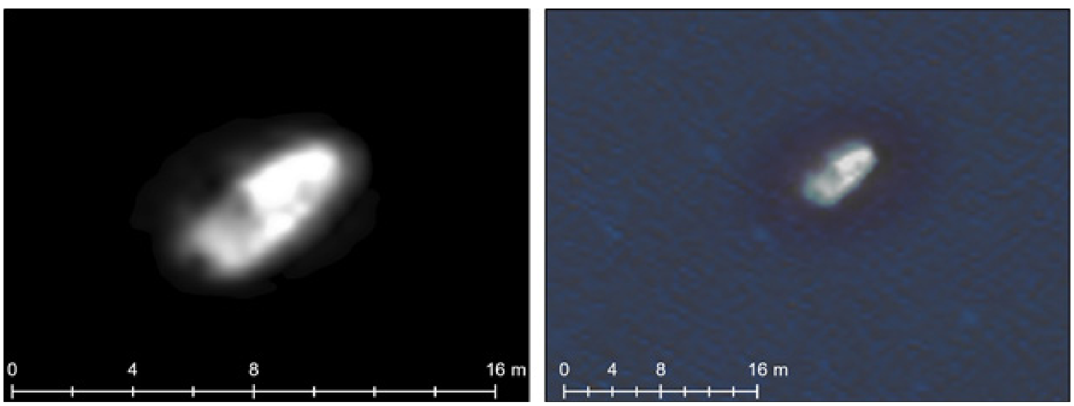
Simard, P., K.R. Wall, D.A. Mann, C.C. Wall, C.D. Stallings. 2016. Quantification of boat visitation rates at artificial and natural reefs in the eastern Gulf of Mexico using acoustic recorders. PLoS ONE 11(8):e0160695.

Appendix

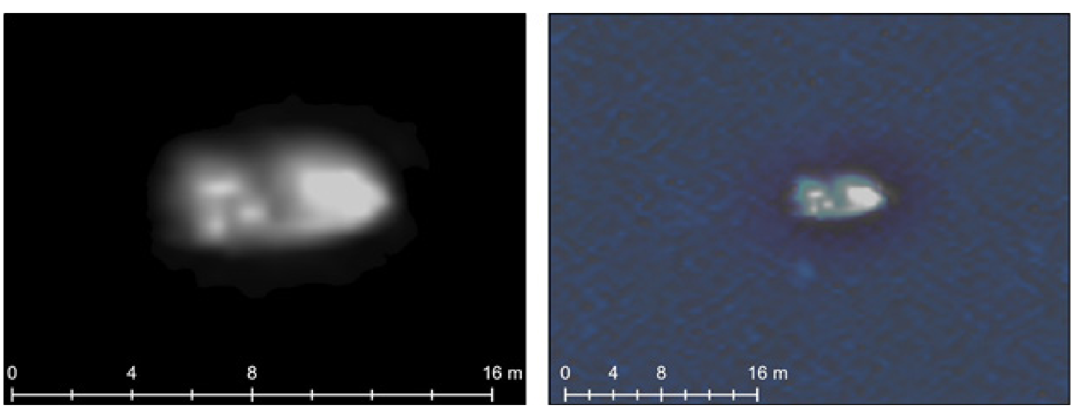
Appendix A. Satellite images of boats from Apr. 16 – Oct. 12, 2019. Scale bars are in meters.



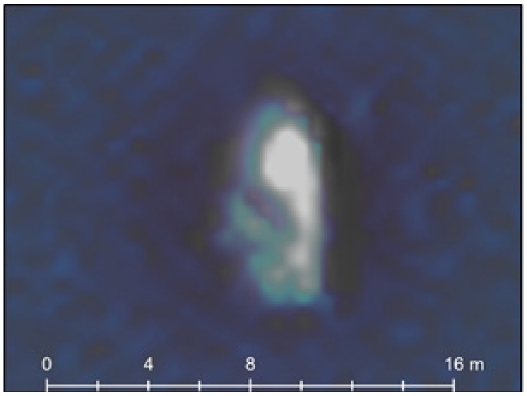
Date: 05/21/2019 at 03:17pm
Data Source: WV1 Panchromatic 52cm resolution
Location: -80.86700 W, 31.40012 N
Description: 6.4m length x 2.5m width, Class 1, slow speed

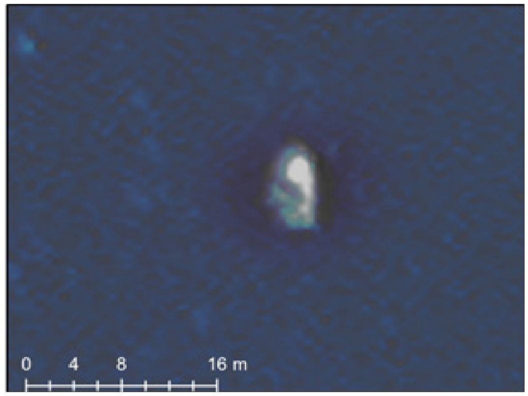


Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location: -80.86767 W, 31.40012 N
Description: 6.0m length x 2.3m width, Class 1, center console, adrift near the NDBC Buoy.

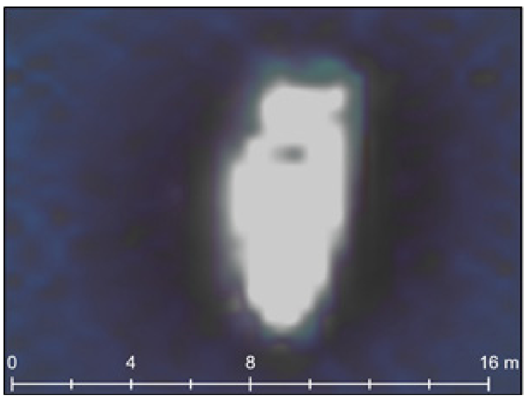


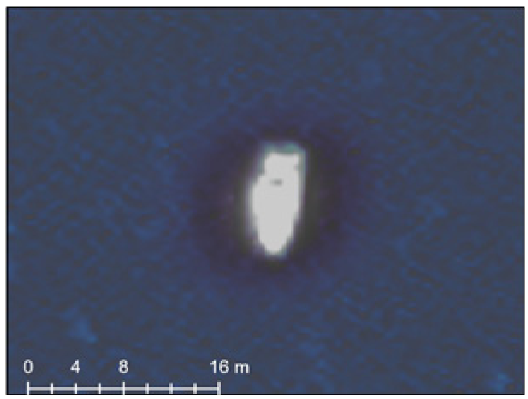
Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location: -80.86875 W, 31.39903 N
Description: 6.4m length x 2.5m width, Class 1, adrift



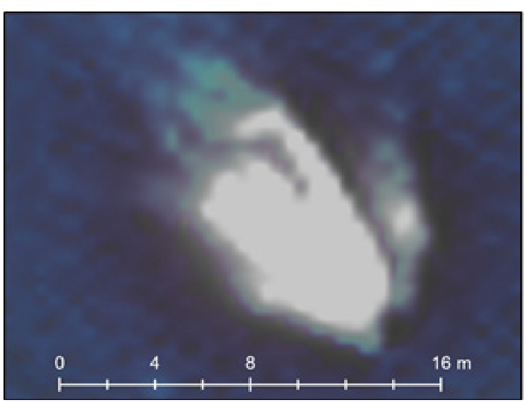


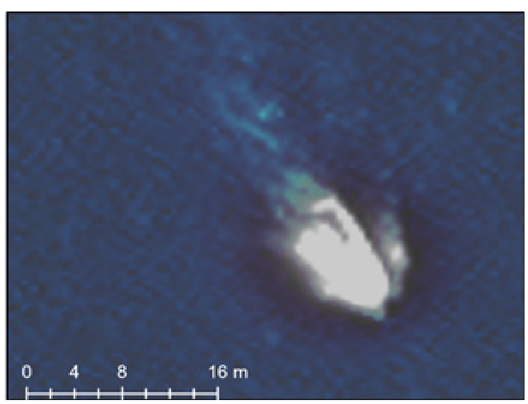
Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location:-80.86786 W, 31.40378 N
Description: 6.7m length x 2.0m width, Class 1, center console twin outboard, adrift





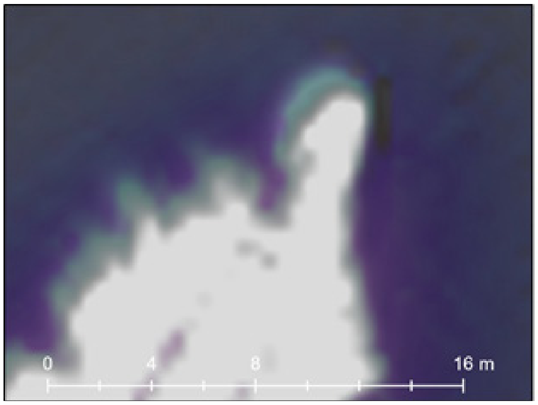
Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location: -80.86127 W, 31.40557 N
Description: 9.1m length x 3.8m width, Class 2, adrift

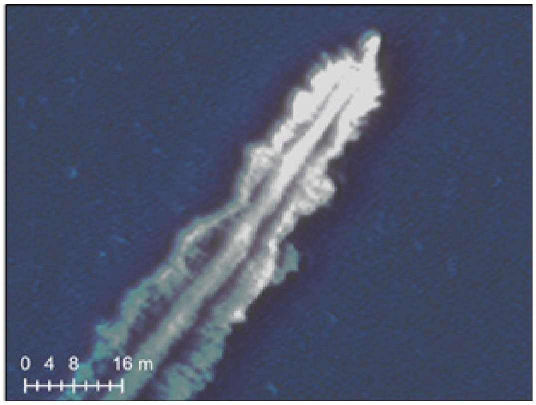




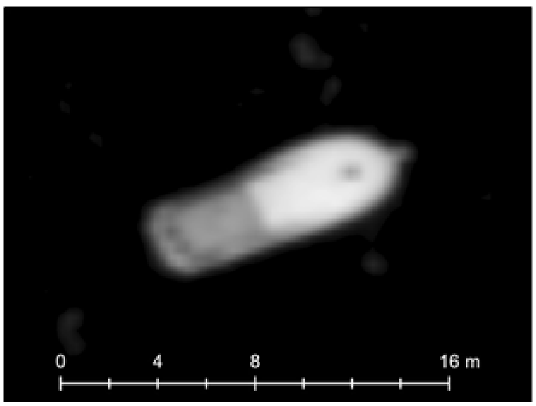
Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location: -80.91924 W, 31.39074 N
Description: 11.1m length x 5.1m width, Class 2, Sportfishing vessel, slow speed

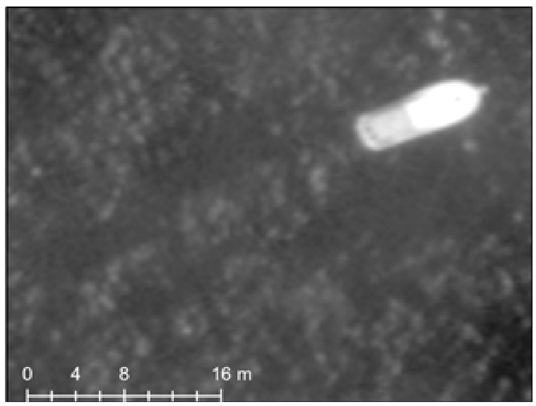
Appendix



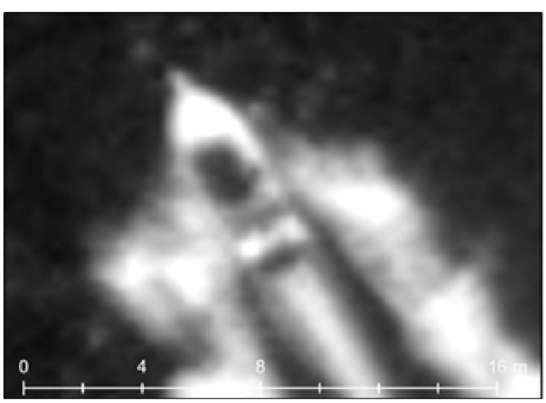


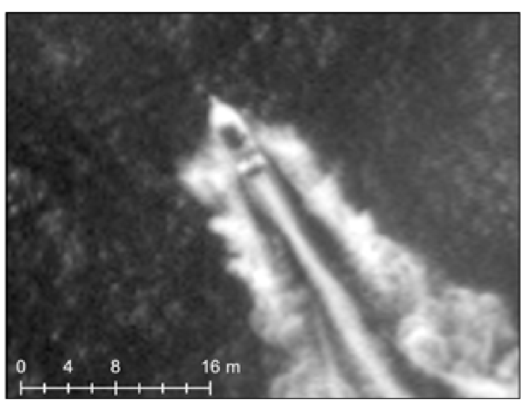
Date: 05/25/2019 at 12:00pm
Data Source: WV2 Multispectral Pan Sharpened 63cm resolution
Location: -80.90031 W, 31.37473 N
Description: 7.4m length x 1.8m width, Class 1, center console twin outboards, high speed in the Research Area.



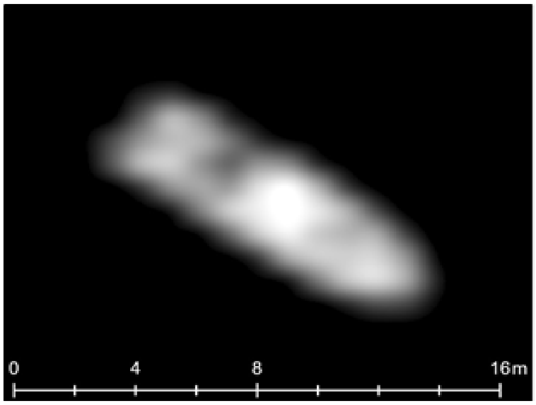


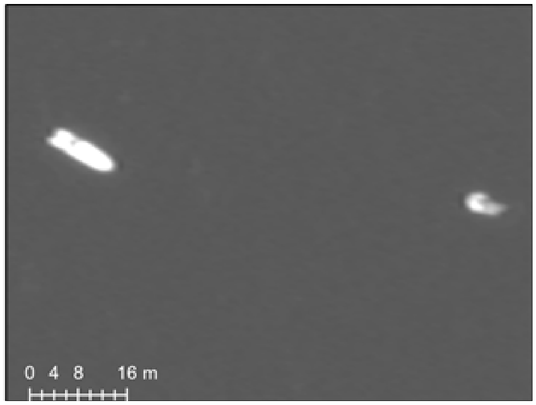
Date: 06/07/2019 at 12:25pm
Data Source: WV3 Panchromatic 32cm resolution
Location: -80.86929 W 31.39994 N
Description: 11.3m length x 3.5m width, Class 2, Sportfisher, adrift



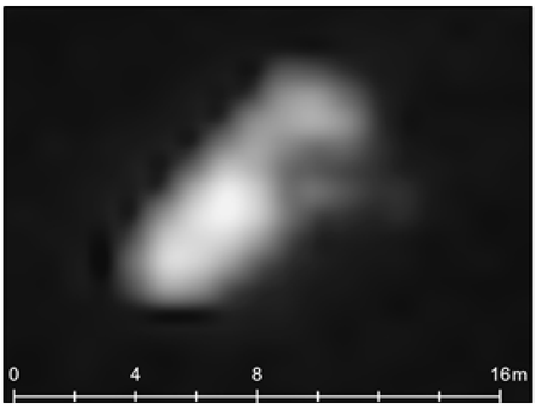


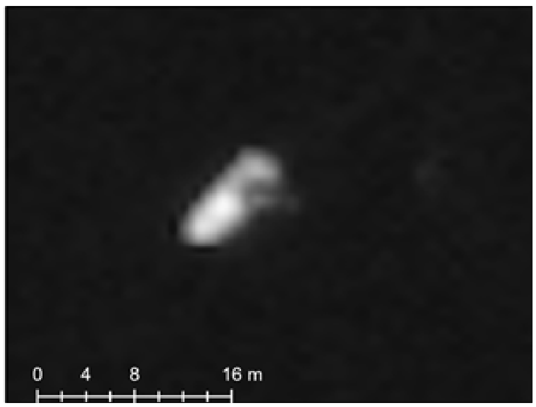
Date: 06/07/2019 at 12:25pm
Data Source: WV3 Panchromatic 32cm resolution
Location: -80.89448 W, 31.41629 N
Description: 8.5m length x 2.8m width, Class 1, center console twin outboard, high speed



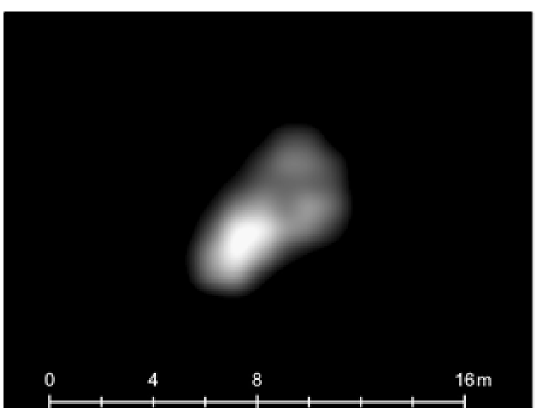


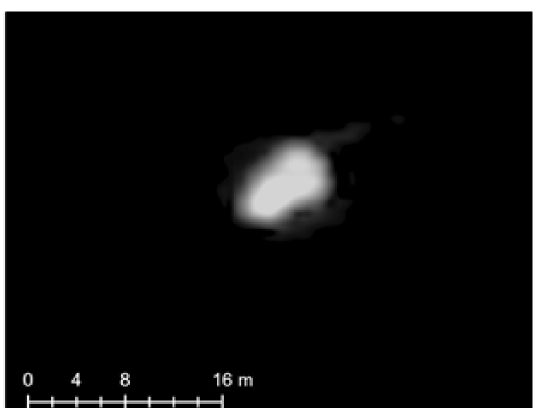
Date: 06/15/2019 at 3:31pm
Data Source: WV1 Panchromatic 83cm resolution
Location: -80.86879 W, 31.40003 N
Description: 10.0m length x 3.5m width, Class 2, center console, adrift near GR NOAA buoy





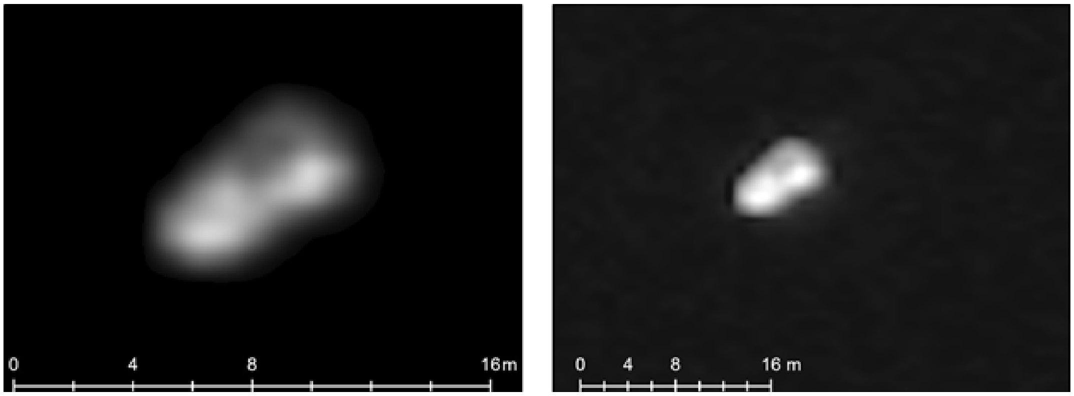
Date: 06/15/2019 at 3:31pm
Data Source: WV1 Panchromatic 83cm resolution
Location: -80.87200 W 31.40107 N
Description: 10.0m length x 3.0m width, Class 2, center console, adrift or slow speed



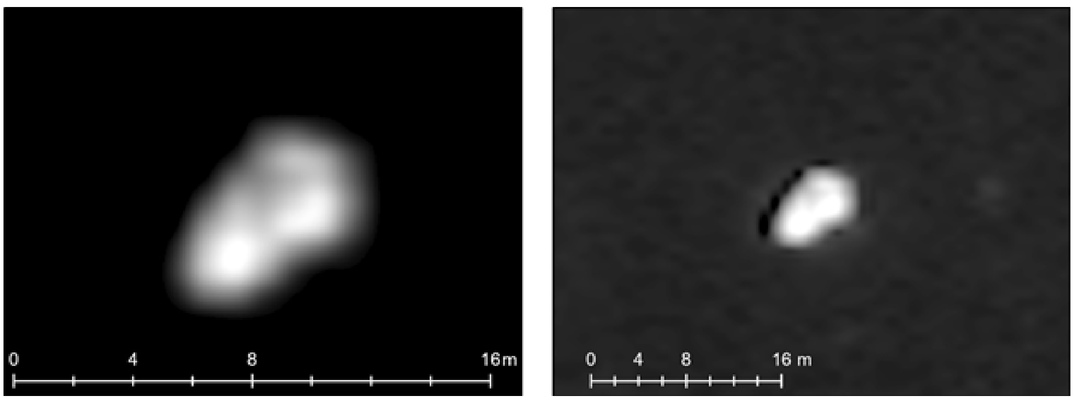


Date: 06/15/2019 at 3:31pm
Data Source: WV1 Panchromatic 83cm resolution
Location: -80.87700 W, 31.40110
Description: 7.0m length x 2.5m width, Class 1, adrift or slow speed

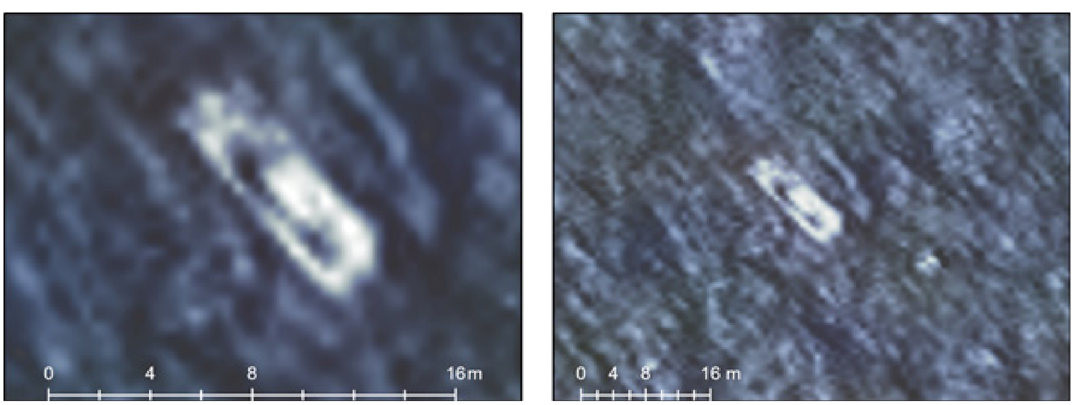
Appendix



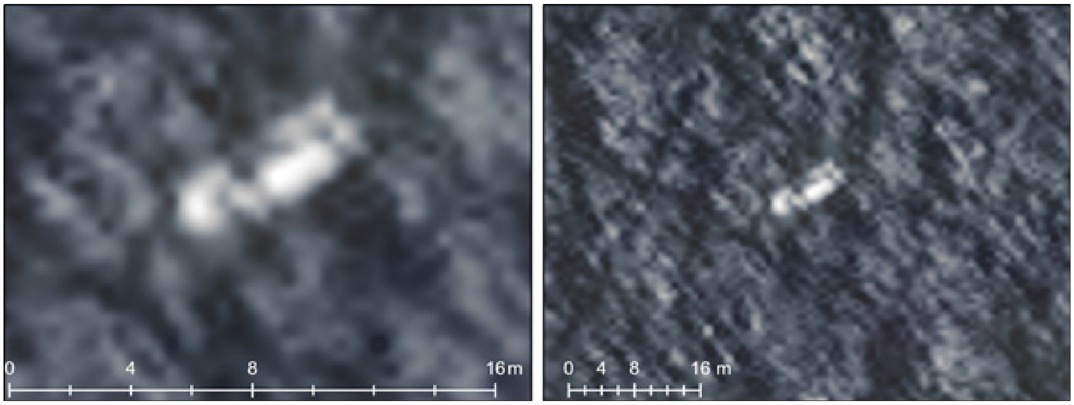
Date: 06/15/2019 at 3:31pm
Data Source: WV1 Panchromatic 83cm resolution
Location: -80.87900 W, 31.40229 N
Description: 7.0m length x 2.5m width, Class 1, adrift



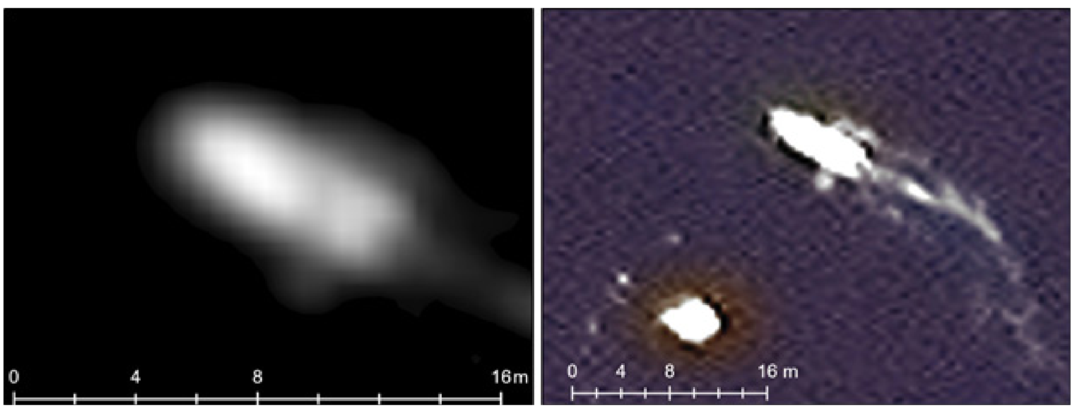
Date: 06/15/2019 at 3:31pm
Data Source: WV1 Panchromatic 83cm resolution
Location: -80.88800 W, 31.39180 N
Description: 7.0m length x 2.5m width, Class 1, adrift



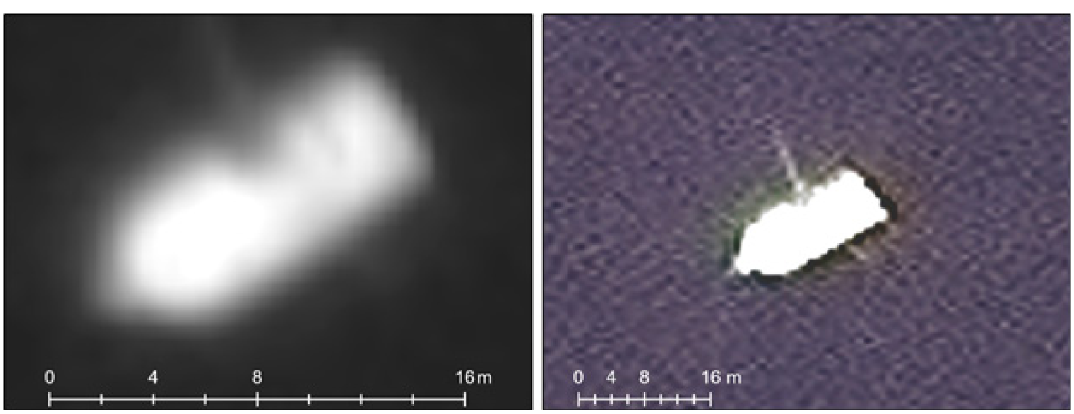
Date: 06/23/2019 at 12:32pm
Data Source: WV2 Multispectral Pan-sharpened 53cm resolution
Location: -80.86656 W, 31.40062 N
Description: 9.3m length x 2.8m width, Class 2, center console, adrift



Date: 06/23/2019 at 12:32pm
Data Source: WV2 Multispectral Pan-sharpened 53cm resolution
Location: -80.86790 W, 31.39945 N
Description: 7.0m length x 2.5m width, Class 1, center console, slow speed

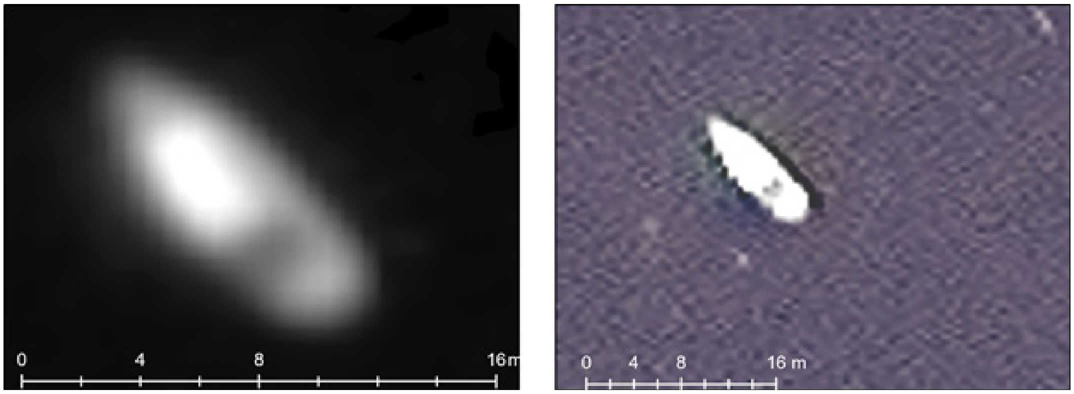


Date: 07/02/2019 at 12:01pm
Data Source: WV2 Panchromatic & Pan-sharpened 50cm resolution
Location: -80.86773 W, 31.40015 N
Description: 8.5m length x 3.2m width, Class 2, slow speed

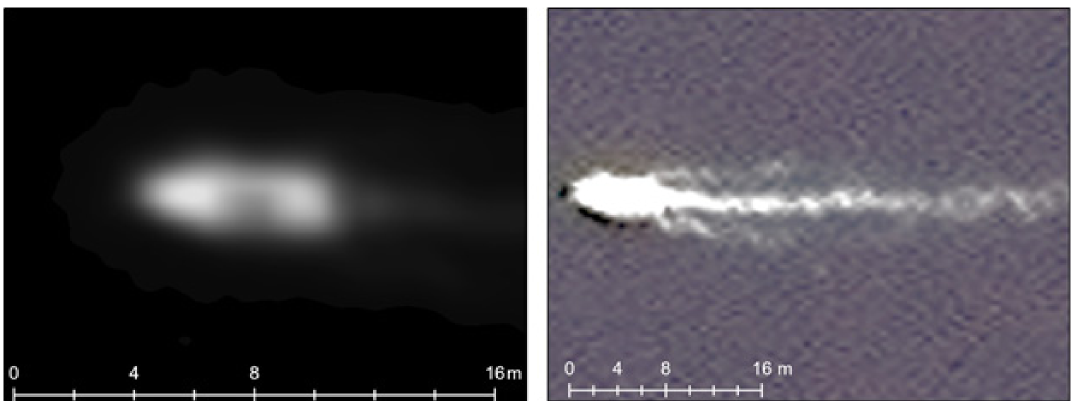


Date: 07/02/2019 at 12:01pm
Data Source: WV2 Panchromatic & Pan-sharpened 50cm resolution
Location: -80.87020 W, 31.40091 N
Description: 13.8m length x 5.5m width, Class 3, Sportfisher with outriggers, slow speed

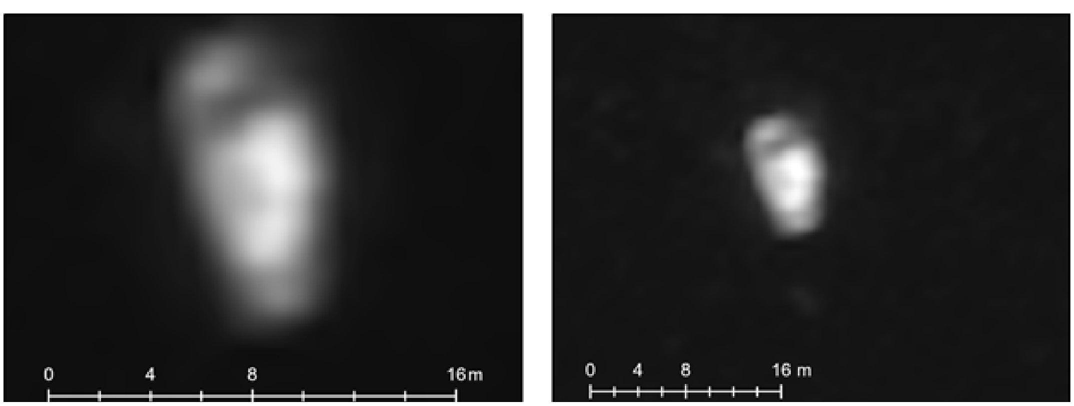
Appendix



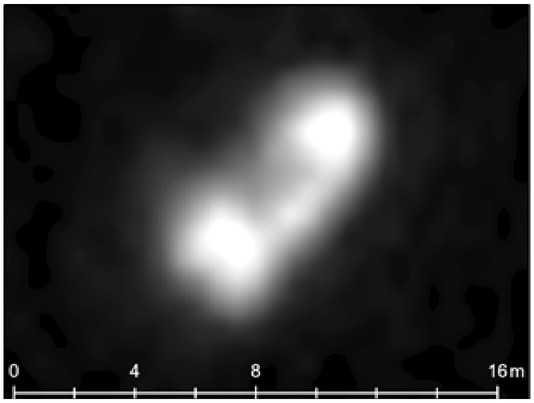
Date: 07/02/2019 at 12:01pm
Data Source: WV2 Panchromatic & Pan-sharpened 50cm resolution
Location: -80.87024 W, 31.40237 N
Description: 11.5m length x 3.5m width, Class 2, R/V *Sam Gray* on AIS, slow speed

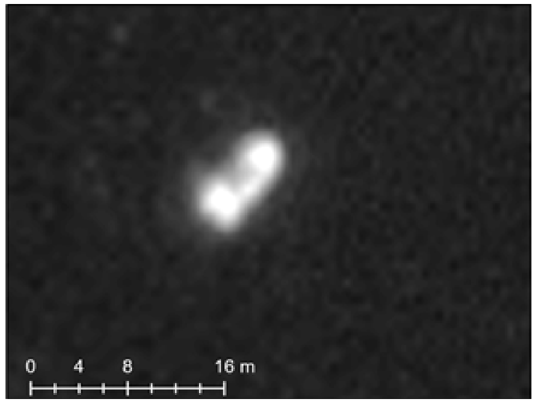


Date: 07/02/2019 at 12:01pm
Data Source: WV2 Panchromatic & Pan-sharpened 50cm resolution
Location: -80.85044 W, 31.38176 N
Description: 6.5m length x 2.5m width, Class 1, slow speed in Research Area

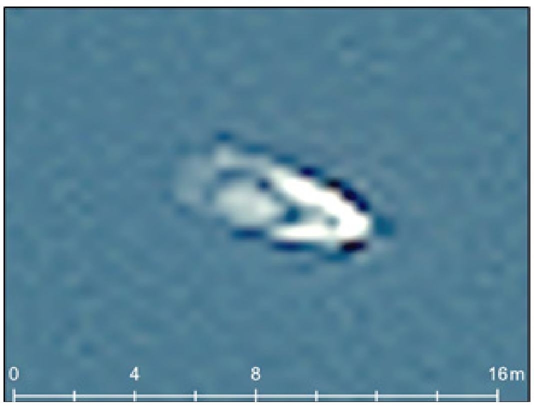


Date: 07/11/2019 at 3:23pm
Data Source: WV1 Panchromatic 74cm resolution
Location: -80.83976 W, 31.38526 N
Description: 11.5m length x 3.5m width, Class 2, R/V *Sam Gray* on AIS, adrift in Research Area

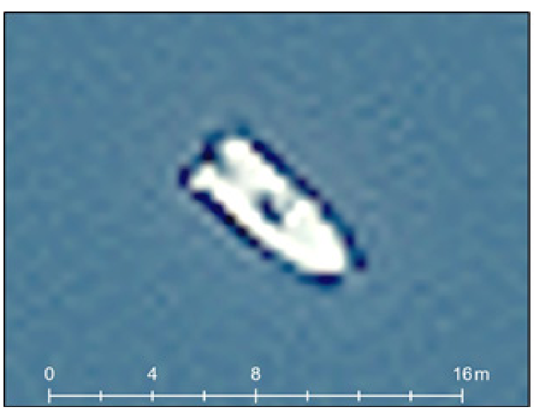


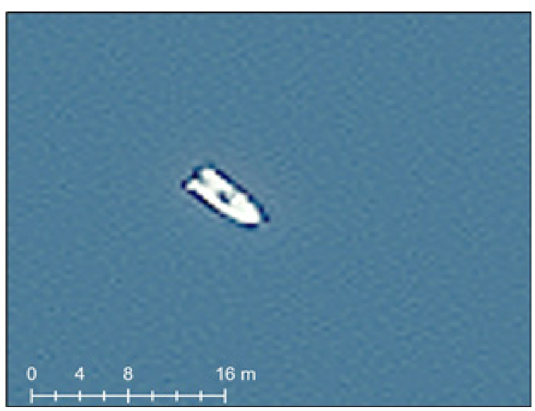


Date: 07/15/2019 at 12:23pm
Data Source: WV2 Panchromatic 62cm resolution
Location: -80.88690 W, 31.37775 N
Description: 9.4m length x 3.7m width, Class 2, adrift in GR Research Area



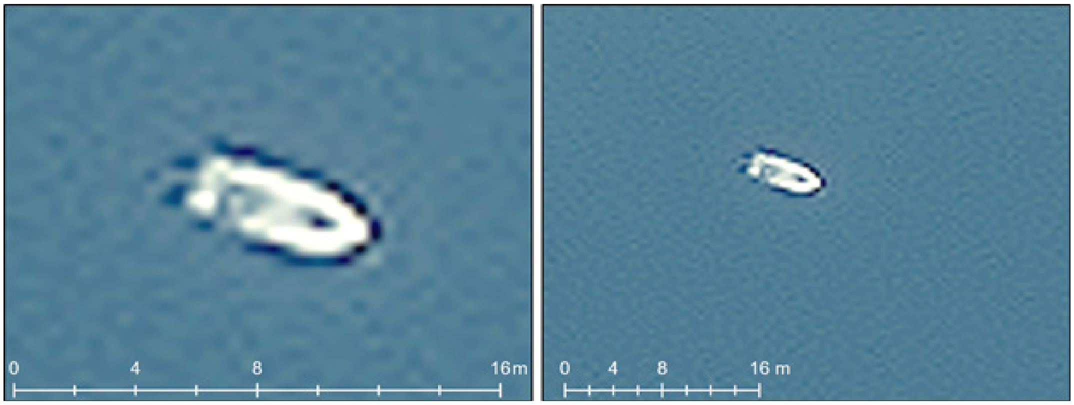
Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.87013 W, 31.39955 N
Description: 6.5m length x 2.6m width, Class 1, center console, adrift



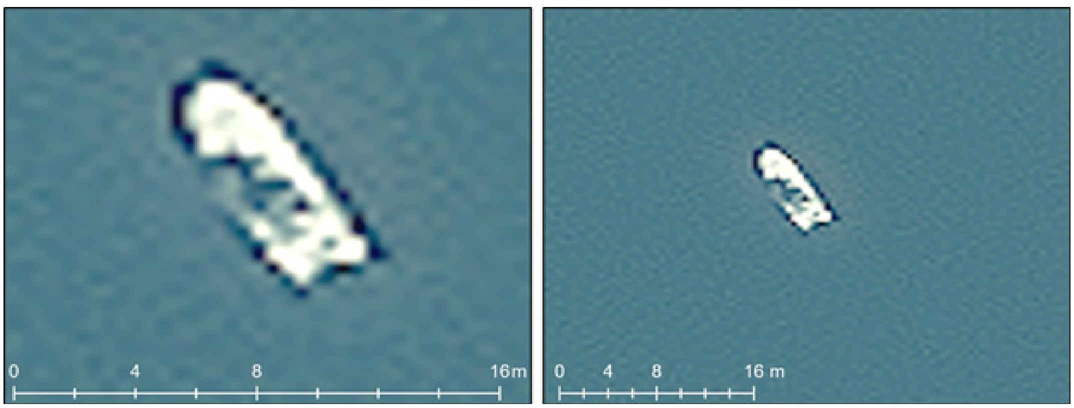


Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.86357 W, 31.40285 N
Description: 6.7m length x 2.6m width, Class 1, center console, adrift

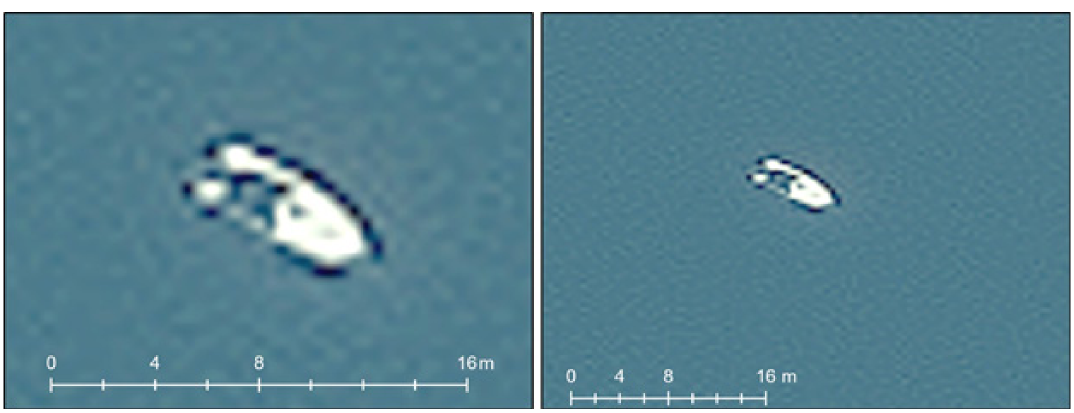
Appendix



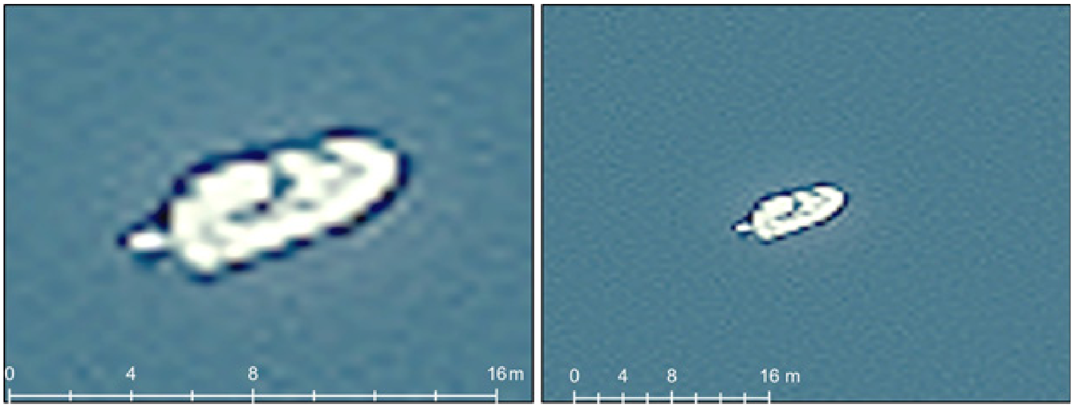
Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.86171 W, 31.40329 N
Description: 6.2m length x 2.4m width, Class 1, center console, adrift



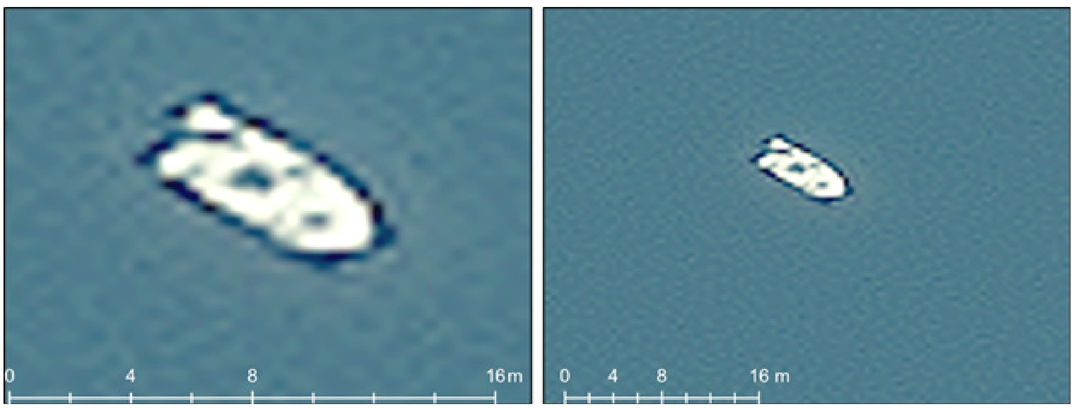
Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.86178 W, 31.40533 N
Description: 8.4m length x 3.0m width, Class 1, center console, adrift



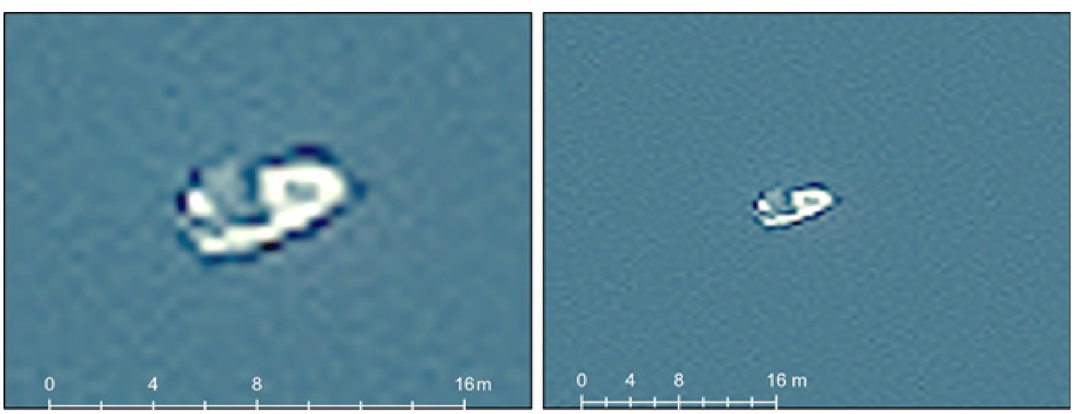
Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.86434 W, 31.40992 N
Description: 6.6m length x 2.5m width, Class 1, center console, adrift



Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.85122 W, 31.40250 N
Description: 7.9m length x 2.9m width, Class 1, center console, adrift



Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.85063 W, 31.40249 N
Description: 7.3m length x 2.9m width, Class 1, center console, adrift



Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.88431W, 31.39513 N
Description: 6.0m length x 2.0m width, Class 1, center console, adrift

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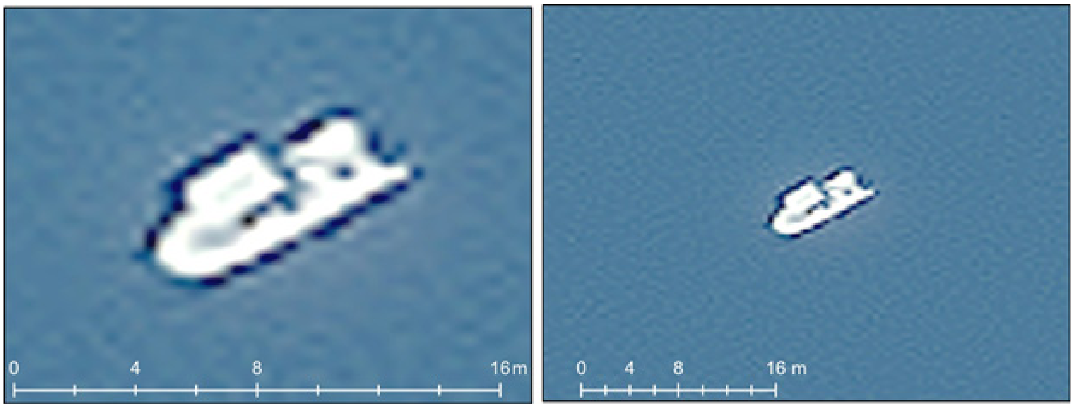
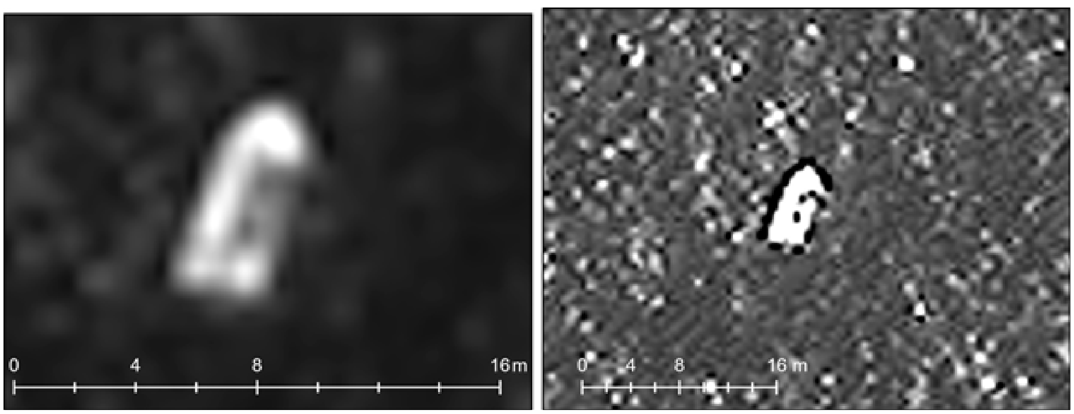
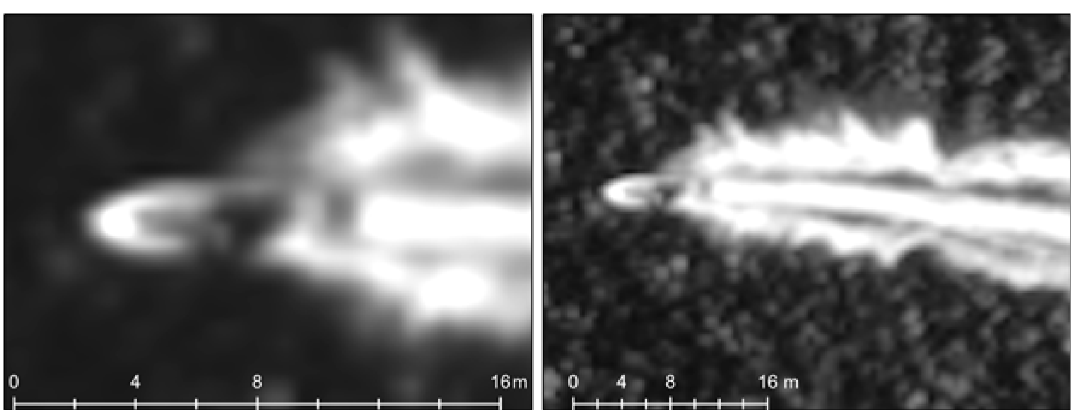


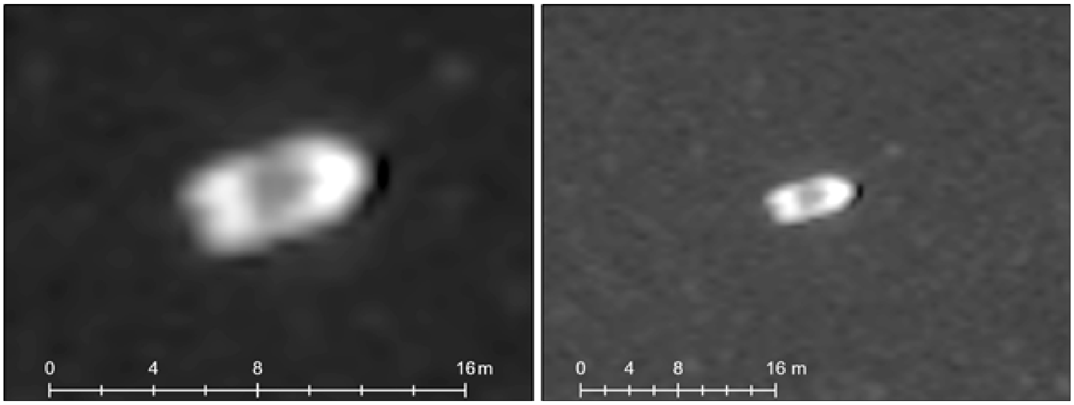
Date: 07/20/2019 at 12:09pm
Data Source: WV3 Pan sharpened 45cm resolution
Location: -80.89079 W, 31.39776 N
Description: 8.3m length x 2.8m width, Class 1, center console, adrift



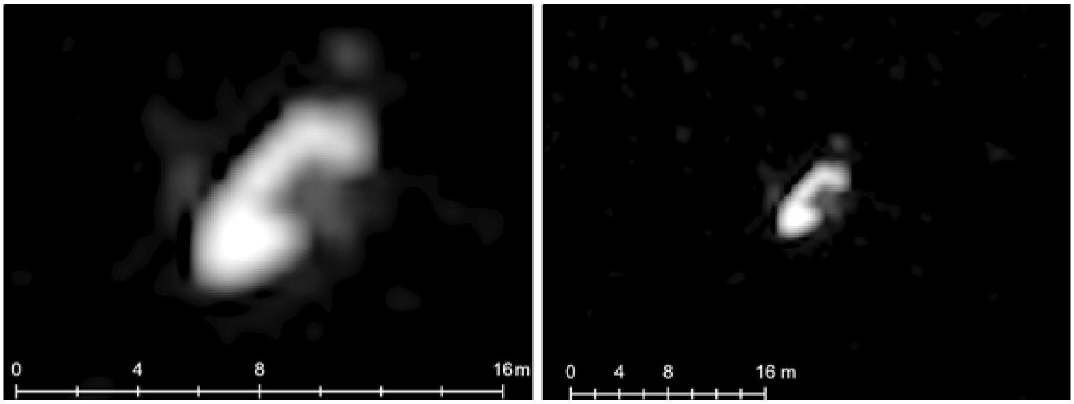
Date: 08/06/2019 at 3:14pm
Data Source: WV1 Panchromatic 53cm resolution
Location: -80.87241 W, 31.38740 N
Description: 7.7m length x 2.5m width, Class 1, adrift



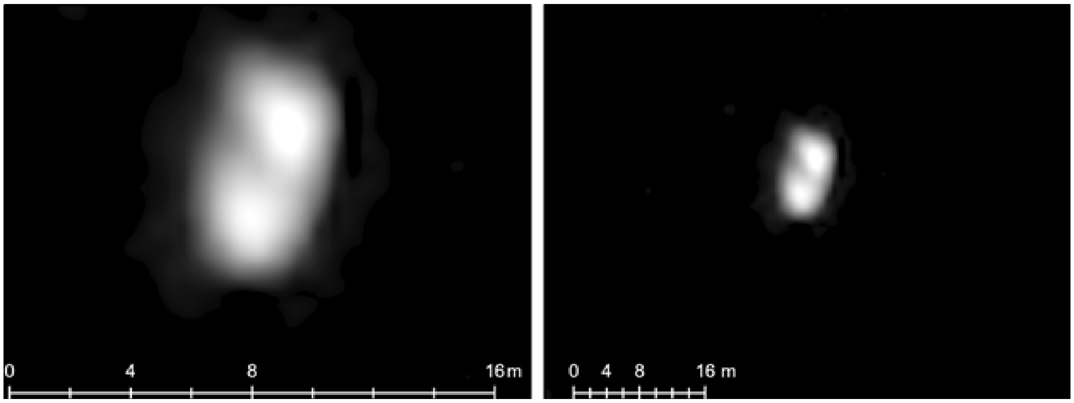
Date: 08/06/2019 at 3:14pm
Data Source: WV1 Panchromatic 53cm resolution
Location: -80.90198 W, 31.40611 N
Description: 8.4m length x 2.3m width, Class 1, center console twin outboard, fast speed



Date: 08/10/2019 at 3:14pm
Data Source: WV1 Panchromatic 56cm resolution
Location: -80.86243 W, 31.40433 N
Description: 6.4m length x 2.8m width, Class 1, adrift



Date: 08/10/2019 at 3:14pm
Data Source: WV1 Panchromatic 56cm resolution
Location: -80.86496 W, 31.40593 N
Description: 7.5m length x 2.8m width, Class 1, adrift



Date: 08/22/2019 at 12:23pm
Data Source: WV2 Multispectral Pan sharpened 61cm resolution
Location: -80.86735 W, 31.40342 N
Description: 7.5m length x 3.0m width, Class 1, adrift

U.S. Department of Commerce

Wilbur L. Ross, Jr., *Secretary*

National Oceanic and Atmospheric Administration

Neil Jacobs, *Administrator, Acting*

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