USING VIDEO SURVEYS TO EXAMINE THE EFFECT OF HABITAT ON GAG OCCURRENCE

by

GINA ALVAREZ

(Under the Direction of Adam Fox and Cecil Jennings)

The economically important Gag (*Mycteroperca microlepis*) fishery was declared overfished in the Gulf of Mexico in 2009. Although Gag are no longer listed as overfished, fisheries managers are concerned that stocks may not be recovering. Our objective was to identify habitat characteristics important to Gag, and their effect on Gag occurrence throughout the West Florida Shelf (WFS). We obtained data from three separate fisheries-independent video surveys that occurred in the WFS from 2010-2017. We ran a separate mixed effects logistic regression for each survey, and used Akaike's Information Criteria to determine the best fitting models. Our results indicate that increased rock coverage, relief, latitude, and depth had an overall positive effect on Gag occurrence, as did the coverage of sea whip. Managers may be able to help Gag and encourage their recovery by using these data to establish or expand protected areas that contain favorable characteristics.

INDEX WORDS: Gag, *Mycteroperca microlepis,* West Florida Shelf, Gulf of Mexico, Habitat

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DEDICATION

I would like to dedicate this to my soul mate, Dan Marotta, for loving and embracing me, and motivating me through the most difficult times, no matter the burden. I would also like to thank my precious and loving family Marielle (mother), Luis (father), Bianca (sister), Luis (grandfather), Dulce-Maria (grandmother), Inma (aunt), and Raymond (uncle), for raising me, never giving up on me, and instilling an attitude that has allowed me to survive. Lastly, I would like to thank my close friends (you know who you are) for supporting me and loving me yet to this day.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Gag (*Mycteroperca microlepis,* Serranidae) is a deep-bodied fish belonging to the subfamily Epinephelinae. The species is an economically important marine fish found along the continental shelf of the southeastern United States and Mexico from Massachusetts to the Yucatan Peninsula (Figure 1.1; Hoese *et al.* 1961; Manooch and Haimovici 1978; McGovern *et al.* 1998; Renan *et al*. 2006; Gruss *et al*. 2017). Gag can live up to 30 years, reach up to 129 cm total length (TL), and weigh up to 30 kg (Collins *et al.* 1998; Lombardi *et al.* 2013). Because of their protogynous nature, populations are naturally female-skewed (Coleman *et al.* 1996; Collins *et al.* 1998). These fish display ontogenetic shifts in habitat use, generally moving to greater depths as they mature and also are capable of extensive migrations across their range presumably to spawn (Heinisch and Fable 1999; McGovern *et al*. 2005; Lindberg *et al.* 2006). During all life stages, Gag are strongly associated with benthic structure (e.g., seagrass and reefs) and exhibit site fidelity after establishing residence (Kiel 2004; Lindberg *et al.* 2006; Coleman *et al*. 2011).

Life History

Mature Gag form spawning aggregations at the edge of the continental shelf primarily during February to April (Gilmore and Jones 1992; Koenig *et al.* 1996; Collins *et al.* 1998; McGovern *et al.* 1998). Their spawning grounds occur solely in the southeastern U.S. (Manooch and Haimovici 1978; Collins *et al.* 1998; Gruss *et al.* 2017). In the past, major spawning sites ocurred off the coasts of Florida (Koenig *et al.* 2000). Today, dominant spawning sites are limited to the northeastern Gulf of Mexico (GOM), straddling the “Big Bend” region of western

Florida (Koenig *et al.* 1996; Coleman *et al.* 2011). Spawning occurs in deep (50-120 m) water; sites are characterized by rocky features of varous relief (up to 8 m) and terrace drop-offs (Koenig *et al.* 1996; Collins *et al.* 1998; Koenig *et al*. 2000; Coleman *et al.* 2011). Outside of the few major spawning sites that have been identified, little is known about other potential spawning habitat for the species. Males reside at spawning sites year-round, and large groups of females will visit many sites during the spawning season (Gilmore and Jones 1992; Koenig *et al.* 2000; Coleman *et al.* 2011). Gag are broadcast spawners, and females can produce 10,000-865,000 eggs (Collins *et al.* 1998). Fertilized eggs hatch within 2-5 days and larvae spend the next 6-8 weeks adrift in oceanic currents that transport them towards the coast (Fitzhugh *et al.* 2005; Weisberg *et al.* 2014).

Age-0 juvenile Gag (TL 10-23 cm) recruit to estuaries between April and June (Keener *et al.* 1988; Ross and Moser 1995; Renan *et al.* 2006; Adamski *et al.* 2011). Within the estuary, Gag prefer habitat with complex benthic structure including seagrass beds, oyster reefs, mangrove roots, and rock pilings (Mullaney 1994; Ross and Moser 1995; Renan *et al.* 2006; Casey *et al.* 2007; Switzer *et al.* 2012). During this stage, juveniles grow rapidly and experienced nearly 100% survival throughout a season in St. George Sound, FL (Ross and Moser 1995; Koenig and Coleman 1998). The abundance of juveniles over seagrass beds begins to decline in late summer, when juveniles appear over hard bottom habitat, both within and outside the estuary (Ross and Moser 1995; Heinisch and Fable 1999). By the end of October, most juveniles have moved from the estuary to nearshore reefs in the completely marine environment (Ross and Moser 1995; Heinisch and Fable 1999; Lindberg *et al.* 2006; Switzer *et al.* 2012; Kingon *et al.* 2014). Little is known about the movement patterns and habitat preferences of juvenile Gag that have left the estuary and now reside in the marine habitat (age 0+; TL 23-70 cm) (SEDAR 2014).

Detailed information about marine juvenile Gag habitat use is lacking, but they may use nearshore marine reefs as nurseries until maturity. Marine juveniles tend to spend an average of 9.8 months at nearshore artificial reefs, yet the use of natural reefs by marine juveniles is largely unknown (Kiel 2004; Lindberg *et al.* 2006; unpublished data from Fox Lab at University of Georgia).

Females mature upon reaching ~70 cm TL, at ~5 years of age (Fitzhugh *et al.* 2006). Adult female Gag frequent artificial reefs and natural reefs with moderate hard-bottom and high relief, at a wide range of depths (Coleman *et al.* 2011, Gruss *et al.* 2017 and 2018). Adult females are thought to form pre-spawning aggregations over shallow reefs (<50 m) during November to February (Coleman *et al*. 2011; Lowerre-Barbieri *et al.* 2020). After spawning, most females return to shallow reefs but some continue to inhabit spawning sites year-round (McGovern *et al*. 2005; Coleman *et al.* 2011; Lowerre-Barbieri *et al.* 2020). Although numerous studies have characterized spawning habitat, few have focused on habitat used by females outside the spawning season.

Gag transition to male at ~10 years of age (TL ~100 cm) (McErlean and Smith 1964; Fitzhugh *et al.* 2005; SEDAR 2014). The mechanism triggering this sexual change is not known but has been hypothesized as being social cues regarding fish size and sex ratio during spawning (Coleman *et al.* 2011). However, a recent documention showed that transitionals occurred before, during, and after the spawning period, both at spawning sites and in all-female pre-spawning aggregations, which suggests that sex ratio might not be required for initation of sex transiton (Lowerre-Barbieri *et al.* 2020). Male Gag reside at 1-2 spawning sites and remain there year-round (Coleman *et al*. 2011).

Status

Gag are one of a group of fishes collectively sold as "grouper" and are economically important as both a commercial fishery and a recreational fishery. Like other groupers, Gag flesh is highly desirable in the seafood marketplace. In the GOM, the commercial grouper fishery is currently worth $15 million USD annually. The most lucrative commercial fishery exists in the northeastern GOM where Gag abundance is greatest. Gag are also highly prized among anglers, especially in Florida where 99% of recreational landings occur (SEDAR 2014).

Historically, commercial and recreational fishing both contributed to the overharvest of Gag. Fishing for Gag intensified in the late 1970s, when fishermen turned to the species following the crashes of other popular fisheries. At the time, regulations on Gag harvest were nonexistent, and commercial fishermen began targeting spawning aggregation to increase their efficiency (Koenig *et al.* 1999; Coleman *et al*. 2011). By 1999, there was also a popular recreational fishery for Gag, which was responsible for 78% of Gag landings (by number) in Florida (Koenig *et al.* 1999). Because both commercial and recreational fishermen targeted the largest individuals (i.e., males), the proportion of males declined, and spawning aggregations were fished to extirpation, possibly related to reproductive failure caused by sperm limitation (Coleman *et al.* 1996; Beets and Friedlander 1998; Reed *et al.* 2005). Gag populations also demonstrated other indications of overfishing, including truncated size structure and reduced size at maturity (Koenig *et al.* 1996; McGovern *et al.* 1998).

Attempts to address the decline of Gag populations began in 1990 with the implementation of regulations including gear restrictions, recreational bag limits and commercial quotas, and size limits aimed at protecting juveniles. The Oculina Experimental Closed Area was established in eastern Florida in 1994, in part to protect Gag spawning aggregations and Gag spawning habitat that had previously been devastated by bottom fishing. In 2000, two additional marine protected areas (MPAs), Madison-Swanson and Steamboat Lumps, were created in the northeastern GOM specifically to protect known Gag spawning sites. Despite these measures, Gag abundance continued to decline; the species also experienced a severe mortality event related to red tide (i.e., harmful algal blooms) in 2005. The GOM Gag stock was declared overfished and undergoing overfishing in 2009 (SEDAR 2009; SEDAR 2014).

To rebuild Gag stocks, the GOM Fishery Management Council and Gulf Coast states implemented additional management actions including seasonal closures for the recreational fishery to prevent harvest during part of the spawning period, individual quotas for the commercial fishery, annual catch limits for both the recreational and commercial fisheries, and a seasonally restricted MPA in the northeast GOM, The Edges, to protect Gag spawning activity. Soon after, Gag abundance increased and in 2014, the status of the GOM stock was declared not overfished or undergoing overfishing (SEDAR 2016). Despite this official upgrade in stock status, managers recognize that there is uncertainty about the long-term effectiveness of current management strategies (SEDAR 2016). Recent catch data indicates that spawning stock biomass has increased at a lower rate than predicted by stock assessment models. The 2016 stock assessment update introduced a competing model of Gag abundance that included both sexes (males were not previously included); the new model indicated that the GOM Gag were overfished and experiencing overfishing (SEDAR 2016). In addition to this uncertainty, ongoing threats such as habitat destruction from fishing gear, discard mortality, and red tide negatively interfere with the recovery of the species (Gray *et al*. 2013; SEDAR 2014; Weisberg *et al*. 2014).

Remote Underwater Video (RUV)

The use of remote underwater video (RUV) is relatively new in the study of marine fisheries and provides important data that otherwise is not available from traditional sampling methods. Some of the most valuable and widely collected data in fisheries are the abundances and sizes of fishes, which are used to assess stocks. These data often have been collected with various methods such as traps, seines, and trawls. Although informative, these methods provide data that are limited by the individual technique's inherit biases. These biases can be caused by a multitude of factors, such as the physical characteristics of gear (e.g., hook or mesh size), which target a certain size range, and thus does not sample all life history stages. To solve this issue, many agencies and other research groups have implemented the use of non-capture methods to sample a larger part of organisms' life histories. For example, the National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program (SEAMAP) historically used traps to obtain relative abundances of reef fishes offshore. After learning about many issues with the traps, such as that certain species would avoid the trap, they replaced the traps with cameras to obtain relative abundance data.

Not all non-capture methods are equally effective. Video surveys in particular have become popular and established over the years for their many advantages. Many underwater visual censuses performed by divers are being replaced by video surveys to allow for a less intrusive technique that does not alter fish behavior in the same way. A literature review of the relevant literature found that overall, RUVs revealed higher abundance and fish diversity than underwater visual censuses did in seagrass meadows, especially in denser seagrass meadows where fish could hide more easily (Zarco-Perello and Enriquez 2019). Another advantage to using RUVs is that they are minimally invasive towards the environment, including both habitat and fishes. With the decline of many fish stocks and known vulnerability of many habitats to fishing gear, researchers are now more concerned with the effect of their sampling methods than they were historically. RUVs do not inflict fishing mortality or are not known to pose threats to the habitat sampled; and for this reason, RUVs are becoming very popular as a research tool. The other unique advantage of RUVs is that information about the associated habitat can be gathered in addition to count and size data. For example, the Florida Fish and Wildlife Research Institute used habitat measured from RUVs to classify suitable habitat for Red Groupers (*Epinephelus morio*) and then used that information to calibrate relative abundance given the habitat sampled (Guenther *et al.* 2014).

Although RUVs have been established as useful, they are not exempt from their own biases. Often RUVs are attached to a baited housing to lure fish into the field of view or closer to the camera for measuring and identifying. This can be problematic if the target species are not scavengers or carnivores. The presence of food can also create a dynamic in which the cautious fish remain out of sight. Currently, RUVs with 360-degree view are being used to minimize these detection issues. In Australia, sightings of species that were seen less frequently on single-view baited RUVs increased when using a 360-degree-view baited RUV (Whitmarsh *et al.* 2018).

Modeling Species Occurrence

Understanding the distribution of wildlife is an integral component in successful natural resource management. Often though, obtaining a census of a species throughout its entire range or a specified area is logistically challenging. For this reason, scientists frequently use statistical tools that can predict the likelihood of species occurrence based on environmental variables. This information is often coupled with spatial analyses to map current and potential distributions

(Gruss *et al*. 2017), but also used to elucidate species-habitat relationships (Gruss *et al*. 2018). Both endeavors generate information that can be used to inform management decisions that deal with spatial boundaries. Studies like these have been conducted on a wide range of species such as Indian Bison (*Bos gaurus*), Formosan Squirrel (*Callosciurus erythraeus*), Common Cranes (*Grus grus*), and epibenthic fishes (Franco *et al*. 2000; Miyamoto *et al*. 2004; Azzellino *et al*. 2012; Imam and Kushwaha 2013).

Figure

Figure 1.1 Range of Gag (*Mycteroperca microlepis*) delineated in red. Extent of offshore range not shown here. Modified from https://mapswire.com/north-america/physical-maps/.

CHAPTER 2

USING VIDEO SURVEYS TO EXAMINE THE EFFECT OF HABITAT ON THE OCCURRENCE OF GAG[1]

[1] Alvarez G., Gandy D., Irwin B., Fox A., Jennings C. A. To be submitted to *Marine and Coastal Fisheries*

Introduction

Gag (*Mycteroperca microlepis,* Serranidae) are deep-bodied marine fish belonging to the subfamily Epinephelinae. The species is an economically important reef fish found along the continental shelf of the southeastern United States and Mexico from Massachusetts to the Yucatan Peninsula (Hoese *et al.* 1961; Manooch and Haimovici 1978; McGovern *et al.* 1998; Renan *et al*. 2006; Gruss *et al*. 2017). Gag are especially abundant in the eastern Gulf of Mexico (GOM), where the most lucrative commercial and recreational fishery exists. They can live up to 30 years, reach up to 129 cm total length (TL), and weigh up to 30 kg (Collins *et al.* 1998; Lombardi *et al.* 2013). Because of their protogynous nature, populations are naturally female-skewed (Coleman *et al.* 1996; Collins *et al.* 1998). These fish display ontogenetic shifts in habitat use, generally moving to greater depths as they mature and also are capable of extensive migrations across their range presumably to spawn (Heinisch and Fable 1999; McGovern *et al*. 2005; Lindberg *et al.* 2006). During all life stages, Gag are strongly associated with benthic structure (e.g., seagrass and reefs) and exhibit site fidelity after taking residence (Kiel 2004; Lindberg *et al.* 2006; Coleman *et al*. 2011).

Historically, commercial and recreational fishing for Gag contributed to their decline. Fishing pressure intensified in the late 1970s when commercial fishermen began to target spawning aggregations (Koenig *et al.* 1999; Coleman *et al*. 2011). By 1999, there was also a popular recreational fishery for Gag, which was responsible for 78% of Gag landings (by number) in Florida (Koenig *et al.* 1999). Because both commercial and recreational fishermen targeted the largest individuals (i.e., males), the proportion of males declined, and many spawning aggregations were fished to extirpation - possibly related to reproductive failure caused by sperm limitation (Coleman *et al.* 1996; Beets and Friedlander 1998; Reed *et al.* 2005).

Attempts to address the decline of Gag populations began in 1990 with the implementation of regulations including gear restrictions, recreational bag limits and commercial quotas, and size limits aimed at protecting juveniles. Further, marine protected areas (MPAs) Madison-Swanson and Steamboat Lumps were designated specifically to protect known Gag spawning sites year-round. Despite these measures, Gag abundance continued to decline; the species also experienced a severe mortality event related to red tide in 2005. The GOM Gag stock was declared overfished and undergoing overfishing in 2009 (SEDAR 2009; SEDAR 2014).

To rebuild Gag stocks, the GOM Fishery Management Council and Gulf Coast states implemented additional management actions that included seasonal closures to the recreational fishery to prevent harvest during the spawning period, individual quotas for the commercial fishery, annual catch limits for both the recreational and commercial fisheries, and a seasonally restricted marine protected area (MPA) in the northeast GOM, The Edges, to protect Gag spawning activity. Gag abundance increased and, in 2014 the status of the GOM stock was declared not overfished or undergoing overfishing (SEDAR 2016). Despite this official upgrade in stock status, managers recognize that there is uncertainty about the long-term effectiveness of current management strategies (SEDAR 2016). In 2016, an updated stock assessment introduced a competing model of Gag abundance that included both sexes (males were previously not included); the new model indicated that the GOM Gag were still overfished and undergoing overfishing (SEDAR 2016). Additionally, ever since the Gag fishery was delisted from overfished and undergoing overfishing, both recreationally and commercially harvested Gag landings have not reached the stock's respective annual catch limits (ACL; 42-53% of 1.9 M lb ACL, except 1.7 M lb in 2014; 40-75% of 1.2 M lb ACL, except 1.1 M lb ACL in 2014), which increases the concern over the current regulations' ability to prevent overfishing and sustain the fishery.

Although the current regulations take into account what is known about the species and the fishery as a whole, there are still major gaps in the scientific knowledge of Gag life history. This information gap is due in part to the difficulty of studying Gag: their life history is complex and requires multiple habitats from the coast to the edge of the continental shelf. Simplified, the Gag life cycle is as follows: in late winter/early spring, adults aggregate at the edge of the continental shelf to spawn, and the larvae then get carried inshore via oceanic currents (McGovern *et al.* 1998; Weisberg *et al.* 2014). Inshore, larvae grow into juveniles, which use seagrass beds and other complex benthic structures such as oyster beds as nursery areas (Renan *et al.* 2006). By fall, juveniles appear to migrate to the nearshore marine environment where they inhabit hard bottom habitats such as manmade reefs and natural ledges (Lindberg *et al.* 2006). As they mature, Gag move to greater depths where they continue to use hard bottom habitats. In winter, adult females are thought to form pre-spawning aggregations over shallow reefs (<50 m; Coleman *et al*. 2011; Lowerre-Barbieri *et al.* 2020). They then migrate to and congregate at the deep-water spawning sites where males reside year-round (Coleman *et al*. 2011). The current understanding of Gag habitat requirements is based on relatively few studies within the broad extend of the species' range.

Offshore studies (e.g., Gilmore and Jones 1992; Gledhill *et al.* 2005; Coleman *et al*. 2011; Campbell *et al*. 2013) that have characterized Gag habitat focused largely on shelf-edge reefs where adult abundance is high, males live year-round, and where spawning aggregations occur. Some studies have also focused on nearshore artificial or natural reefs with large topographic features. According to those previous studies, most of which have focused on the northeastern GOM, Gag occur over rocky outcrops, ledges, pinnacles, ridges, thickets of *Oculina* spp. (a type of hard coral), and manmade reefs with relief varying from <1 m to 20 m, although Gag are less common over areas of low relief (Gilmore and Jones 1992; Gledhill *et al.* 2005; Lindberg *et al.* 2006; Coleman *et al*. 2011; Campbell *et al*. 2013; Kingon *et al.* 2014; Keenan *et al.* 2018; Switzer *et al.* 2020). These findings on habitat use have been the basis for guiding management decisions related to Gag. For example, understanding the role of west Florida's shelf-edge reefs as spawning habitat led to the designation of some of these reefs as MPAs to protect them from fishing activity. Although these reefs are clearly important, Gag do occupy other habitats throughout their life cycle and adult females are found shelf-wide year-round (Gruss *et al.* 2017). The lack of rigorous protection – such as that given to important spawning sites – in the remainder of the shelf creates concern over the vulnerability of the fishery, especially while the GOM Gag stock status remains uncertain. Particularly, there is concern that the current protection of spawning sites is not sufficient to mitigate the effect of overfishing on the entire stock. Implementing additional protected areas could increase available refuge from fishing and potentially bolster the entire fishery, but this would require a more comprehensive understanding of Gag habitat across their entire range.

The goal of this study was to investigate how habitat influences Gag occurrence throughout a large part of the West Florida Shelf (WFS). Although previous studies have discussed the habitat in which Gag occur at individual reefs, habitat characterization is lacking for the remainder of the WFS, which renders information regarding Gag habitat largely unknown. More specifically, our objective was to model Gag occurrence in relation to fine scale habitat characteristics/variables to determine if those variables serve as important indicators to predicting Gag occurrence across the WFS.

Methods

Study Site—The West Florida Shelf is a carbonate platform in the eastern Gulf of Mexico that extends westward of mainland Florida (Figure 2.1). The WFS is low-gradient and relatively shallow; it lies at depths of 20-200 m before it transitions into the West Florida Slope and eventually the West Florida Escarpment. Unlike the rest of the shelf in the Gulf of Mexico, only about 5% of the WFS has been mapped at high resolution (https://www.marine.usf.edu/scamp/about/project-overview/). The WFS is thought to be primarily covered with unconsolidated substrates such as sand, and interspersed with hard bottom features of varying size and relief; these include: pinnacles, pavement, rocky outcrops, ledges, and fossilized reefs, some of which have been designated as marine protected areas (Coleman *et al.* 2011, Hine and Locker 2011). Although reefs comprise a minority of the known habitat, they are home to most species found on the WFS, which make them vital to economically important fish species, including snappers and groupers.

Data Collection—To investigate the habitat variables that affect Gag occurrence, we analyzed data from the WFS collected by three separate fisheries-independent reef fish surveys from 2010-2017. The surveys consisted of video from stationary underwater camera arrays designed to capture imagery of reef fishes and their associated reef habitat. These surveys were run by the following groups: the Florida Fish and Wildlife Research Institute (FWRI) , the National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program (SEAMAP) Reef Fish Video Survey, and the NOAA Panama City, FL office (PC).

Video Survey Sampling Design—All three surveys employed a stratified random sampling design. Seafloor mapping was an integral component to all three video surveys.

Acoustic surveys were conducted to identify known reef habitat within the sampling area of each study prior to camera array deployment. The types of acoustic survey gear and how they were used to select camera sites differed among surveys.

The following paragraphs describe the surveys' sampling methods for the years we included in this study (FWRI: 2010-2016; SEAMAP: 2012-2017; and PC: 2010-2016). The FWRI video survey area spanned the WFS and covered a large range of depths. Sampling was concentrated up to ~160 km offshore of central Florida (Figure 2.2) - an area of the WFS that was not mapped or sampled by other video surveys - but also occurred offshore of northern Florida, where it overlapped with other video surveys. The sampling area for this study was divided into geographic zones (4-7 and 9-10) based on the National Marine Fisheries Service statistical grid (Figure 2.2). These were further divided into depth classes (inshore:10-37 m; offshore: >37 m), which created a total of 12 strata. Because virtually all habitat in the sampling area was unknown, the site selection procedure for camera array deployment was integrated with the side-scan sonar surveys that identified reefs. The annual goal was to conduct 100 side-scan sonar rectangles per geographic zone, which were randomly allocated in proportion to the area of each strata within the zone. The side-scan sonar sites marked the center of 0.3 x 2.1 nautical miles (nm) rectangles that were mapped perpendicular to the shoreline and gridded into 21 units (0.1 x 0.3 units). Within each rectangle, simple random sampling was used to select three units from those identified to contain reef; randomization was achieved by using a random number generator in Excel and ArcGIS 10.3. From the three units, only one was selected for camera array deployment; the other two sites were used as alternatives if the selected site were unavailable. If the selected unit to be sampled contained a large reef or multiple types of hard bottom habitat, two camera arrays were deployed at least 100 m apart.

The NOAA SEAMAP video survey covered the GOM from Brownsville, TX to the Dry Tortugas, FL and focused on the primary banks of the GOM. The sampling area was separated into regions (western and eastern GOM); our analysis only used data from their eastern sampling region (Figure 2.3). Each region was divided into 10-min latitude x 10-min longitude blocks, which were stratified by sub-regions (Texas, Louisiana, Northeast GOM, and South FL) and by the total area of known reef per block (<20 km^2 or ≥20 km^2). Blocks were randomly selected based on the strata weights, which were calculated to reflect the total area of known reefs within a stratum in proportion to that of its region. Within blocks, 10 (0.1 x 0.1 nm) sampling units known to have reef (as identified with a multi-beam echosounder) were randomly selected for camera array deployment; randomization was achieved using the Proc Surveyselect in SAS.

The PC video survey focused on the inner shelf of the Florida panhandle and the Big Bend region of Florida at depths less than 60 m (Figure 2.4). The survey employed a 2-stage unequal probability sampling design. The sampling area was comprised of 5-min latitude x 5-min longitude blocks that were stratified by region (east of Cape San Blas, FL and west of Cape San Blas, FL), sub-region, and depth zones (10-20 m, 20-30 m, >30 m) for a total of 18 strata. Blocks were randomly selected based on the strata weights, which were calculated to reflect the total area of known reefs (as identified by side-scan sonar surveys) within a stratum in proportion to that of its region; randomization was achieved using a number generator within Excel. Within each block, known reef sites were stratified by habitat quality (Good, Fair, and Poor), which were based on the following habitat metrics: proximity to nearest reef, size, rugosity, and relief; a greater measure of each variable corresponded to better habitat quality. Once a block was selected, known reef sites of at least 250 m apart were randomly selected based on strata weights (40% Good, 40% Fair, and 20% Poor).

Camera Arrays—The cameras and deployment methodologies were fairly similar among all video surveys during the time frame analyzed. Camera arrays contained at least two opposing cameras to maximize the field of view and thus maximize the pool of potential videos from which to select for reading. Cameras were used to identify species, measure lengths of fish (using stereo still cameras or video cameras from which stills could be acquired), enumerate fish, and describe habitat (using video cameras). Camera arrays were baited with either frozen mackerel or squid to attract fish sufficiently close to the camera for species identification and fish measurement. Arrays differed among surveys in their configuration and the make/model of cameras used; within each survey, array configuration and cameras used varied by year (Table 2.1). Depending on the survey, one or two arrays were deployed on site and recorded for 30 or 45 min, but in all surveys only the final 20 min of each video were read (to avoid filming any silt plume created during deployment). The location, date, and depth were recorded for each site.

After array retrieval, videos from all cameras were screened, at which time specific camera(s) were pre-selected for future reading. In all video surveys, the camera with the best view of habitat was chosen. When similar views were produced, a camera was chosen by simple random sampling. Cameras were removed from the pre-selection pool if viewing issues listed in Table 2.2 were present.

Video Reading—Readers assessed videos (hereafter referred to as samples) according to each survey's protocol, which will be addressed in the next paragraph. All video reading entailed identifying fish species and enumerating the maximum number of individuals of each species (defined as the most individuals observed in a single video frame during the 20-min video), describing habitat, and noting other variables that could affect image quality or readability. Readers described habitat by visually estimating the percent composition of substrate, percent composition and coverage of attached epifauna, and the maximum vertical relief, which was defined as the estimated height of the tallest substrate present. Habitat variables and their definitions sometimes differed among surveys, though most variables were measured across all surveys (Tables 2.3-2.5).

For FWRI and SEAMAP, the initial reader watched the video on a large, high-definition screen in a dark room. Identification of species required annotation of two to three characteristics (e.g., anal fin rounded, body flattened, or swims with dorsal and anal fin). For quality control, at least two readers were required to read the entire sample. The second reader checked the initial reader's work. If both readers did not agree, a third person (qualified as an expert reader), made the final decision based on their own read. For PC, most video assessments were done by a single reader – only 20% of surveys were read by multiple readers. Then any differences among the replicated reads were assessed and taken to an expert reader who made a final determination.

Data Preparation—We analyzed samples from 2010-2017 because, by 2010, all surveys had implemented acoustic surveys to detect reefs and improve camera array placement. We omitted SEAMAP video survey samples that were collected from 2010 and 2011 because of a change in their method of coding habitat that occurred during this time. We removed samples we considered of poor quality from further analysis. This included samples that were read at a length other than the standard 20 min, as well as samples coded as "miscellaneous".

Although the surveys shared common goals and their methods overlapped in many instances, they did have important differences in habitat coding and site selection. Therefore, we conducted a separate analysis of each survey. For each survey, we used a Pearson correlation analysis to determine if our predictor variables were auto correlated, which we defined as having a correlation coefficient >0.7 or <-0.7 (correlations can be found in the Appendix Figures A1-3).

From the correlated pairs of variables, we retained the variable most likely to affect the association and, if none were obvious, we retained the variable thought to have the greater effect on the occurrence of Gag based on published literature (Tables 2.3-2.5). We also removed variables if they had a low number of observations (<3% of total samples) and if they were irrelevant given the context of this study (Tables 2.3-2.5). Because Gag can be camera shy (personal communication - Ted Switzer, Florida Fish and Wildlife Research Institute), we classified Gag presence/absence in each sample, rather than using potentially biased numerical counts.

Modeling—We used logistic regression, a type of generalized linear model (GLM), to evaluate whether there was a relationship between Gag occurrence and habitat characteristics.

We created a set of candidate models containing variables that the literature suggested might predict Gag presence; these variables included percent coverage by rock (ROCK), percent coverage by hard coral (HCOR), maximum vertical relief (REL), latitude (LAT), and depth (DEP). To avoid inadvertently dismissing variables that had not previously been hypothesized as important, our candidate model set also included a model created using Akaike Information Criteria (AIC)-based backwards stepwise selection (hereafter the stepwise model) on all available variables.

For each of the three surveys, the candidate model suite contained a model for each individual variable, combinations (additive and/or interactive) of variables, and the stepwise model. However, because the PC survey did not span a broad range of latitudes, we did not include the individual variable LAT or the interaction of LAT*DEP. Month and year were included as random effects in all models. Values measured as fixed effect variables were centered around the mean for convergence of models.

All regression models met the logistic regression assumptions: a binary independent variable (Gag presence), observations independent of each other, an absence of correlation, and linearity of independent variables and logarithmic odds. AIC was used to the select the model that best fit the data - the confidence models were defined as those whose Akaike weights were summed in descending order until 0.95 was achieved or surpassed (Burnham and Anderson 2002).

RESULTS

From all three video surveys, we initially selected a total of 3,802 video survey samples based on temporal constraints; From these, we rejected 415 because they were poor quality videos (Table 2.5). Our final data set included 3,387 samples, with 1,563 samples from the FWRI survey (92% of the 1,700 total FWRI samples) spanning 2010-2016, 1,049 samples from the SEAMAP survey (98% of the 1,076 SEAMAP samples) spanning 2012-2017, and 775 samples from the PC survey (76% of the 1,026 PC samples) spanning 2010-2016 (Table 2.6). Sampling sites for all surveys are depicted in Figure 2.5.

Out of a total of 3,387 analyzed samples for all surveys across all years, 301 samples contained Gag (9%). Seventy-one of the 1,563 FWRI samples contained Gag (5%), 96 of the 1,049 SEAMAP samples contained Gag (9%), and 134 of the 775 PC samples contained Gag (17%; Table 2.6).

The top model for FWRI (AIC weight: 49%) was the model created using backward stepwise selection. This model included HCOR, LAT, and DEP as main effects, and ROCK and REL as an interaction (Table 2.7). All main effect variables had a positive effect on the probability of Gag occurrence, and ROCK and REL had a negative interaction. The confidence model set included the top model and 3 additional models, each of which had an AIC weight of

19%, 16%, and 16% respectively. The set of confidence models included variables HCOR, ROCK, REL, LAT, and DEP, each of which had a positive effect on the probability of Gag occurrence. All interactions between variables - ROCK*REL and LAT*DEP- were negative.

The top model for SEAMAP (AIC weight: 99%) was the model created using backward stepwise selection. This was the only model in the confidence model. The model included variables LAT, DEP, ALG and WHIP as main effects, and ROCK and REL as an interaction (Table 2.8). All main effect variables except ALG had a positive effect on the probability of Gag occurrence, and ROCK and REL had a negative interaction.

The top model for PC (AIC weight: 99%) was the model created using backward stepwise selection. This was the only model in the confidence model. The model included variables DEP, EPIF and WHIP as main effects, and ROCK and REL as an interaction (Table 2.9). All main effect variables except EPIF had a positive effect on the probability of Gag occurrence and ROCK and REL had a negative interaction. All model coefficients can be found in Appendix Tables A1-3. Graphical relationships for all surveys are displayed in Appendix Figures A4-19.

DISCUSSION

We successfully used data collected via underwater video cameras to relate the occurrence of Gag to certain habitat characteristics over large sections of the West Florida Shelf. Our study analyzed these fisheries-independent data from a wide geographic region within the species' range and gained new insight about favorable Gag habitat. Although other studies have looked at Gag habitat, most have focused on specific areas previously known to be important to the species. Because our sample sites were selected without consideration of Gag presence, the information about the factors that influence Gag occupancy is applicable throughout the entire

WFS. The use of video survey data also provided a unique opportunity to ground-truth habitat where Gag were observed. Although we conducted separate analyses of three underwater video surveys, our results indicated many similarities in the environmental variables that influenced Gag occurrence.

Rock and Relief—The percent coverage of rock (ROCK) and maximum vertical relief (REL) were present in the confidence model set for all surveys, which suggests that these variables are important indicators of Gag habitat across the WFS. Previous studies on individual reefs documented the occurrence of Gag over rocky features such as ledges, pinnacles, and outcrops (Gilmore and Jones 1992; Koenig *et al.* 2000; Coleman *et al.* 2011; Switzer *et al.* 2020). Our results confirm that across the WFS, as rock increases, so too does the likelihood of Gag. Using fisheries-dependent data, Gruss *et al.* (2018) also observed a positive effect of hard bottom on Gag occurrence. However, the substrate data in that study was of poor resolution and quality; because we used FIM video camera data, we were able to base our results on the actual characteristics of the habitat at each site where Gag were observed.

The video surveys we analyzed each used different definitions of rock when estimating percent rock coverage – particles could be anywhere from 6.35 cm to >4 m. Our results suggest that rock is important for Gag, regardless of its size, but we are unable to ascertain whether any particular size of rock increases the likelihood of Gag occurrence. Further studies that divide rock particle sizes into specific, standardized bins would provide insights into if and how substrate size affects Gag occurrence.

We found that relief was also an important factor in determining Gag occurrence and that its effect on Gag was positive. Previous studies at individual reefs and areas within the Gag's range (i.e., Florida Panhandle) observed Gag over habitats with relief, including artificial reef, potholes, and rocky features (Koenig *et al.* 2000; Lindberg *et al.* 2006; Coleman *et al.* 2011; Keenan *et al.* 2018; Switzer *et al.* 2020). Furthermore, a positive effect of relief on Gag occurrence was demonstrated at the major banks of the West Florida Shelf (Campbell *et al.* 2013). However, our findings confirmed the positive influence of relief on Gag occurrence throughout the WFS.

We hypothesized that a positive interaction existed between rock and relief, based on the idea that rock comprised most relief. Although this interaction was present in the confidence models for all surveys, the effect of the interaction was actually negative. In other words, rock was a greater driver of Gag occurrence in areas of less relief, whereas relief was a greater driver of Gag in areas of less rock. Although both rock and relief are important, this suggests that across the WFS, Gag are using areas with low-relief rock in addition to areas of high-relief substrates. Indeed, studies on individual reefs have found that Gag center their movements around high-relief reef, but occasionally stray away and move to areas of low-relief hard bottom to forage (Kiel 2004; Lindberg *et al.* 2006; Biesinger *et al.* 2011). Other substrate variables can also contribute to relief including manmade reef, rubble, shell/gravel, and sand (e.g., potholes or sandhills); rock may not be as important to Gag if the relief is available from another source – for instance, Gag have been observed using potholes, which are depressions in unconsolidated substrates (Keenan *et al.* 2018; Switzer *et al.* 2020). The use of non-rock features that provide relief may help explain our results.

Depth and Latitude—Depth (DEP) was present in the confidence models of all three surveys. Adult Gag form spawning aggregations that occur at depths of 50-120 m at the shelf edge, which is also where the dominant commercial fishery grounds occur (Koenig *et al*. 1996; Coleman *et al.* 2011). Depth is an important influence on Gag abundance along the WFS edges

(Campbell *et al.* 2013). However, we found that the effect of depth on Gag occurrence varied among the three surveys we examined, which suggests a non-linear response. In the FWRI survey, which sampled throughout the WFS, and the SEAMAP survey, which focused on offshore areas, depth had a positive influence on Gag occurrence. The PC survey occurred in relatively shallow waters away from the shelf edge; therefore, we did not expect that depth would be an important explanatory variable for Gag occurrence in that survey. However, our results indicated that in the PC survey, depth had a negative effect on Gag occurrence. Because the region in which the PC survey occurred is heavily biased towards juveniles (DeVries *et al.* 2013), our findings suggest that juvenile Gag occurrence may increase with decreasing depth. In fact, a WFS-wide study that relied on fisheries-dependent data also found that juveniles were more likely to be found with decreasing depths, whereas adult Gag were more likely to be found with increasing depths (Gruss *et al*. 2018). Future studies that use fisheries-independent data and incorporate length/age information could clarify whether the effect of depth varies as a result of location or ontogenetic shifts.

Latitude (LAT) was present in the confidence model set of FWRI and SEAMAP surveys; however, latitude was not investigated in our analysis of the PC survey, which means that latitude is also an important predictor of Gag occurrence. The idea that Gag are more prevalent in the northern GOM stems from the knowledge that their spawning sites occur in the northern GOM, which is also where the dominant commercial fishing grounds occur (Koenig *et al*. 1996; Coleman *et al.* 2011). Previous WFS-wide studies that used fisheries-dependent data showed that overall, Gag were more likely to be found in the northern GOM (Gruss *et al.* 2017, 2018). Our results, which derive from fisheries-independent data, confirm that latitude does in fact have a positive effect on Gag throughout the WFS.

Our results indicate that the effect of depth on Gag was reduced as latitude increased, which may be because Gag at higher latitudes are more widely distributed and less constrained by depth. A study that used fisheries-dependent data found that, in addition to the edge of the WFS, year-round adult Gag occurrence was relatively high in the Big Bend region of Florida, which features relatively shallow waters (<50 m; Gruss *et al.* 2017, 2018). Therefore, the widespread occurrence of adult Gag in the northern WFS could be driving the reduced effect of depth that we observed at higher latitudes. Another potential explanation for the reduced effect of depth at higher latitudes may be because we were unable to include information about Gag age in our study design. Although juvenile Gag exist throughout the WFS at various latitudes, fishery-dependent data suggest that they are more prevalent in the northern WFS (Gruss *et al.* 2017, 2018). Because juveniles and adults demonstrate different depth preferences, this may explain why depth had a negative effect on Gag occurrence in the PC survey, which was largely concentrated in the northern WFS. The inclusion of length/age data in subsequent studies could provide insight into this possibility. Regardless of what life history stage(s) drives our results, the contribution of other factors besides depth (e.g., availability of substrate) also may vary with latitude. Large-scale rugosity is greater in the northern WFS (above the 28° latitude mark) due to the shelf's geology (Hansen *et al.* 2008), and the lack of rugosity in more southerly portions of the WFS may limit Gag distribution in those areas.

Hard Coral—Hard coral was present in the confidence models for the FWRI survey, but not for the other two surveys. Historically, extensive mesophotic reefs comprised of hard coral – *Oculina* spp. – served as primary spawning grounds for Gag off the east coast of Florida (Gilmore and Jones 1992; Koenig *et al.* 2000; Reed *et. al* 2005). Mesophotic reefs made from hard coral also exist on the WFS, but are concentrated at depths beyond where Gag are found

(Gil-Agudelo *et al.* 2020). Instead, at depths where Gag reside on the WFS, hard corals occur as part of a mixed epifaunal community (Schroeder *et al.* 20015). Hard coral reefs may provide structural complexity that benefits Gag or their prey species, and that complexity is not present in areas where hard corals are only one part of an epifaunal community. Alternately, the hard coral that are present at historic Gag spawning sites along the Atlantic coast may not actually be important to Gag at all – the effect of hard coral on Gag presence/abundance has not been quantified, and Gag have also been observed using bare rock habitat even on banks where *Oculina* spp. occurs (Gilmore and Jones 1992; Koenig *et al.* 2000). The large confidence interval for the effect of hard coral on Gag occurrence in the FWRI model suggests that the inclusion of hard coral in the confidence models may be the result of just a few sites that featured both hard coral and Gag.

Other Variables: Sea Whip, Algae, and Epifauna—Several other variables that had not been identified in previous literature as important indicators of Gag occurrence were present in some of our confidence models. Most previous studies that have recorded Gag focused on characterizing landscape features and not the epifaunal community. Because the video surveys we analyzed also documented epifaunal community at each site, we can potentially gain insights into how epifauna affects the occurrence of Gag. For instance, in our SEAMAP and PC analyses, our confidence models contained the percent coverage of sea whip (WHIP) as a positive influence on Gag occurrence – there are various potential explanations for this. The appearance of sea whip in our confidence set may be because sea whip distributions are related to rugosity, a measure related to relief (Silva and MacDonald 2017), and that the variable actually has no direct relationship to Gag. However, sea whips themselves do provide relief, which may attract Gag. For example, there is a significant positive correlation between the abundance of fish and coverage of sea whips at artificial reefs in the Mid-Atlantic Bight, (Schweitzer and Stevens 2019). Fish were often found among sea whips, rather than within the artificial reef cavities; prey species drawn to sea whip might in turn attract Gag to that site. Observational studies would be required to further investigate this relationship and ascertain whether Gag directly interact with sea whip.

Algae and epifauna were also identified as being important indicators of Gag habitat and had a negative effect on Gag occurrence. Our findings that Gag occurrence decreased with an increase in percent coverage by algae (ALG) in the SEAMAP survey and in percent coverage by epifauna (EPIF) in the PC survey has not been reported in the literature. Although they did not meet our cutoff of |0.70|, the correlation between algae and epifauna was 0.68 in the PC survey, suggesting that these variables are moderately correlated. Additionally, algae make up a taxonomically and ecological diverse group, and without further classification of the algae at each sample site, determining whether there are specific relationships between some kinds of algae and the presence of Gag would not be possible.

Applications—Information about habitats where Gag occur has direct implications for species management and conservation. Hard bottom habitats with relief have been reported as prime habitat for Gag (Koenig *et al.* 2000, Coleman *et al.* 2011). However, most studies that describe Gag habitat have focused on areas such as the MPAs designed to protect spawning habitat, where Gag are known to occur in high numbers. The spatial extent of our study allowed us to characterize habitat used by Gag across a large part of their range, including many areas where habitat had not been previously studied. Our findings that a positive relationship existed between the occurrence of Gag with both rock and relief reinforce their importance for Gag and confirm that these variables are important for Gag across the whole WFS.

Gag continue to face many pressures including overfishing, which threaten the sustainability of this valuable fishery. Marine Protected Areas can be an effective tool for protecting fish species and helping rebuild stocks (Rossiter and Levine 2013). Several existing MPAs have been designated with the specific goal of protecting Gag spawning aggregations. However, Gag life history requires a variety of habitats, many of which are not currently protected. Our study identified habitat characteristics important to Gag throughout a large portion of the eastern GOM. The creation of new MPAs that protect areas with habitat characteristics (e.g., rocky, high-relief areas in the northern GOM) that positively relate to the occurrence of Gag could be vital to ensuring the sustainability of Gag stocks in the GOM. Additionally, the creation of artificial reefs can provide valuable new habitat to support fish populations (Dupont *et al.* 2008). Although we did not specifically investigate artificial reef substrates, our findings can still be used to help develop man-made reefs with specific Gag-friendly characteristics (e.g., high relief, surfaces that encourage the growth of sea whip). By creating and protecting habitat that attract Gag, fisheries managers can provide ideal habitat to encourage the conservation and growth of Gag populations.

Tables

Table 2.1. Camera array specifications. Data from the Florida Fish and Wildlife Research Institute, National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program, and the NOAA Panama City, FL office fisheries-independent video surveys were used to study the effect of habitat on Gag occurrence in the West Florida Shelf during 2010-2016, 2012-2017, and 2010-2016. For each year we describe the camera array, provide specifications for the camera (including whether it is color, monochrome [mono], and/or high definition [HD]), lens, field of view (FOV), and the software used to view imagery.

Table 2.1. Camera array specifications.

Survey	Year(s)	Array	Video camera	Lens	Horizontal FOV	Viewing software
FWRI	2010-2015	180° apart (2 cameras)	Arecont AV21050DN (color) 1600x1200	Computar H220414C-MP 8 mm	90.4°	LuxRiot digital video recorder
	2016		FLIR BFLY-U3-23S6M-C (mono) 1920x1200	Kowa LM6HC 6 mm	86°	SeaGIS
SEAMAP	2012-2016	Orthogonal (4 cameras)	Arecont AV21050DN (color) 1600x1200	Kowa LM4NCL 3.5mm	74°	LuxRiot digital video recorder
	2017	hemispherical (6 cameras)	FLIR BFLY-U3-23S6M-C (mono) 1920x1200	Kowa LM6HC 6 mm	86°	SeaGIS
PC	2010	orthogonal (4 cameras)	Arecont AV21050DN (color) (x1 camera)	Kowa LM6HC 6 mm	65°	LuxRiot digital video recorder
			Sony HDR-FX (color) HD (x3 cameras)	Built-in 4.5 mm	64°	VLC media player
	2011		Arecont AV21050DN (color) HD (x2 cameras)	Kowa LM6HC 6 mm	65°	LuxRiot digital video recorder
			Sony HDR-FX1 (color) HD (x2 cameras)	Built-in 4.5 mm	64°	VLC media player
	2012-2014		Arecont AV21050DN (color) HD (x2 cameras)	Kowa LM6HC 6 mm	65°	LuxRiot digital video recorder
			GoPro Hero 3 or Hero 3+ (x2 cameras)	Stock lens	cropped to 65°	VLC media player
	2015-2016		Arecont AV21050DN (color) HD (x2 cameras)	Kowa LM6HC 6 mm	65°	SeaGIS
			GoPro Hero 3 or Hero 3+ (x2 cameras)	Stock lens	cropped to 65°	

Table 2.2. Reasons for removal of video samples from analysis. Samples were obtained from fisheries-independent video surveys conducted by the Florida Fish and Wildlife Research Institute (FWRI; 2010-2016), the National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program (2012-2017), and the NOAA Panama City, FL office (PC; 2010-2016) and used to study the effect of habitat on gag occurrence in the West Florida Shelf.

Reasons for removal of samples
• [All surveys] more than 50% of the field of view was obscured by permanent objects (e.g., epifauna or substrate)
• [All surveys] high turbidity (videos in which the substrate-water interface was not visible)
• [All surveys] dark (often caused by lens failing to adjust to surrounding lighting)
• [All surveys] out of focus
• [All surveys] field of view changed more than 90% during recording because of dragging
• [FWRI survey] array not upright

Table 2.3. Variables measured in the FWRI video survey. Definitions of variables measured by the the Florida Fish and Wildlife Research Institute fisheries-independent video survey (2010-2016) and used to evaluate their influence on the occurrence of Gag in the West Florida Shelf. Variables hypothesized to have a positive relationship are indicated with a plus sign (+), and those not thought to have an effect are indicated with a (X). Variables available for backwards stepwise selection are indicated with a (Y) and those not available are indicated with a (N), along with the reason.

Table 2.3. Variables measured in the FWRI video survey.

Variable Name	Definition	Hypothesized effect	Availability for stepwise model
% Rock	Estimated coverage of seafloor by rock (in intervals of 10%). Defined as substrate > 6.35 cm.	+	Y
% Shell	Estimated coverage of seafloor by shell (in intervals of 10%).	X	Y
% Rubble/Pebble	Estimated coverage of seafloor by rubble/pebble (in intervals of 10%). Substrate <6.35 cm and relief ≤0.1 m.	X	Y
% Sand	Estimated coverage of seafloor by sand (in intervals of 10%).	X	N. Highly correlated with % Rock which is more likely to be an important substrate (r = -0.77).
% Dead Coral	Estimated coverage of seafloor by dead coral (in intervals of 10%).	X	N. Low number of observations (<3% of total samples).
% Detritus	Estimated coverage of seafloor by detritus (in intervals of 10%).	X	N. No observations.
% Mud	Estimated coverage of seafloor by mud (in intervals of 10%).	X	N. No observations.
% Unknown Substrate	Estimated coverage of seafloor by unknown substrate (in intervals of 10%).	X	N. No observations.

% Manmade	Estimated coverage of seafloor by manmade substrate (in intervals of 10%).	X	N. Low number of observations (<3% of total samples).
% Total Epifauna	Estimated coverage of seafloor by total epifauna (in intervals of 1%).	X	N. Highly correlated with % Algae which drives the % Total Epifauna (r = 0.87).
% Hard Coral	Estimated coverage of seafloor by hard coral (in intervals of 1%).	+	Y
% Soft Coral	Estimated coverage of seafloor by soft coral (in intervals of 1%).	X	Y
% Sponge	Estimated coverage of seafloor by sponge (in intervals of 1%).	X	Y
% Algae	Estimated coverage of seafloor by algae (in intervals of 1%).	X	Y
% Grass	Estimated coverage of seafloor by seagrass (in intervals of 1%).	X	N. Low number of observations (<3% of total samples).
% Unknown	Estimated coverage of seafloor by unknown epifauna (in intervals of 1%).	X	N. This variable does not provide relevant information about habitat.
Maximum Vertical Relief (m)	Estimate of maximum vertical relief of tallest substrate to 0.1 m.	+	Y
Depth (m)	Depth in m.	+ (higher latitudes)	Y

Longitude (DD)	Longitude in decimal degrees.	X	N. Highly correlated with Latitude which is more likely to drive Gag occurrence (r = -0.85).
Latitude (DD)	Latitude in decimal degrees.	+	Y
Month	Month of sampling.	NA	NA
Year	Year of sampling.	NA	NA

Table 2.4. Variables measured in the SEAMAP video survey. Definitions of variables measured by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program fisheries-independent video survey (2012-2017) and used to evaluate their influence on the occurrence of Gag in the West Florida Shelf. Variables hypothesized to have a positive relationship are indicated with a plus sign (+), and those not thought to have an effect are indicated with a (X). Variables available for backwards stepwise selection are indicated with a (Y) and those not available are indicated with a (N), along with the reason.

Table 2.4. Variables measured in the SEAMAP survey.

Variable Name	Definition	Hypothesized effect	Availability for stepwise model
% Rock	Estimated coverage of seafloor by rock (in intervals of 1%). Defined as solid continuous rock >4 m.	+	Y
% Shell/Gravel	Estimated coverage of seafloor by shell/gravel (in intervals of 1%). Defined as substrates from 2 mm-4 m.	X	Y
% Silt/Sand/Clay	Estimated coverage of seafloor by silt/sand/clay (in intervals of 1%). Defined as particle size <2 mm.	X	N. Highly correlated with % Shell/Gravel which is more likely to be an important substrate (r = -0.74).
% Manmade	Estimated coverage of seafloor by manmade substrate (in intervals of 1%).	X	N. Low number of observations (<3% of total samples).
% Total Epifauna	Estimated coverage of seafloor by total epifauna (in intervals of 1%). Living organism that is attached/sessile to any of the listed substrate types or is loosely lying on the bottom, alive, and not moving (e.g. *Codium* spp., *Sargassum* spp.).	X	N. Highly correlated with % Algae which drives % Total Epifauna (0.75).
% Hard Coral	Estimated coverage of seafloor by hard coral (in intervals of 1%). Hard/stony coral of the order Scleractinia and the Hydrocoral families Milliporidae and Stylasteridae.	+	Y
% Soft Coral	Estimated coverage of seafloor by soft coral (in intervals of 1%). Octocorals and Antipatharians other than the sea whips.	X	Y

% Sponge	Estimated coverage of seafloor by sponge (in intervals of 1%). Any member of the phylum Porifera.	X	Y
% Algae	Estimated coverage of seafloor by algae (in intervals of 1%). Phyla Chlorophyta (green), Phaeophyta (brown) and Rhodophyta (red).	X	Y
% Grass	Estimated coverage of seafloor by seagrass (in intervals of 1%). *Thalassia testudinum, Syringodium filiforme, and Halophila baillonis*.	X	N. No observations.
% Other	Estimated coverage of seafloor by epibenthic organisms (in intervals of 1%). Other identifiable epibenthic organisms. This could include: Mollusks, Crinoids, Tunicates, Anemones, Zooanthids, Corallimorphs, Hydroids, Bryozoans, Tube anemones and Sea pens.	X	Y
% Sea whip	Estimated coverage of seafloor by sea whip (in intervals of 1%). Includes only the Antipatharian *Cirrhipathes (Stichopathes) leutkeni* and the Octocoral genus *Ellisella*.	X	Y
% Unknown	Estimated coverage of seafloor by unknown epifauna (in intervals of 1%). Unidentifiable Epifauna.	X	N. This variable does not provide relevant information about habitat.
Maximum Vertical Relief (m)	Estimate of maximum vertical relief of tallest substrate to 0.1 m.	+	Y
Depth (m)	Depth in m.	+ (higher latitudes)	Y

Longitude (DD)	Longitude in decimal degrees.	X	N. Highly correlated with Latitude which is more likely to drive Gag occurrence (r = -0.83).
Latitude (DD)	Latitude in decimal degrees.	+	Y
Month	Month of sampling.	NA	NA
Year	Year of sampling.	NA	NA

Table 2.5. Variables measured in the PC video survey. Definitions of variables measured by the National Atmospheric and Oceanic Administration Panama City, FL office fisheries-independent video survey (2010-2016) and used to evaluate their influence on the occurrence of Gag in the West Florida Shelf. Variables hypothesized to have a positive relationship are indicated with a plus sign (+), and those not thought to have an effect are indicated with a (X). Variables available for backwards stepwise selection are indicated with a (Y) and those not available are indicated with a (N), along with the reason.

Table 2.5. Variables measured in the PC video survey.

Variable Name	Definition	Hypothesized effect	Availability for stepwise model
% Rock	Estimated coverage of seafloor by rock (in intervals of 1%). Defined as substrate >6.35 cm.	+	Y
% Shell/Gravel	Estimated coverage of seafloor by shell/gravel (in intervals of 1%). Substrate <6.35 cm and relief ≤ 0.1 m.	X	Y
% Silt/Sand/Clay	Estimated coverage of seafloor by silt/sand/clay (in intervals of 1%). Defined as particle size <2mm.	X	Y
% Manmade	Estimated coverage of seafloor by manmade substrate (in intervals of 1%).	X	N. Low number of observations (1% of total samples).
% Total Epifauna	Estimated coverage of seafloor by total epifauna (in intervals of 1%). Living organism that is attached/sessile to any of the listed substrate types or is loosely lying on the bottom, alive, and not moving (e.g. *Codium* spp., *Sargassum* spp.).	X	Y
% Hard Coral	Estimated coverage of seafloor by hard coral (in intervals of 1%). Hard/stony coral of the order Scleractinia and the Hydrocoral families Milliporidae and Stylasteridae.	+	Y
% Soft Coral	Estimated coverage of seafloor by soft coral (in intervals of 1%). Octocorals and Antipatharians other than the sea whips.	X	Y

% Sponge	Estimated coverage of seafloor by sponge (in intervals of 1%). Any member of the phylum Porifera.	X	Y
% Algae	Estimated coverage of seafloor by algae (in intervals of 1%). Phyla Chlorophyta (green), Phaeophyta (brown) and Rhodophyta (red).	X	Y
% Grass	Estimated coverage of seafloor by seagrass (in intervals of 1%). *Thalassia testudinum, Syringodium filiforme, and Halophila baillonis*.	X	N. Low number of observations (<3% of total samples).
% Other	Estimated coverage of seafloor by epibenthic organisms (in intervals of 1%). Other identifiable epibenthic organisms. This could include: Mollusks, Crinoids, Tunicates, Anemones, Zooanthids, Corallimorphs, Hydroids, Bryozoans, Tube anemones and Sea pens.	X	Y
% Sea Whip	Estimated coverage of seafloor by sea whip (in intervals of 1%). Includes only the Antipatharian *Cirrhipathes (Stichopathes) leutkeni* and the Octocoral genus *Ellisella*.	X	Y
% Unknown	Estimated coverage of seafloor by unknown epifauna (in intervals of 1%). Unidentifiable Epifauna.	X	N. This variable does not provide relevant information about habitat.
Maximum Vertical Relief (m)	Estimate of maximum vertical relief of tallest substrate to 0.1 m.	+	Y
Depth (m)	Depth in m.	X	Y
Longitude (DD)	Longitude in decimal degrees.	X	N. Highly correlated with latitude which is more likely to drive Gag occurrence (r = -0.78).

Latitude (DD)	Latitude in decimal degrees.	X	N. Narrow window of latitudes.
Month	Month of sampling.	NA	NA
Year	Year of sampling.	NA	NA

Table 2.6. Sampling periods and effort. Data collected by the Florida Fish and Wildlife Research Institute, the National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program, and the NOAA Panama City, FL office fisheries-independent video surveys during 2010-2016, 2012-2017, and 2010-2016 were used to study the effect of habitat on Gag occurrence in the West Florida Shelf. For each year, we list the months sampled, total number of samples included in analysis (n_{total}), and total number of sites where Gag occurred (n_{occ}).

Survey	Year	Months	n_{total}	n_{occ}
FWRI	2010	Jun.-Jul.	155	2
	2011	Jun.-Sep.	201	13
	2012	Jun.-Sep.	213	11
	2013	Jul.-Oct.	159	2
	2014	Jun.-Oct.	298	13
	2015	May-Oct.	310	8
	2016	May-Aug.	227	22
SEAMAP	2012	Jun.-Aug.	242	33
	2013	Apr.-Jun.	133	18
	2014	Jun.-Aug.	181	13
	2015	May-Sep.	122	15
	2016	May-Jul.	178	6
	2017	May-Jun.	193	11
PC	2010	Jun.-Nov.	122	45
	2011	Jan.-May; Nov.-Dec.	119	36
	2012	May-Oct.	137	13
	2013	Jan.-Feb.; Oct.-Dec.	91	15
	2014	Feb.-Aug.	133	15
	2015	Jan.; Aug.-Dec.	128	7
	2016	Jan.-Mar.	45	3

Table 2.7. Summary table of Akaike's Information Criteria (AIC) for candidate set of logistic regression models used to investigate the relationship between habitat and Gag occurrence in video survey data from the West Florida Shelf collected by the Florida Fish and Wildlife Research Institute video survey (2010-2016). Although not shown, all models include month and year as random effects. The confidence model set, defined as all models whose Akaike weights sum, in descending order, to 0.95, is outlined with a box. The model created using backwards stepwise selection is indicated by double brackets. Variables in these models include percent coverage by hard coral (HCOR), percent coverage by rock (ROCK; substrate >6.35 cm), maximum vertical relief (REL; in m), latitude (LAT; in decimal degrees), and depth (DEP; in m).

Model	K	AIC	Delta AIC	AICWt
[[HCOR + ROCK * REL + LAT + DEP]]	9	535.48	0.00	0.49
HCOR + ROCK * REL + LAT * DEP	10	537.33	1.85	0.19
HCOR + ROCK + LAT * DEP	8	537.83	2.25	0.16
HCOR + ROCK + REL + LAT * DEP	9	537.77	2.29	0.16
REL + LAT * DEP	7	544.45	8.96	0.01
HCOR + ROCK * REL + LAT	8	552.30	16.82	0.00
HCOR + ROCK + REL + LAT	7	552.41	16.92	0.00
HCOR + ROCK + LAT	6	553.53	18.05	0.00
REL + LAT	5	554.89	19.40	0.00
HCOR + ROCK * REL	7	557.71	22.23	0.00
HCOR + ROCK + REL	6	557.89	22.41	0.00
ROCK	4	558.87	23.39	0.00
HCOR + ROCK	5	558.93	23.44	0.00
DEP	4	560.88	25.40	0.00
LAT	4	561.32	25.84	0.00
REL	4	562.14	26.65	0.00
HCOR	4	566.25	30.77	0.00

Table 2.8. Summary table of Akaike's Information Criteria (AIC) for candidate set of logistic regression models used to investigate the relationship between habitat and Gag occurrence in video survey data from the West Florida Shelf collected by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program video survey (2012-2017). Although not shown, all models include month and year as random effects. The confidence model set, defined as all models whose Akaike weights sum, in descending order, to 0.95, is outlined with a box. The model created using backwards stepwise selection is indicated by double brackets. Variables in these models include percent coverage by algae (ALG), percent coverage by sea whip (WHIP), percent coverage by rock (ROCK; substrate >4m), maximum vertical relief (REL; in m), latitude (LAT; in decimal degrees), and depth (DEP; in m).

Model	K	AIC	Delta AIC	AICWt
[[ALG + WHIP + ROCK * REL + LAT + DEP]]	10	538.08	0.00	0.99
HCOR + ROCK * REL + LAT * DEP	10	547.35	9.27	0.01
REL + LAT * DEP	7	549.17	11.09	0.00
HCOR + ROCK + REL + LAT * DEP	9	552.23	14.15	0.00
HCOR + ROCK + REL * LAT	8	563.20	25.12	0.00
HCOR + ROCK * REL + LAT	8	573.41	35.33	0.00
REL + LAT	5	575.31	37.23	0.00
HCOR + ROCK + REL +LAT	7	578.13	40.05	0.00
DEP	4	583.04	44.97	0.00
HCOR + ROCK * REL	7	586.98	48.91	0.00
HCOR + ROCK + LAT	6	588.81	50.73	0.00
REL	4	590.04	51.96	0.00
HCOR + ROCK +REL	6	590.81	52.74	0.00
LAT	4	594.23	56.15	0.00
ROCK	4	601.45	63.37	0.00
HCOR + ROCK	5	602.83	64.75	0.00
HCOR	4	614.85	76.66	0.00

Table 2.9. Summary table of Akaike's Information Criteria (AIC) for candidate set of logistic regression models used to investigate the relationship between habitat and Gag occurrence in video survey data from the West Florida Shelf collected by the National Atmospheric and Oceanic Administration Panama City, FL office video survey (2010-2016). Although not shown, all models include month and year as random effects. The confidence model set, defined as all models whose Akaike weights sum, in descending order, to 0.95, is outlined with a box. The model created using backwards stepwise selection is indicated by double brackets. Variables in these models include percent coverage by epifauna (EPIF), percent coverage by sea whip (WHIP), percent coverage by rock (ROCK), maximum vertical relief (REL; in m), and depth (DEP; in m).

Model	K	AIC	Delta AIC	AICWt
[[EPIF + WHIP + ROCK * REL + DEP]]	9	640.55	0.00	0.99
HCOR + ROCK + REL	6	651.51	10.96	0.00
HCOR + ROCK * REL	7	651.85	11.31	0.00
ROCK	4	652.41	11.86	0.00
HCOR + ROCK	5	654.41	13.86	0.00
REL	4	660.26	19.71	0.00
HCOR	4	671.96	31.42	0.00

Figures

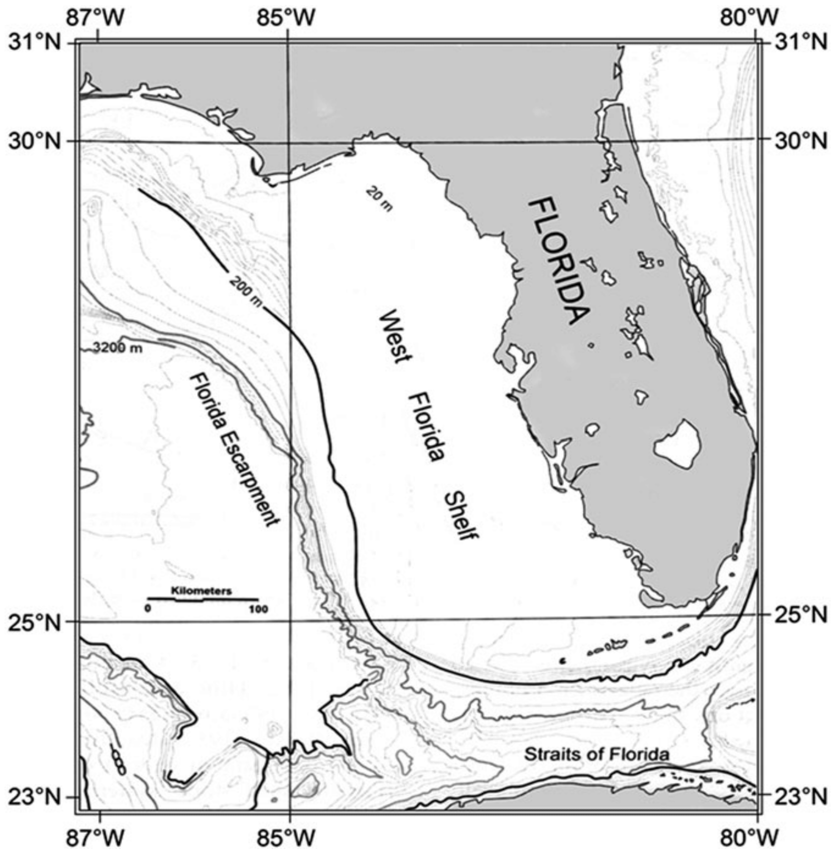

Figure 2.1. Map of the West Florida Shelf in the eastern Gulf of Mexico. From Hine *et al.* (2003).

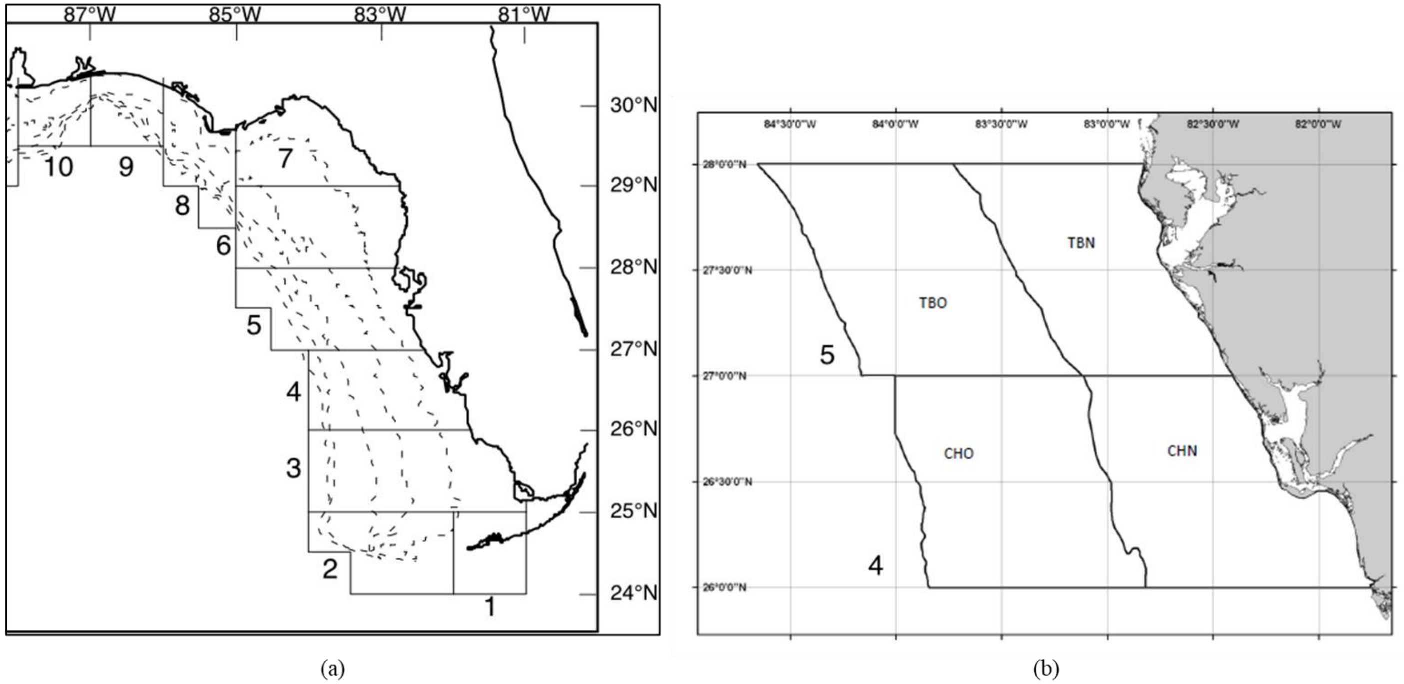

Figure 2.2. Sampling area for the Florida Fish and Wildlife Research Institute (FWRI) video survey.

Figure 2.2. Sampling area for the Florida Fish and Wildlife Research Institute (FWRI) video survey. Sampling area stratified by geographic regions based on the eastern portion of the National Marine Fisheries Service statistical grid (a) and depth (portion of the area shown in b). Data collected from the FWRI video survey was used to study the effect of habitat on the occurrence of Gag in the West Florida Shelf during 2010-2016. In this study, only samples from geographic regions 4-7 and 9-10 were used. Figure 2.2 (b) exemplifies how National Marine Fisheries Service statistical zones 4 [Charlotte Harbor (CH)] & 5 [Tampa Bay(TB)] were divided into depth zones [Nearshore (N): 10-37 m and Offshore (O): >37 m]. Sites consisting of 0.1 x 0.3 nm sampling units known to contain reef were randomly chosen in proportion to the stratum area, and 1-2 camera arrays were then deployed at least 100 m apart for data collection. Figure 2.2 (a) is from https://www.fisheries.noaa.gov/bulletin/request-comments-changes-allowable-fishing-effort-gulf-mexico-commercial-shrimp. Figure 2.2 (b) is modified from Thompson *et al.* (2015).

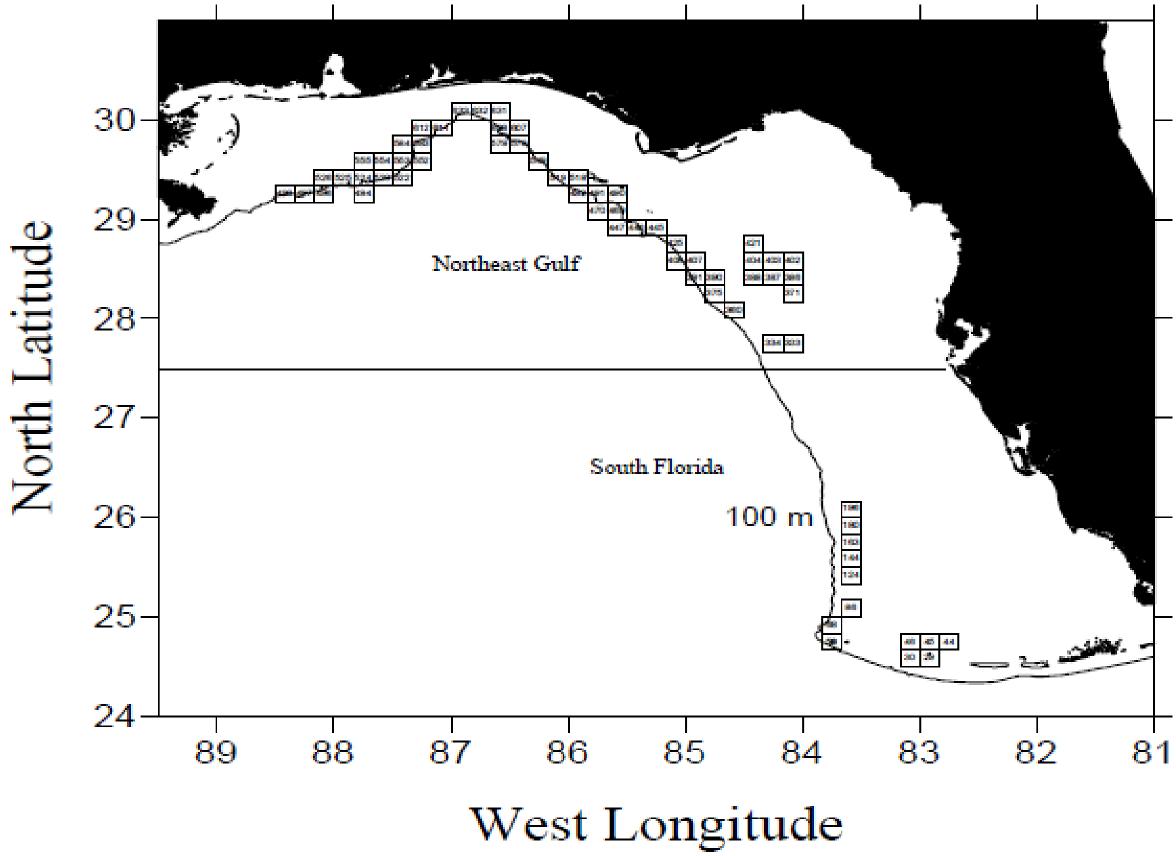

Figure 2.3. Eastern region of the sampling area for the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program's fisheries-independent video survey. Data from this survey were used to study the effect of habitat on the occurrence of Gag in the West Florida Shelf during 2012-2017. The eastern Gulf of Mexico (GOM) region was divided into 10-min latitude x 10-min longitude blocks which were stratified by sub-region (Northeast Gulf and South Florida) and total area of known reef within each block (<20 km^2 or ≥20 km^2). Blocks were then randomly selected based on strata weights which were calculated to reflect the area of known reef within a stratum in proportion to that of the eastern GOM region. Within the blocks, 10 (0.1 x 0.1 nm) sampling units known to have reef were then randomly selected for deployment of camera array. From Campbell *et al*. (2013).

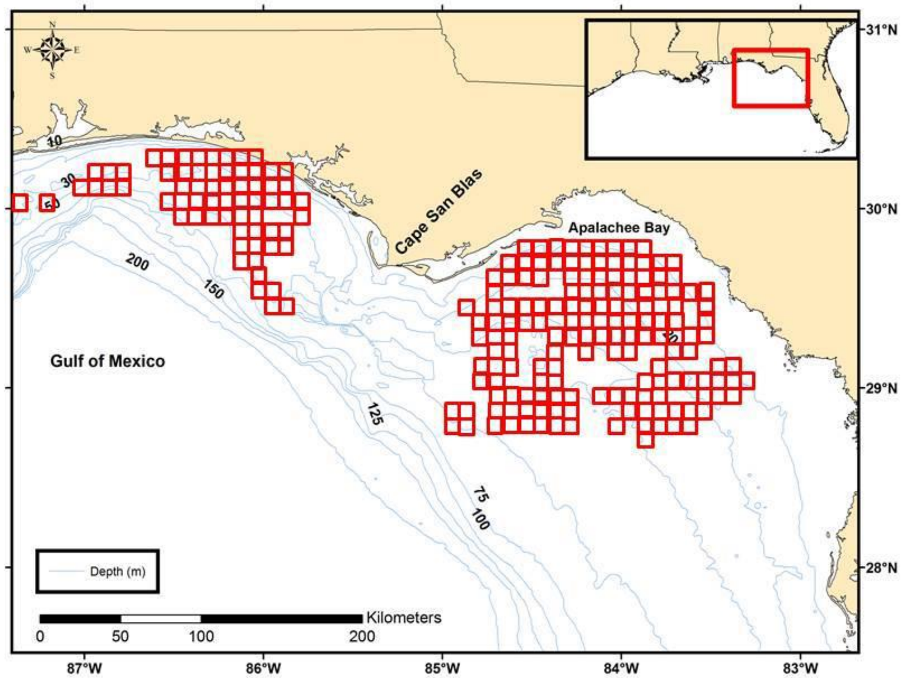

Figure 2.4. Sampling area for the National Atmospheric and Oceanic Administration Panama City, FL office fisheries-independent video survey. Data from this survey were used to study the effect of habitat on the occurrence of Gag in the West Florida Shelf during 2010-2016. Blocks of 5-min latitude x 5-min longitude were stratified by region (east of Cape San Blas and west of Cape San Blas), sub-region, and depth (10-20 m, 20-30 m, >30 m), and randomly selected based on the strata weights, which were calculated to reflect the total area of known reefs within a stratum in proportion to that of its region. Within each block, known reef sites were stratified by habitat quality (Good, Fair, and Poor). Once a block was selected, known reef sites of at least 250 m apart were randomly selected based on strata weights (40% Good, 40% Fair, and 20% Poor). From Gardner *et al*. (2017).

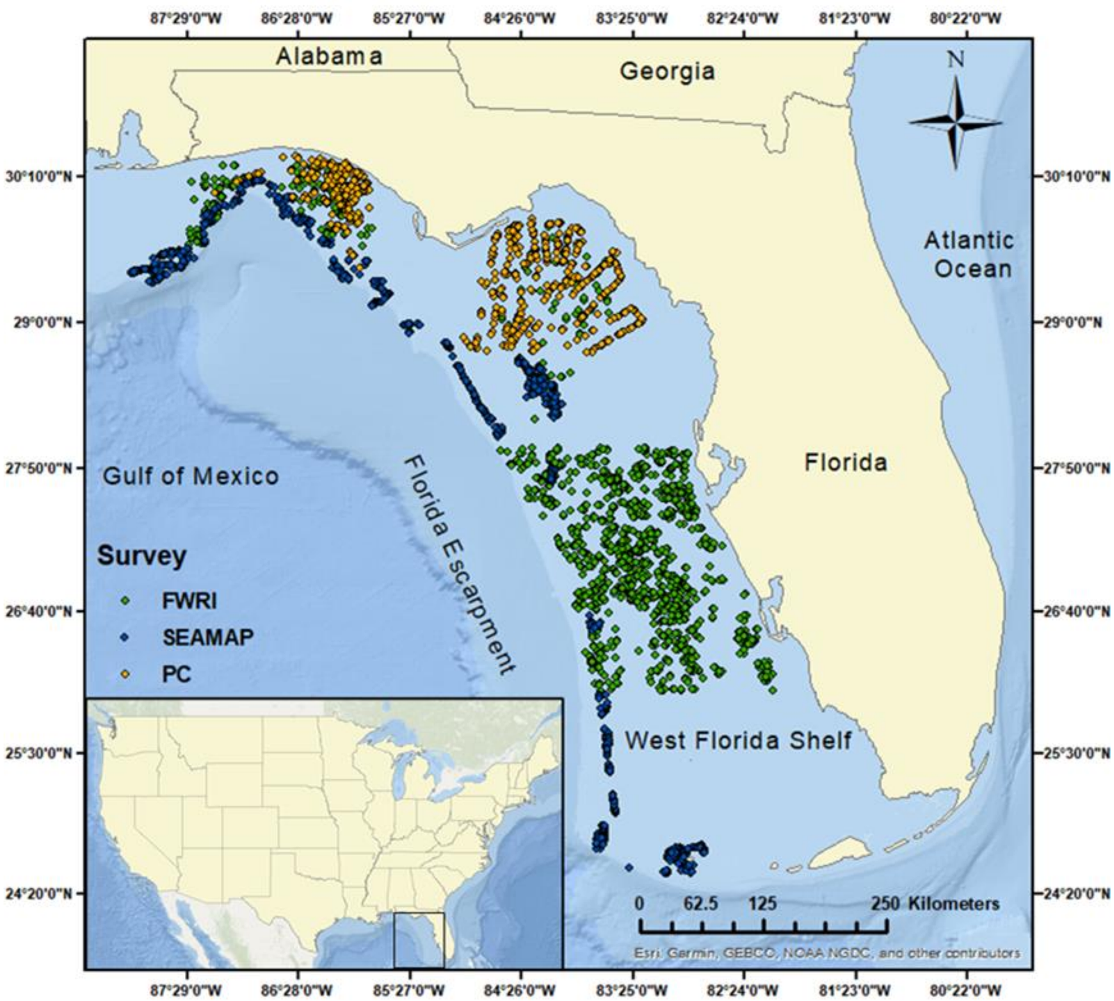

Figure 2.5. Combined sampling distribution of three underwater fisheries-independent video surveys. Video data from 3,387 sites were used to study the effect of habitat on the occurrence of Gag in the West Florida Shelf; sites from each video survey are indicated using different colors. Green points indicate samples from the Florida Fish and Wildlife Research Institute video survey (FWRI), blue indicates samples from the National Atmospheric and Oceanic Administration (NOAA) Southeast Area Monitoring and Assessment Program video survey (SEAMAP), and gold indicates samples from the NOAA Panama City, FL office video survey (PC).

CHAPTER 3
CONCLUSIONS

Throughout the history of Gag management, regulations have been created and adjusted numerous times in an attempt to protect the Gulf of Mexico Gag fishery from overfishing, and later to recover it from being overfished. Nonetheless, these efforts have not proved successful; the status of the Gag fishery remains uncertain and is not likely to improve without further intervention. Current regulations for the Gag fishery were implemented largely as a result of the best available science. However, potentially important information on Gag is still lacking, which makes future management decisions more difficult to justify. In particular, information regarding Gag's use of habitat is relatively scarce when considering their large range and complex life history. A major hindrance on obtaining these types of data has been because a large part of Gag habitat has not been characterized, including the West Florida Shelf, where they are thought to be the most abundant (Koenig *et al*. 1999). Most studies that have investigated Gag habitat have focused at the reef-scale, particularly at reefs where Gag are thought to be more abundant or at the large scale, but at the cost of relying on low-resolution habitat data (Gilmore and Jones 1992; Koenig *et al.* 2000; Lindberg *et al.* 2006; Coleman *et al.* 2011; Gruss et al. 2017, 2018; Switzer *et al.* 2020). Although these data have advanced our understanding of Gag habitat use, a large gap remains in our understanding of the habitat that Gag use – information that is required to guide management decisions such as those regarding spatial management.

To fill this gap, we used fisheries-independent underwater video survey data collected throughout the West Florida Shelf to identify habitat characteristics that were important in determining Gag occurrence. The spatial extent of our study coupled with the use of a groundtruthing method (video cameras) provided a unique opportunity to discern Gag-habitat relationships at a level that had not been done before. Our results (presented in Chapter 2) build upon our knowledge of Gag by showing that many of the variables that previous studies have reported to be important for Gag at the reef scale are in fact also important across the entire WFS. These habitat characteristics are essential to consider when proposing the expansion of current MPAs or creating new ones.

Our study demonstrated that the importance of habitat characteristics such as % coverage of rock (ROCK) and maximum vertical relief (REL) on Gag occurrence is not limited to individual reefs in the WFS, but persists throughout the WFS. Not only do these variables hold true across a large region, but the effects of these habitat characteristics observed/inferred at individual reefs in previous studies (Gilmore and Jones 1992; Koenig *et al.* 2000; Coleman *et al.* 2011; Switzer *et al.* 2020) were also consistent with our results that rock and relief have a positive effect on Gag occurrence. These results highlight the importance of hard bottom and relief as Gag habitat; protection of these habitats are likely to protect Gag given their positive influence. These results also highlight the value in continuing to map the remainder of the WFS where hard bottom habitat likely remains unexplored. Efforts to identify potential Gag habitat would benefit from mapping surveys that identify substrates as well as relief given their importance in predicting the occurrence of Gag.

This study also showed that depth and latitude were important indicators of Gag occurrence. Depth is an important influence on Gag abundance along the WFS edges (Campbell *et al.* 2013). However, our results indicate that the effect of depth on Gag occurrence varied among the three surveys we examined, which suggests a non-linear response. In the PC analysis, the effect of depth on Gag occurrence was negative, whereas the effect was positive for FWRI and SEAMAP surveys. Although this study did not differentiate among lengths/ages, the surveys could have been biased in sampling certain life history stages as is most likely true in the PC survey (DeVries *et al.* 2013). If this is the case, then the differences in the effect of depth could be a reflection of the respective depth preferences of the life history stages. When designing MPAs, or spatial regulations in general, the depth should be considered if aiming to maximize survival of a certain life history stage.

Similar to the findings of other studies that used fisheries-dependent data to map the distribution of Gag, our results from fisheries-independent data showed that the likelihood of Gag occurrence increases with an increase in latitude. Our results emphasize the importance of current conservation efforts in the northern GOM where major spawning and nursery habitat are protected. The data from our study also showed that the effect of depth has less of an influence on Gag as latitudes increased. This may be because at higher latitudes, Gag are more widely distributed and less constrained by depth as shown in other studies that used fisheries-dependent data (Gruss *et al.* 2017, 2018). Adult Gag were predicted to be found at varying depths in the Big Bend region of Florida (Gruss *et al.* 2017, 2018). Additionally, marine juveniles were more likely to occur at depths (<50 m) in the Big Bend compared to anywhere else in Florida (Gruss *et al.* 2017, 2018). Our findings of the increase in likelihood of Gag occurrence with increasing latitudes, coupled with the reduced effect of depth with increasing latitudes suggests that the northern GOM might contain more suitable habitat for Gag overall. In fact, bathymetry maps show increased rugosity in the northern WFS due to the geology of the shelf and, if Gag are drawn to areas with rocky relief, the lack of this favorable substrate in the southerly portions of the WFS might limit their distribution. Regardless of what controls distribution of Gag in the northern GOM, additional MPAs in the northern GOM might greatly benefit Gag overall.

Our results show that overall, the association between Gag and certain habitat characteristics at isolated reefs, and within the fisheries, also holds true across the WFS. Habitat with the greatest coverage of rock and relief and located in higher latitudes at various depths are likely to support more Gag than areas without those characteristics. As the status of Gag remain uncertain, the creation of MPAs designated to protect habitat where Gag are most likely to occur could help alleviate the negative pressures that impede the health of the population. However, management decisions that restrict fishing or other potential threats are less likely to occur without evidence that supports their enactment. Until now, fisheries-independent studies that used high-resolution habitat data were limited spatially. Our findings provide evidence of the relationship between Gag and habitat throughout the WFS; therefore, managers can apply this information to decisions that affect areas throughout the WFS.

Our results also emphasize the importance in characterizing the rest of the WFS habitat. As indicated by the confidence models of all analyses, throughout the WFS Gag occurrence is affected by depth, latitude, substrate, and relief – this underscores the importance of mapping efforts that measure these variables. In addition to protecting existing Gag habitat, the creation of artificial reefs can provide valuable new habitat to support fish populations (Dupont *et al.* 2008). Although we did not specifically investigate artificial reef substrates, our findings can still be used to help develop man-made reefs with specific Gag-friendly characteristics (e.g., high relief). By creating and protecting habitat that attract Gag, fisheries managers can provide ideal habitat to encourage the conservation and growth of Gag populations.

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APPENDICES

Tables

Table A1. Coefficients from the confidence set of logistic regression models constructed using Florida Fish and Wildlife Research Institute video survey data to investigate the effect of habitat on Gag occurrence in the West Florida Shelf. Models are numbered in order from their lowest Akaike's Information Criteria (AIC) value (Model 1) to their highest AIC value (Model 4). Standard deviation estimates are reported for random effects (month and year) and are indicated by ($^{+}$). All fixed effect variables have been centered around the mean.

	Model 1	Model 2	Model 3	Model 4
Variable	Coefficient	Coefficient	Coefficient	Coefficient
Intercept	-3.4671	-3.4803	-3.4990	-3.5069
Month^{+}	0.6453	0.6423	0.6613	0.6474
Year^{+}	0.7234	0.7265	0.7130	0.7242
Relief	0.4192	0.4106		0.2632
Rock	0.7694	0.7650	0.7323	0.5864
Relief * Rock	-0.3612	-0.3474		
Latitude	0.9869	0.9988	0.9949	0.9890
Depth	1.1524	1.1718	1.1889	1.1574
Latitude * Depth		-0.2024	-0.3238	-0.3230
Hard Coral	0.2661	0.2666	0.2611	0.2691

Table A2. Coefficients from the confidence logistic regression model constructed using National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program video survey data to investigate the effect of habitat on Gag occurrence in the West Florida Shelf. Standard deviation estimates are reported for random effects (month and year) and are indicated by ($^{+}$). All fixed effect variables have been centered around the mean.

Variable	Coefficient
Intercept	-3.0057
Month^{+}	0.4412
Year^{+}	0.1993
Relief	0.9349
Rock	0.5056
Relief * Rock	-0.5807
Latitude	0.8361
Depth	1.2550
Sea Whip	0.4407
Algae	-0.8739

Table A3. Coefficients from the confidence logistic regression model constructed using National Atmospheric and Oceanic Administration Panama City, FL office video survey data to investigate the effect of habitat on Gag occurrence in the West Florida Shelf. Standard deviation estimates are reported for random effects (month and year) and are indicated by ($^{+}$). All fixed effect variables have been centered around the mean.

Variable	Coefficient
Intercept	-1.8541
Month^{+}	0.2916
Year^{+}	0.6454
Relief	0.5593
Rock	0.8000
Relief * Rock	-0.5437
Latitude	0.8361
Depth	-0.6688
Sea Whip	0.4553
Epifauna	-0.4761

Figures

	LON	SCOR	HCOR	SPON	EPIF	ALG	GRAS	ROCK	REL	SAND	DEP	DEAD	RUB	LAT	SHEL	MAN	UNK
LON	1	0.1	0.03	0.04	0.08	0	0.06	0.03	-0.03	0.06	-0.3	-0.07	-0.1	-0.85	-0.07	-0.08	0.03
SCOR	0.1	1	0.05	0.18	0.3	0.05	0.04	0.21	0.07	-0.18	-0.11	0	-0.02	-0.06	0.04	-0.02	0.02
HCOR	0.03	0.05	1	0.08	0.21	0.11	0.02	0.18	0.06	-0.14	-0.1	0.01	0	0.04	-0.02	-0.01	-0.02
SPON	0.04	0.18	0.08	1	0.52	0.25	0.16	0.22	0.05	-0.24	-0.17	0.01	0.16	0.06	0	-0.03	0.01
EPIF	0.08	0.3	0.21	0.52	1	0.87	0.15	0.31	0.13	-0.32	-0.16	0.01	0.09	0.02	0.05	-0.03	0.1
ALG	0	0.05	0.11	0.25	0.87	1	0.02	0.2	0.07	-0.19	-0.04	-0.01	0.01	0.02	0.03	-0.02	0.02
GRAS	0.06	0.04	0.02	0.16	0.15	0.02	1	0.09	0.05	-0.07	-0.09	-0.01	0.03	0.02	-0.03	-0.01	-0.02
ROCK	0.03	0.21	0.18	0.22	0.31	0.2	0.09	1	0.47	-0.77	-0.13	0.02	-0.07	0.04	-0.07	-0.03	0.04
REL	-0.03	0.07	0.06	0.05	0.13	0.07	0.05	0.47	1	-0.4	-0.04	0.02	0.08	0.04	-0.05	0.13	0.08
SAND	0.06	-0.18	-0.14	-0.24	-0.32	-0.19	-0.07	-0.77	-0.4	1	0.14	-0.08	-0.32	-0.12	-0.45	-0.06	-0.03
DEP	-0.3	-0.11	-0.1	-0.17	-0.16	-0.04	-0.09	-0.13	-0.04	0.14	1	-0.02	-0.01	-0.13	-0.04	-0.05	-0.07
DEAD	-0.07	0	0.01	0.01	0.01	-0.01	-0.01	0.02	0.02	-0.08	-0.02	1	0.1	0.09	0.01	0	-0.01
RUB	-0.1	-0.02	0	0.16	0.09	0.01	0.03	-0.07	0.08	-0.32	-0.01	0.1	1	0.11	-0.04	0	0
LAT	-0.85	-0.06	0.04	0.06	0.02	0.02	0.02	0.04	0.04	-0.12	-0.13	0.09	0.11	1	0.06	0.1	0.01
SHEL	-0.07	0.04	-0.02	0	0.05	0.03	-0.03	-0.07	-0.05	-0.45	-0.04	0.01	-0.04	0.06	1	0.02	-0.01
MAN	-0.08	-0.02	-0.01	-0.03	-0.03	-0.02	-0.01	-0.03	0.13	-0.06	-0.05	0	0	0.1	0.02	1	0.08
UNK	0.03	0.02	-0.02	0.01	0.1	0.02	-0.02	0.04	0.08	-0.03	-0.07	-0.01	0	0.01	-0.01	0.08	1

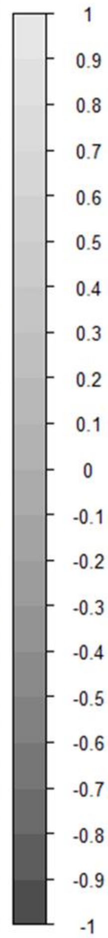

Figure A1. Correlation coefficients from the FWRI analysis.

Figure A1. Correlation coefficients from the FWRI analysis. Pearson correlation coefficients of continuous variables measured in the video survey conducted by the Florida Fish and Wildlife Research Institute. Variables with a correlation coefficient greater than 0.70 or less than -0.70 are considered highly correlated. The strength and direction of the correlation coefficients are also indicated by the shading of the values' text (the shading increases with a decrease in number). Variables ran in the analysis include longitude (LON), percent coverage by soft coral (SCOR), percent coverage by hard coral (HCOR), percent coverage by sponge (SPON), percent coverage by epifauna (EPIF), percent coverage by algae (ALG), percent coverage by seagrass (GRAS), percent coverage by rock (ROCK; substrate >6.35 cm), maximum vertical relief (REL), percent coverage by sand (SAND), depth (DEP), percent coverage by dead coral (DEAD), percent coverage by rubble/pebble (RUB; substrate <6.35 cm and relief ≤ 0.1 m), latitude (LAT), percent coverage by shell (SHEL), percent coverage by manmade substrate (MAN), and percent coverage by unknown epifauna (UNK). Percent coverage by detritus, mud, and unknown substrate were omitted because there were no observations.

	SAND	OTH	WHIP	LAT	DEP	MAN	HCOR	ROCK	REL	LON	EPIF	ALG	SPON	SCOR	SHEL	UNK
SAND	1	0	-0.14	0.03	0.18	-0.04	-0.05	-0.51	-0.4	-0.03	-0.23	-0.02	-0.23	-0.25	-0.74	-0.25
OTH	0	1	0.03	0.03	0.04	-0.01	-0.02	0.01	0.03	-0.05	-0.01	-0.04	-0.02	0.02	0	-0.01
WHIP	-0.14	0.03	1	0.24	0.21	-0.02	-0.04	0.18	0.23	-0.3	0.04	-0.17	-0.03	0.24	0.02	0.11
LAT	0.03	0.03	0.24	1	0.34	0.05	-0.1	0.2	0.14	-0.83	-0.43	-0.42	-0.12	-0.08	-0.2	-0.1
DEP	0.18	0.04	0.21	0.34	1	0.04	-0.21	0.02	-0.07	-0.52	-0.43	-0.24	-0.42	-0.3	-0.22	-0.05
MAN	-0.04	-0.01	-0.02	0.05	0.04	1	-0.01	0.05	0.12	-0.06	-0.02	-0.02	-0.02	0	0	0.02
HCOR	-0.05	-0.02	-0.04	-0.1	-0.21	-0.01	1	0.11	0.17	0.13	0.29	-0.04	0.21	0.11	-0.03	0.04
ROCK	-0.51	0.01	0.18	0.2	0.02	0.05	0.11	1	0.53	-0.25	0.05	-0.11	0.07	0.16	-0.2	0.1
REL	-0.4	0.03	0.23	0.14	-0.07	0.12	0.17	0.53	1	-0.18	0.14	-0.11	0.17	0.26	0.05	0.21
LON	-0.03	-0.05	-0.3	-0.83	-0.52	-0.06	0.13	-0.25	-0.18	1	0.45	0.42	0.22	0.08	0.23	0.11
EPIF	-0.23	-0.01	0.04	-0.43	-0.43	-0.02	0.29	0.05	0.14	0.45	1	0.75	0.4	0.47	0.23	0.19
ALG	-0.02	-0.04	-0.17	-0.42	-0.24	-0.02	-0.04	-0.11	-0.11	0.42	0.75	1	0.07	-0.12	0.11	-0.09
SPON	-0.23	-0.02	-0.03	-0.12	-0.42	-0.02	0.21	0.07	0.17	0.22	0.4	0.07	1	0.32	0.21	0.2
SCOR	-0.25	0.02	0.24	-0.08	-0.3	0	0.11	0.16	0.26	0.08	0.47	-0.12	0.32	1	0.16	0.08
SHEL	-0.74	0	0.02	-0.2	-0.22	0	-0.03	-0.2	0.05	0.23	0.23	0.11	0.21	0.16	1	0.21
UNK	-0.25	-0.01	0.11	-0.1	-0.05	0.02	0.04	0.1	0.21	0.11	0.19	-0.09	0.2	0.08	0.21	1

Figure A2. Correlation coefficients from the SEAMAP analysis.

Figure A2. Correlation coefficients from the SEAMAP analysis. Pearson correlation coefficients of continuous variables measured in the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program. Variables with a correlation coefficient greater than 0.70 or less than -0.70 are considered highly correlated. The strength and direction of the correlation coefficients are also indicated by the shading of the values' text (the shading increases with a decrease in number). Variables ran in the analysis include percent coverage by silt/sand/clay (SAND; particle size <2 mm), percent coverage by other epibenthic organisms (OTH), percent coverage by sea whip (WHIP), latitude (LAT), depth (DEP), percent coverage by manmade substrate (MAN), percent coverage by hard coral (HCOR), percent coverage by rock (ROCK; substrate >4 m), maximum vertical relief (REL), longitude (LON), percent coverage by epifauna (EPIF), percent coverage by algae (ALG), percent coverage by sponge (SPON), percent coverage by soft coral (SCOR), percent coverage by shell/gravel (SHEL; 2 mm-4 m), and percent coverage by unknown epifauna (UNK). Percent coverage by seagrass was omitted because there were no observations.

	ROCK	REL	LAT	HCOR	UNK	SPON	SCOR	WHIP	GRAS	LON	EPIF	ALG	DEP	SHEL	OTH	SAND	MAN
ROCK	1	0.38	0.15	0.1	-0.1	0.09	-0.03	-0.08	-0.05	-0.14	-0.13	-0.18	0.02	-0.23	0.12	-0.61	-0.02
REL	0.38	1	0.1	0.1	-0.01	0.2	0.08	0	-0.01	-0.04	0.07	-0.05	-0.11	-0.16	0.03	-0.29	0.04
LAT	0.15	0.1	1	0.11	0.03	-0.03	-0.05	-0.05	-0.01	-0.78	-0.06	-0.07	-0.04	-0.06	-0.04	-0.04	-0.04
HCOR	0.1	0.1	0.11	1	0.09	0.21	0.06	-0.01	-0.02	-0.08	0.19	-0.04	-0.04	-0.01	-0.04	-0.21	-0.03
UNK	-0.1	-0.01	0.03	0.09	1	0.11	0.04	-0.03	0.03	-0.01	0.41	-0.02	-0.02	0.02	-0.16	-0.22	-0.07
SPON	0.09	0.2	-0.03	0.21	0.11	1	0.3	-0.01	0.22	0.07	0.55	0.08	-0.07	-0.11	-0.07	-0.41	-0.07
SCOR	-0.03	0.08	-0.05	0.06	0.04	0.3	1	-0.05	-0.02	0.19	0.4	0.01	-0.2	-0.1	0.02	-0.21	-0.04
WHIP	-0.08	0	-0.05	-0.01	-0.03	-0.01	-0.05	1	-0.01	0.09	0.23	0.02	-0.09	-0.04	-0.03	-0.09	-0.01
GRAS	-0.05	-0.01	-0.01	-0.02	0.03	0.22	-0.02	-0.01	1	0.02	0.14	0.04	-0.03	0	-0.01	-0.06	0
LON	-0.14	-0.04	-0.78	-0.08	-0.01	0.07	0.19	0.09	0.02	1	0.18	0.12	-0.55	-0.07	0.11	0.02	0.04
EPIF	-0.13	0.07	-0.06	0.19	0.41	0.55	0.4	0.23	0.14	0.18	1	0.68	-0.2	-0.09	-0.04	-0.56	-0.11
ALG	-0.18	-0.05	-0.07	-0.04	-0.02	0.08	0.01	0.02	0.04	0.12	0.68	1	-0.1	-0.02	-0.08	-0.33	-0.06
DEP	0.02	-0.11	-0.04	-0.04	-0.02	-0.07	-0.2	-0.09	-0.03	-0.55	-0.2	-0.1	1	0.19	-0.12	0.03	0
SHEL	-0.23	-0.16	-0.06	-0.01	0.02	-0.11	-0.1	-0.04	0	-0.07	-0.09	-0.02	0.19	1	-0.09	-0.21	-0.03
OTH	0.12	0.03	-0.04	-0.04	-0.16	-0.07	0.02	-0.03	-0.01	0.11	-0.04	-0.08	-0.12	-0.09	1	-0.03	-0.02
SAND	-0.61	-0.29	-0.04	-0.21	-0.22	-0.41	-0.21	-0.09	-0.06	0.02	-0.56	-0.33	0.03	-0.21	-0.03	1	0.01
MAN	-0.02	0.04	-0.04	-0.03	-0.07	-0.07	-0.04	-0.01	0	0.04	-0.11	-0.06	0	-0.03	-0.02	0.01	1

Figure A3. Correlation coefficients from the PC analysis.

Figure A3. Correlation coefficients from the PC analysis. Pearson correlation coefficients of continuous variables measured in the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office. Variables with a correlation coefficient greater than 0.70 or less than -0.70 are considered highly correlated. The strength and direction of the correlation coefficients are also indicated by the shading of the values' text (the shading increases with a decrease in number). Variables ran in the analysis include percent coverage by rock (ROCK; substrate >6.35 cm), maximum vertical relief (REL), latitude (LAT), percent coverage by hard coral (HCOR), percent coverage by unknown epifauna (UNK), percent coverage by sponge (SPON), percent coverage by soft coral (SCOR), percent coverage by sea whip (WHIP), percent coverage by seagrass (GRAS), longitude (LON), percent coverage by epifauna (EPIF), percent coverage by algae (ALG), depth (DEP), percent coverage by shell/gravel (SHEL; substrate <6.35 cm and relief ≤0.1 m), percent coverage by other epibenthic organisms (OTH), percent coverage by silt/sand/clay (SAND), and percent coverage of manmade substrate (MAN).

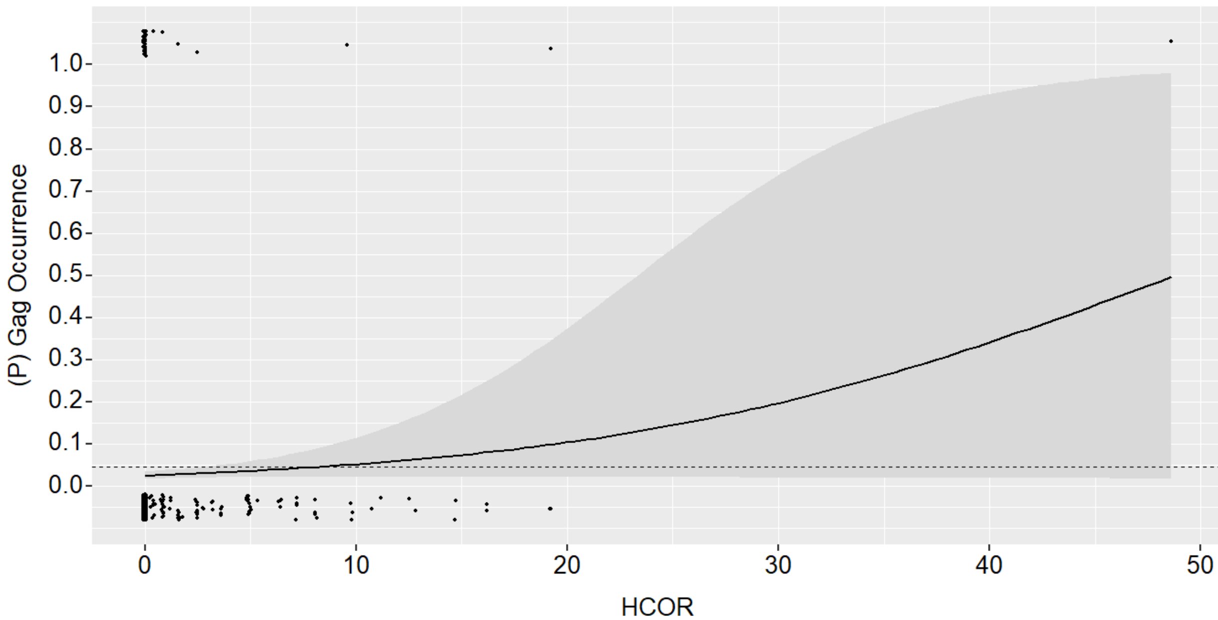

Figure A4. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by hard coral (HCOR; estimated in 1% bins). Data are from the video survey conducted by the Florida Fish and Wildlife Research Institute (FWRI) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top FWRI model that ran without random variables, and predictions for the effect of HCOR were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the FWRI survey (0.05) is indicated by the dashed horizontal line.

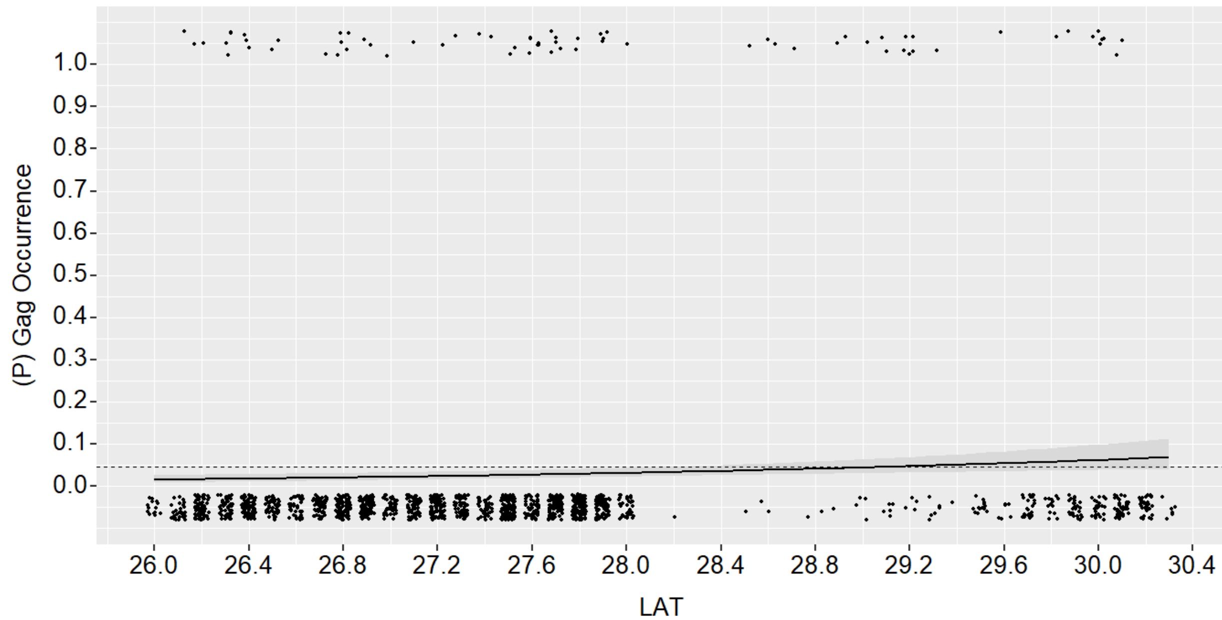

Figure A5. Logistic regression predicting the probability (P) of Gag occurrence in relation to latitude (LAT; in 0.1-decimal degree bins). Data are from the video survey conducted by the Florida Fish and Wildlife Research Institute (FWRI) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top FWRI model that ran without random variables, and predictions for the effect of LAT were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the FWRI survey (0.05) is indicated by the dashed horizontal line.

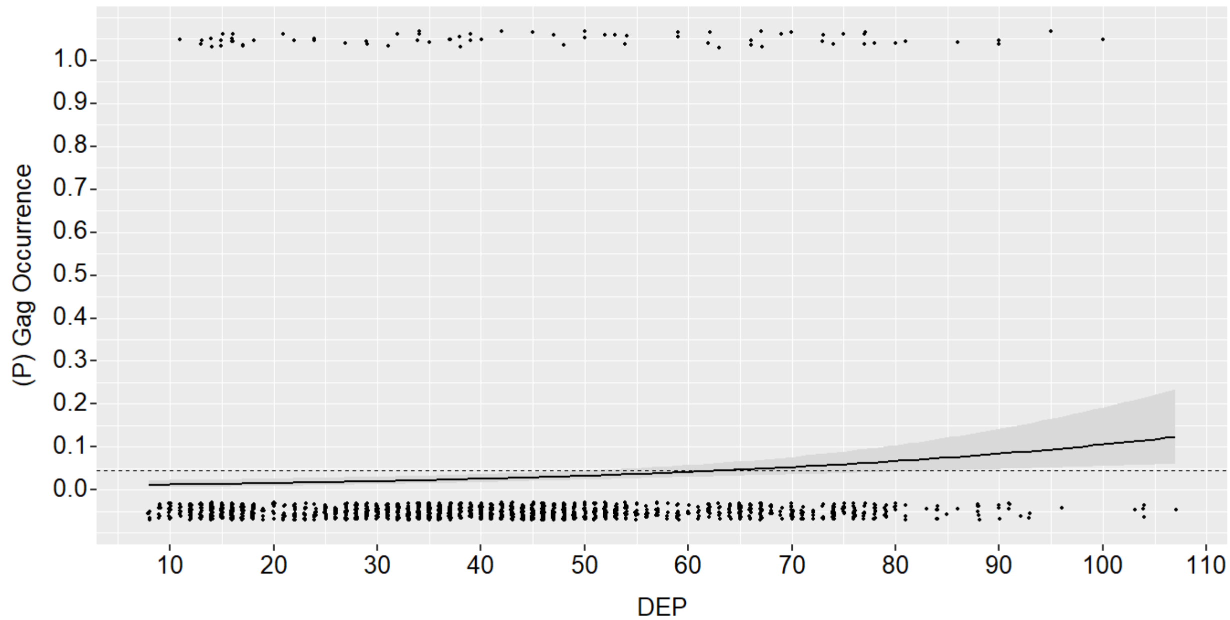

Figure A6. Logistic regression predicting the probability (P) of Gag occurrence in relation to depth (DEP; in 1-m bins). Data are from the video survey conducted by the Florida Fish and Wildlife Research Institute (FWRI) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top FWRI model that ran without random variables, and predictions for the effect of DEP were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the FWRI survey (0.05) is indicated by the dashed horizontal line.

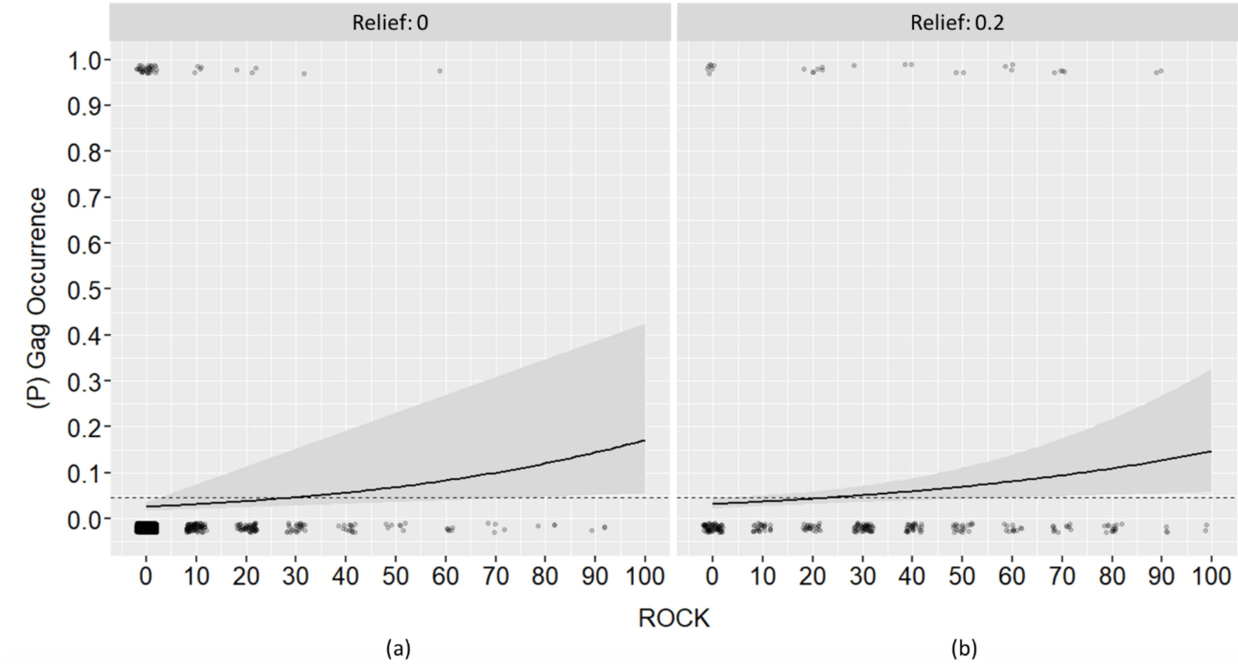

Figure A7. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by rock (ROCK; substrate >6.35 cm; estimated in 10% bins) interacting with maximum vertical relief (REL; estimated in 0.1-m bins). REL value in (a) is based on the 10th and 50th percentile of REL (both are 0 m), and in (b) is based on the 90th percentile of REL (0.2 m). Data are from the video survey conducted by the Florida Fish and Wildlife Research Institute (FWRI) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top FWRI model that ran without random variables, and predictions for the effect of ROCK were made by holding variables other than REL constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the FWRI survey (0.05) is indicated by the dashed horizontal line.

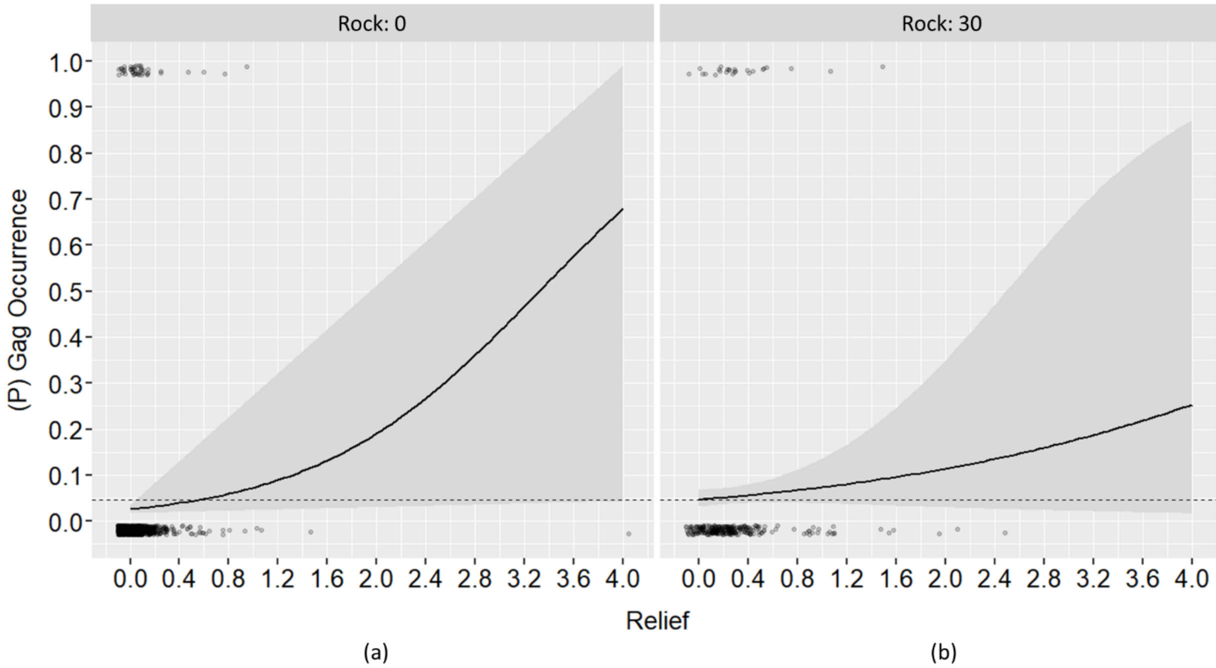

Figure A8. Logistic regression predicting the probability (P) of Gag occurrence in relation to the maximum vertical relief (REL; estimated in 0.1-m bins) interacting with percent coverage by rock (ROCK; substrate >6.35 cm; estimated in 10% bins). ROCK value in (a) is based on the 10th and 50th percentile of ROCK (both are 0%), and in (b) is based on the 90th percentile of ROCK (30%). Data are from video surveys conducted by the Florida Fish and Wildlife Research Institute (FWRI) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top FWRI model that ran without random variables, and predictions for the effect of REL were made by holding variables other than ROCK constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the FWRI survey (0.05) is indicated by the dashed horizontal line.

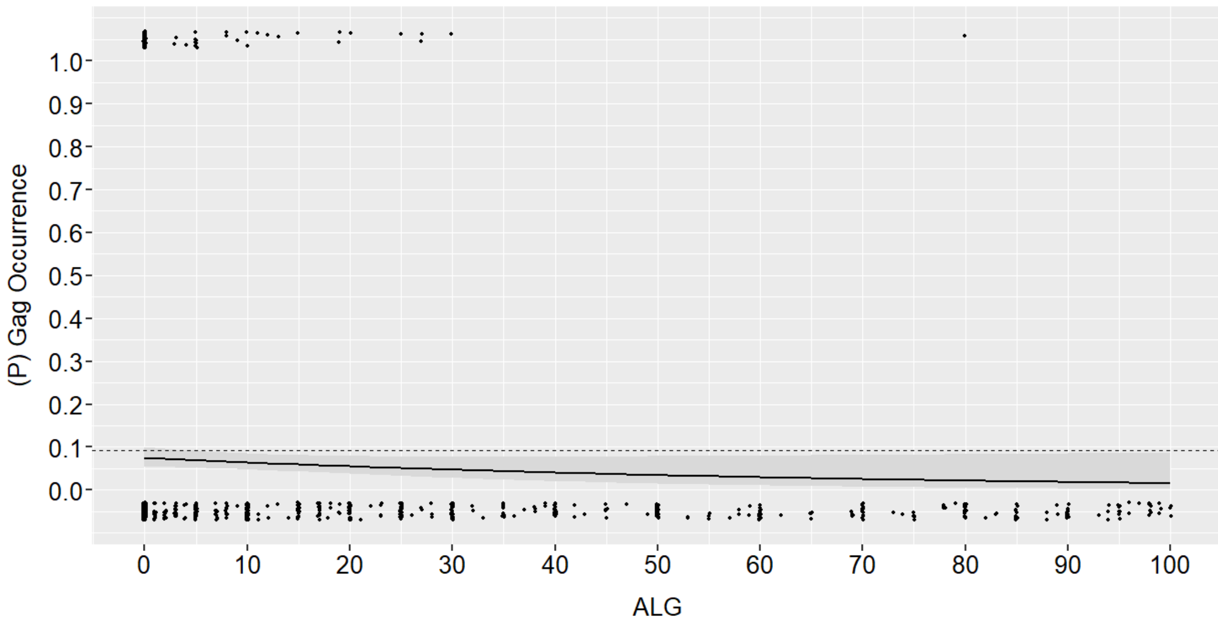

Figure A9. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by ALG (ALG; estimated in 1% bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of ALG were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

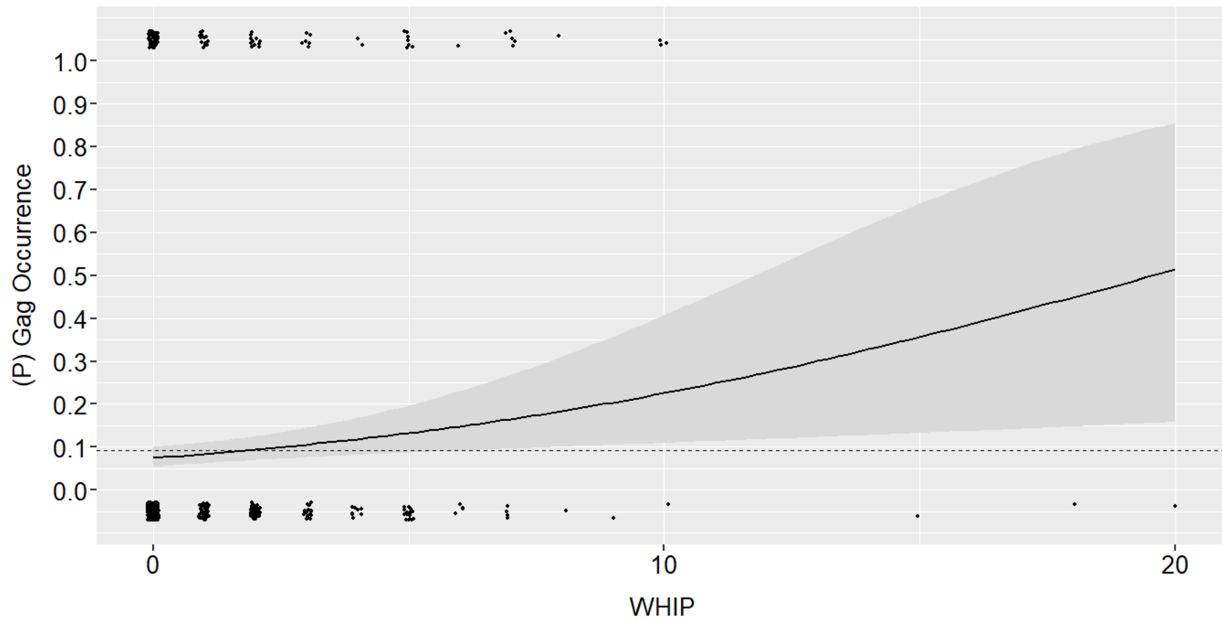

Figure A10. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by sea whip (WHIP; estimated in 1% bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of WHIP were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

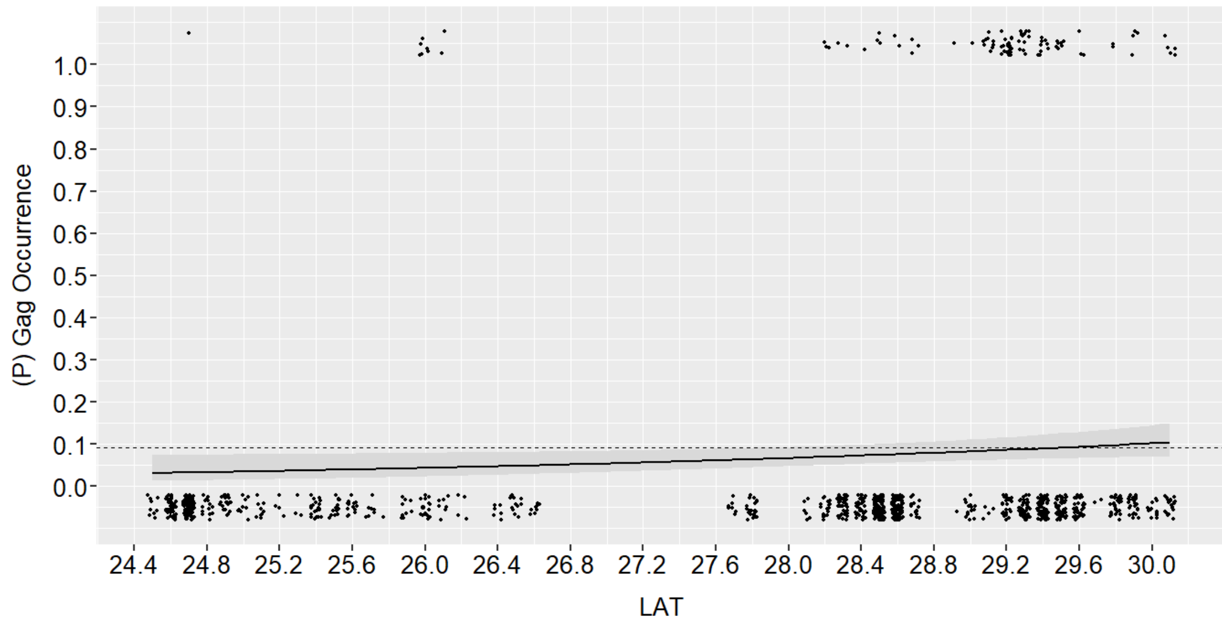

Figure A11. Logistic regression predicting the probability (P) of Gag occurrence in relation to latitude (LAT; in 0.1-decimal degree bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of LAT were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

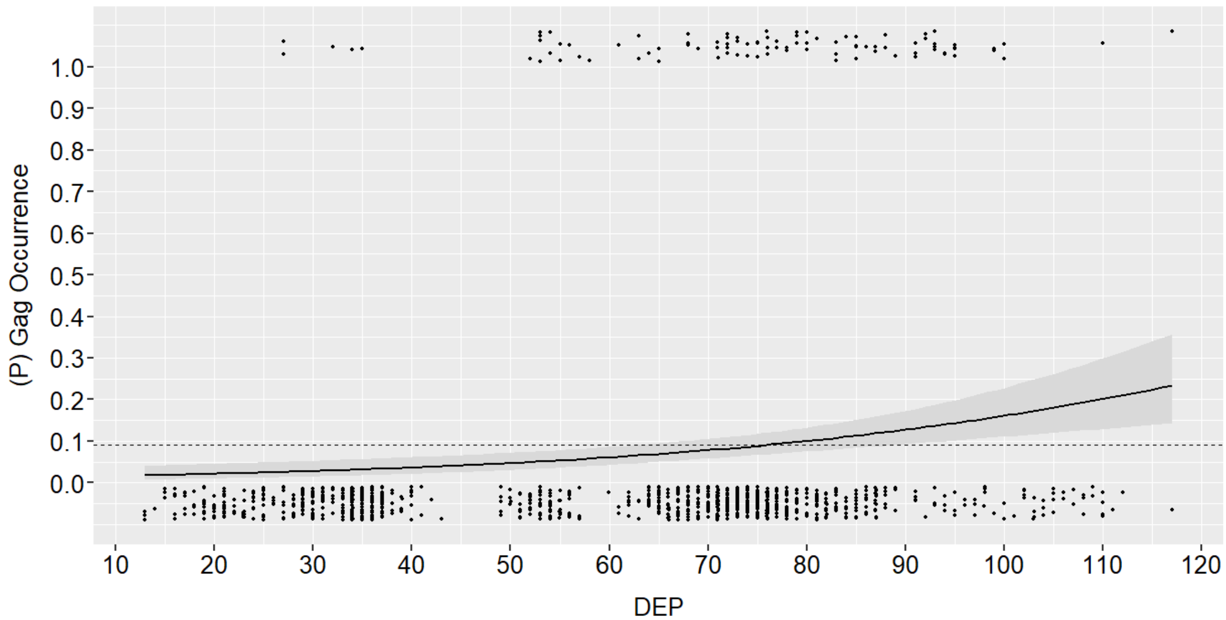

Figure A12. Logistic regression predicting the probability (P) of Gag occurrence in relation to depth (DEP; in 1-m bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of DEP were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

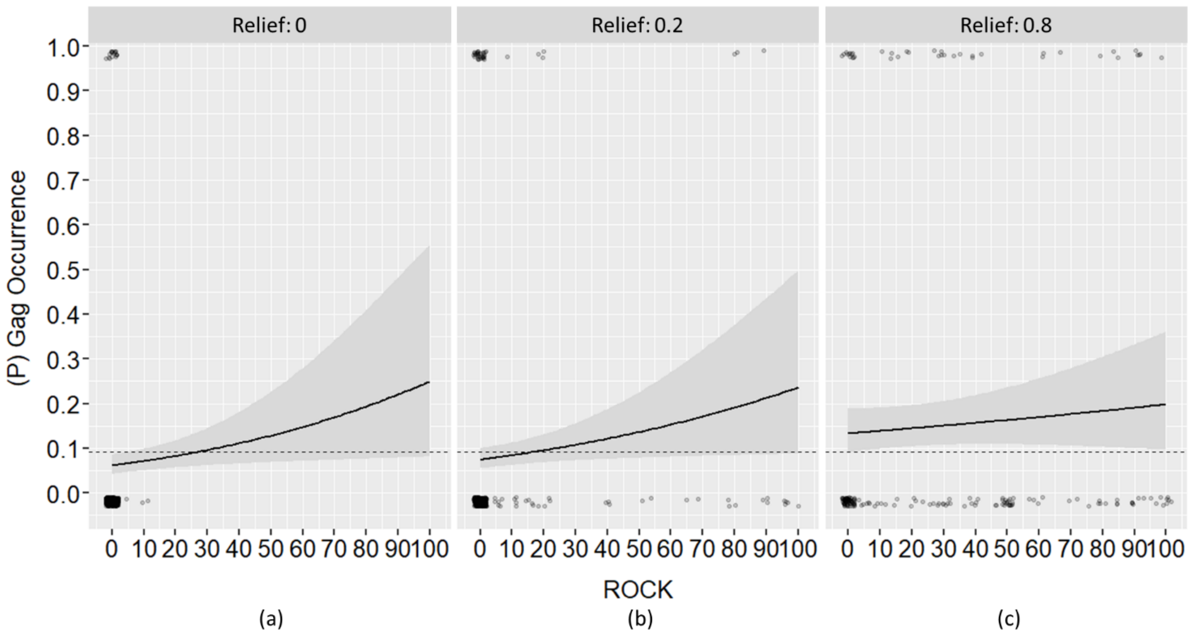
Relief: 0
Relief: 0.2
Relief: 0.8
(P) Gag Occurrence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100
ROCK
(a)
(b)
(c)

Figure A13.

Figure A13. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by rock (ROCK; continuous rock >4 m; estimated in 1% bins) interacting with maximum vertical relief (REL; in 0.1-m bins). REL value in (a) is based on the 10^{th} percentile of REL (0 m), in (b) is based on the 50^{th} percentile of REL (0.2 m), and in (c) is based on the 90^{th} percentile of REL (0.8 m). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of ROCK were made by holding variables other than REL constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

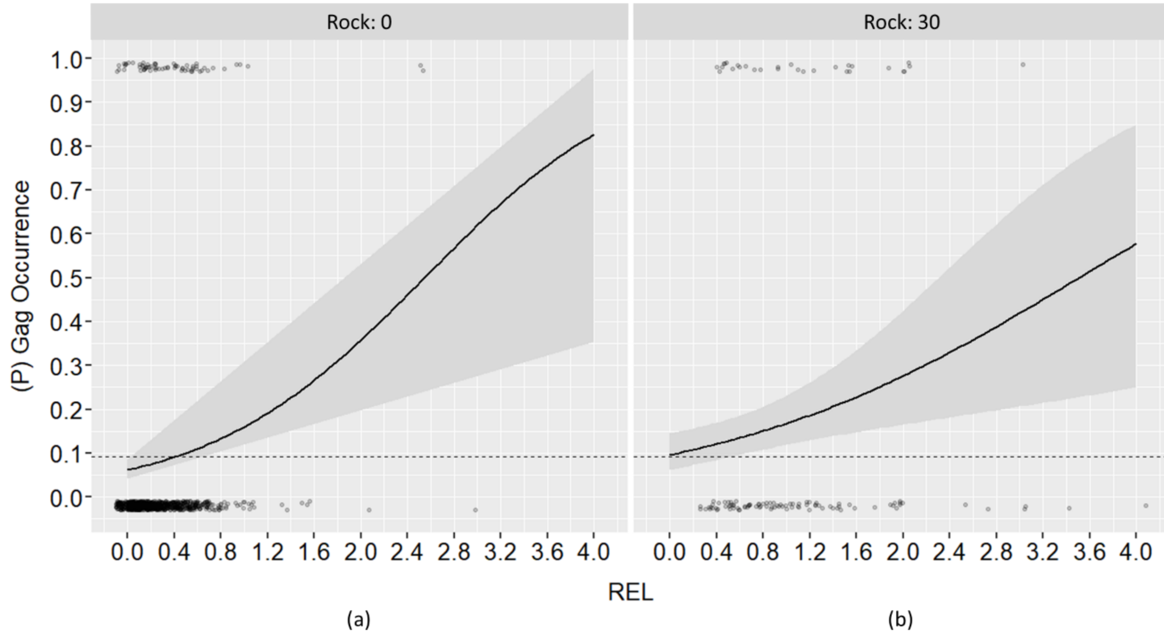
Rock: 0
Rock: 30
(P) Gag Occurrence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0
REL
(a)
(b)

Figure A14.

Figure A14. Logistic regression predicting the probability (P) of Gag occurrence in relation to the maximum vertical relief (REL; in 0.1-m bins) interacting with percent coverage by rock (ROCK; continuous rock >4 m; estimated in 1% bins). ROCK value in (a) is based on the 10^{th} and 50^{th} percentile of ROCK (both are 0%), and in (b) is based on the 90^{th} percentile of ROCK (30%). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Southeast Area Monitoring and Assessment Program (SEAMAP) in 2012-2017 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top SEAMAP model that ran without random variables, and predictions for the effect of REL were made by holding variables other than ROCK constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the SEAMAP survey (0.09) is indicated by the dashed horizontal line.

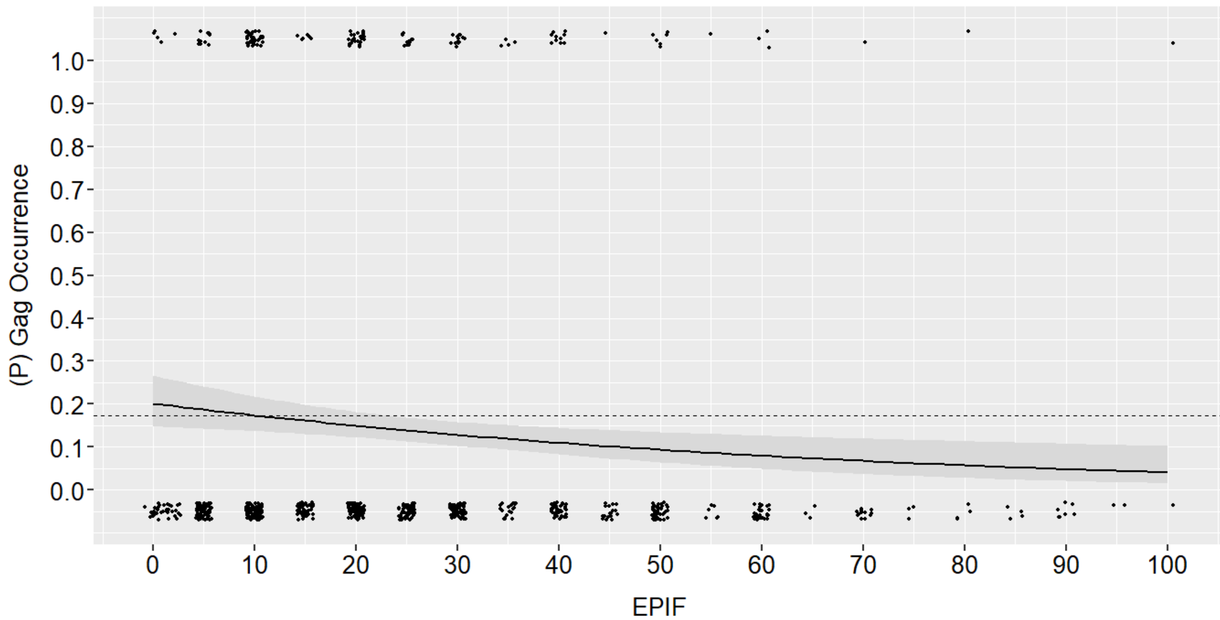

Figure A15. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by epifauna (EPIF; estimated in 1% bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office (PC) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top PC model that ran without random variables, and predictions for the effect of EPIF were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the PC survey (0.17) is indicated by the dashed horizontal line.

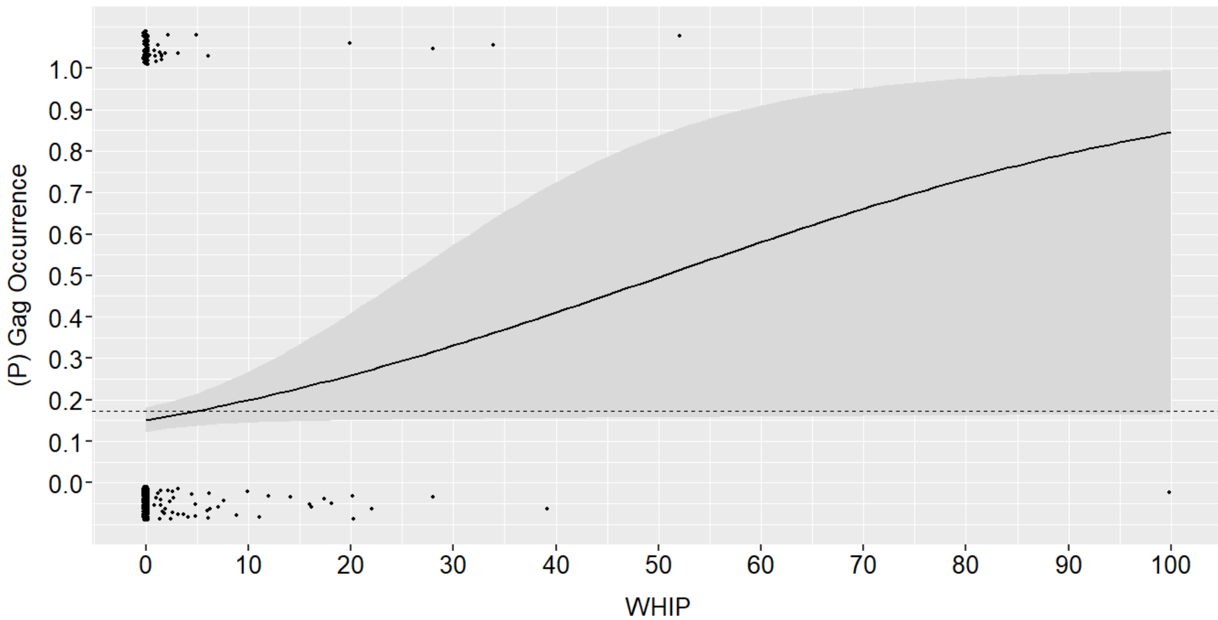

Figure A16. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by sea whip (WHIP; estimated in 1% bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office (PC) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top PC model that ran without random variables, and predictions for the effect of WHIP were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the PC survey (0.17) is indicated by the dashed horizontal line.

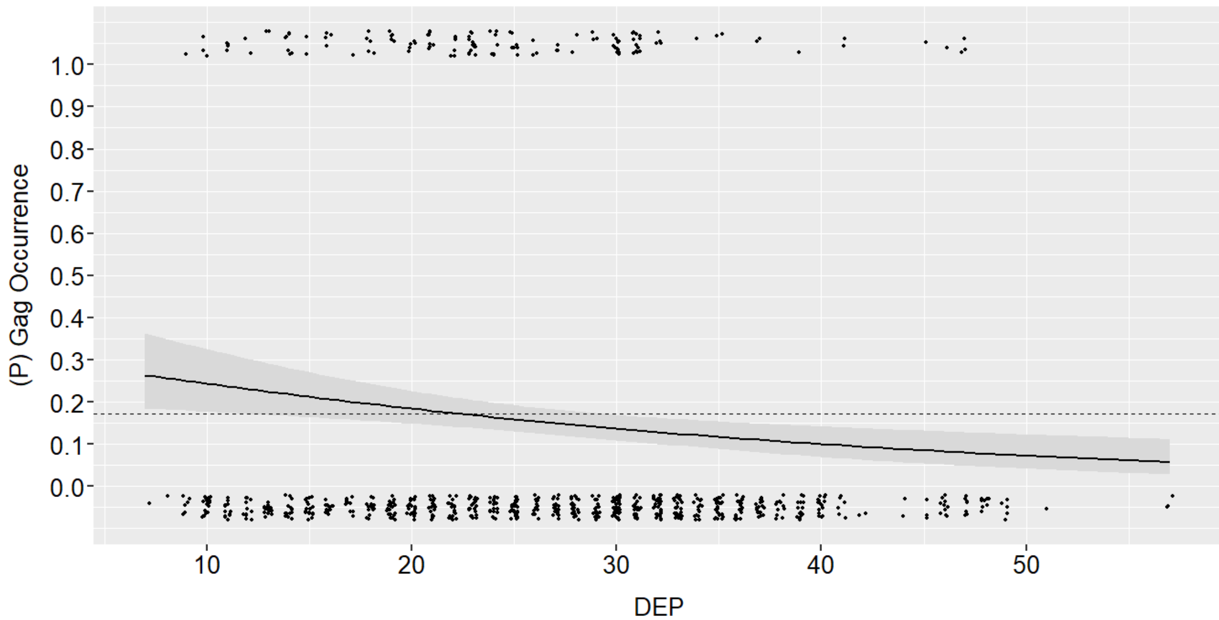

Figure A17. Logistic regression predicting the probability (P) of Gag occurrence in relation to depth (DEP; in 1-m bins). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office (PC) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top PC model that ran without random variables, and predictions for the effect of DEP were made by holding all other variables constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the PC survey (0.17) is indicated by the dashed horizontal line.

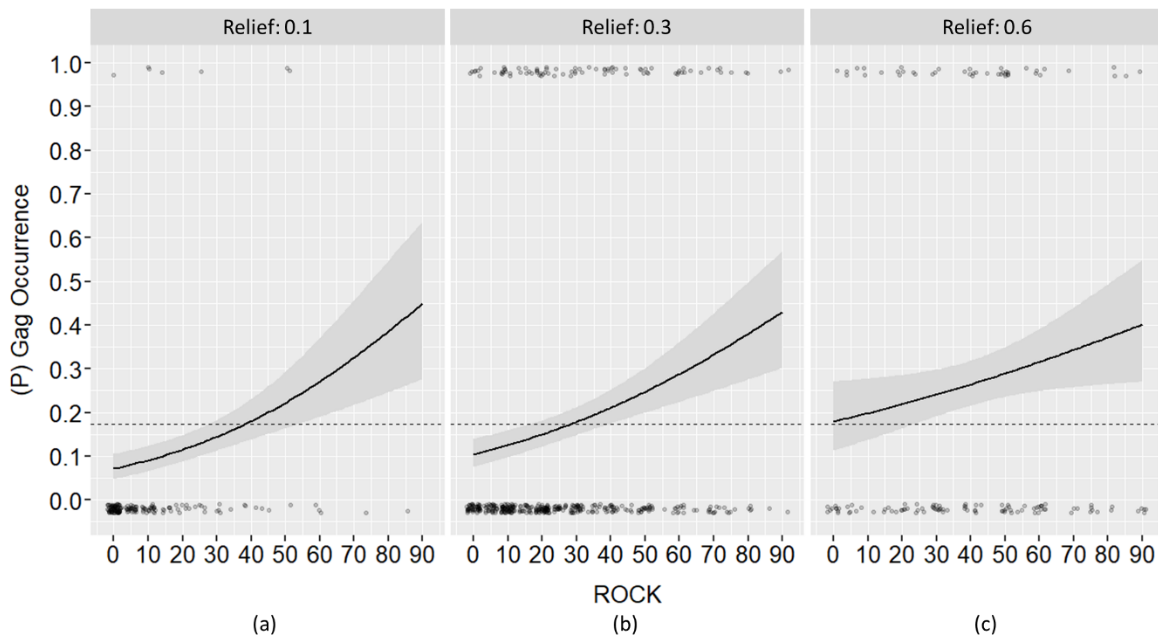

Figure A18. Logistic regression predicting the probability (P) of Gag occurrence in relation to the percent coverage by rock (ROCK; substrate >6.35 cm; estimated in 1% bins) interacting with maximum vertical relief (REL; in 0.1-m bins). REL value in (a) is based on the 10th percentile of REL (0.1 m), in (b) is based on the 50th percentile of REL (0.3 m), and in (c) is based on the 90th percentile of REL (0.6 m). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office (PC) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top PC model that ran without random variables, and predictions for the effect of ROCK were made by holding variables other than REL constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the PC survey (0.17) is indicated by the dashed horizontal line.

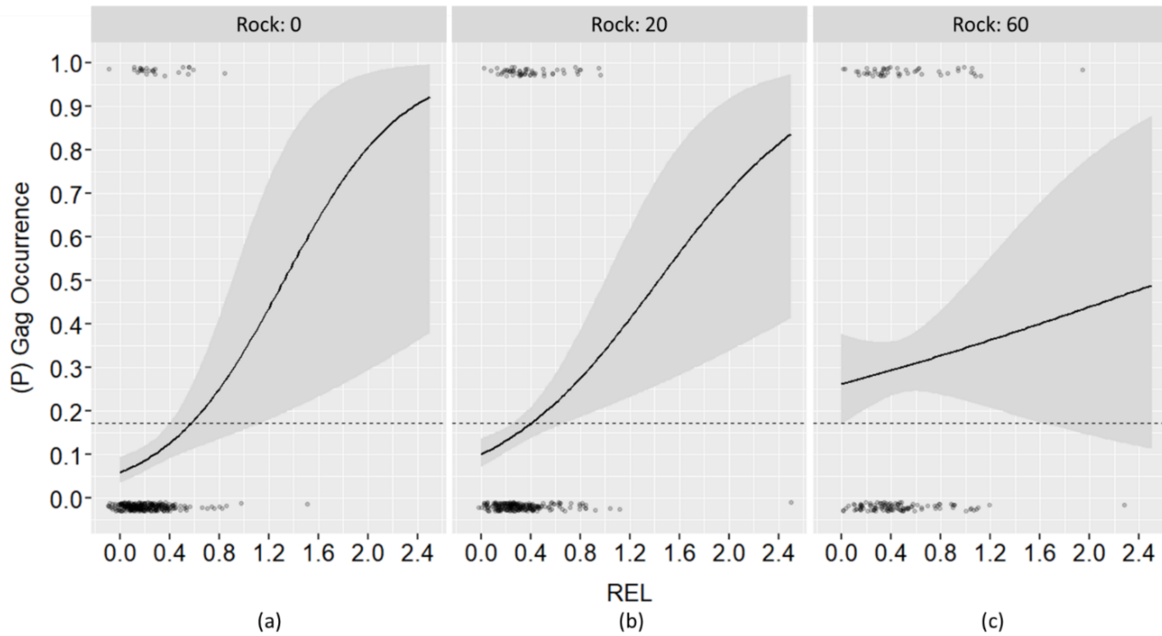

Figure A19. Logistic regression predicting the probability (P) of Gag occurrence in relation to the maximum vertical relief (REL; in 0.1-m bins) interacting with percent coverage by rock (ROCK; substrate >6.35 cm; estimated in 1% bins). ROCK value in (a) is based on the 10th percentile of ROCK (0%), in (b) is based on the 50th percentile of ROCK (20%), and in (c) is based on the 90th percentile of ROCK (60%). Data are from the video survey conducted by the National Atmospheric and Oceanic Administration Panama City, FL office (PC) in 2010-2016 and used to study the effect of Gag occurrence in the West Florida Shelf. Model parameters shown here were derived from a version of the top PC model that ran without random variables, and predictions for the effect of REL were made by holding variables other than ROCK constant at the median. Fixed effects were not centered around the mean because the model converged without random effects. The regression is indicated by a solid line within the shaded 95% confidence interval. Each dot represents a sample; samples with Gag present are jittered above y=1, and those where Gag were absent are jittered below y=0. The mean probability of Gag occurrence in the PC survey (0.17) is indicated by the dashed horizontal line.