Small-Scale Patterns in the Distribution and Condition of Bamboo Coral, *Keratoisis grayi*, in Submarine Canyons on the Grand Banks, Newfoundland

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Keratoisis grayi is one of the most abundant large gorgonian corals found off Newfoundland and Labrador, yet we know little regarding the factors influencing its distribution, abundance, and condition. We employed remotely operated vehicle (ROV) transect data collected in three canyons off the Grand Banks, Newfoundland to quantitatively examine the influence of depth, bottom type, canyon, and trawling intensity on *K. grayi* abundance, height, and condition at small spatial scales. While surveying 105 km of seafloor with a ROV, we observed 5770 *K. grayi* colonies and 167 trawl marks. We found that *K. grayi* were significantly more likely to occur in boulder areas than in cobble or gravel. Bottom depth related positively and significantly with colony height and our models predict that the largest bamboo coral colonies occur in boulders in Halibut Channel, and in boulders and cobble in Haddock Channel. The majority of colonies observed were alive and undamaged, but tipped, broken, dead and partially dead colonies were also recorded. *K. grayi* were more likely to occur in trawled areas, but these colonies were more likely to be damaged, broken, smaller in size, and less abundant than colonies outside trawled areas. These results demonstrate a negative impact of bottom trawling on *K. grayi* colonies off Newfoundland and Labrador and that fishers may specifically target areas where these corals occur.

Keywords: gorgonian coral, trawling, fishing effects, deep-sea, cold-water coral

INTRODUCTION

Deep-sea octocorals have garnered world-wide attention because of their potential longevity (Sherwood and Edinger, 2009), importance for biodiversity and life-history of other taxa (Buhl-Mortensen et al., 2010; Baillon et al., 2012), fragility to fishing damage (Edinger et al., 2007; Yoklavich et al., 2018), and vulnerability to other anthropogenic disturbances such as oil and gas exploration and ocean acidification (Dayton et al., 1995; Gass, 2003; Roberts and Hirshfield, 2004). Deep-sea octocoral conservation concerns underscore the growing need to better understand the factors influencing their distributions at a range of spatial scales.

Previous studies related deep-sea octocoral distributional patterns to temperature (Bryan and Metaxas, 2006; Mortensen et al., 2006), substrate (Baker et al., 2012a), salinity (Mortensen et al., 2006), slope, oxygen (Yesson et al., 2012), and other environmental factors. For example, Paragorgiidae along the Atlantic continental margin occurred primarily between 300 and 500 m, in areas with slopes between 1.1° and 1.4°, temperatures > 5°C, currents between 10 and 30 cm s^{-1}, and low chlorophyll *a* concentrations (Bryan and Metaxas, 2006). Watanabe et al. (2009) reported a strong negative correlation between *Primnoa resedaeformis* abundance and depth and a positive correlation with cobble and/or boulders in the Northeast Channel, off Nova Scotia, Canada.

Given the known vulnerability of cold-water corals to trawling damage, distributional patterns could relate to current and past fishing intensity (Roberts et al., 2009). The majority of research related to this topic has focused on scleractinian corals. For example, an estimated 5–52% of the total area covered by *Lophelia pertusa* in Norwegian waters was damaged by fishing activities (Fossa et al., 2002), and researchers attributed destruction of all but 10% of *Oculina* spp. in a Florida reserve to illegal trawling activity (Koenig et al., 2005). However, trawl survey data, showed highest abundances of gorgonians (and deep-water corals, in general) in areas with little to no past trawling along the eastern Grand Banks and Flemish Cap (Murillo et al., 2010). Althaus et al. (2009) also reported reduced density of scleratinians, antipatharians, and alcyonaceans (combined) on trawled seamounts, compared to untrawled seamounts off Australia.

The octocoral colonies that remain in previously trawled areas may be heavily damaged. In Alaskan waters, only 31 *Primnoa* spp. colonies remained in a trawl path visited 7 years after the removal of 1 t of corals; five large colonies were missing 95–99% of their branches and 80% of the polyps were missing from two smaller colonies (Krieger, 2001). Nearly 50% of the bamboo coral colonies observed in an area subjected to heavy trawling off California and Oregon were damaged or disturbed (Yoklavich et al., 2018).

Keratoisis grayi, a long-lived bamboo coral found throughout the North Atlantic and Mediterranean Sea (Appeltans et al., 2012), is among the most common large gorgonians off Newfoundland and Labrador, Canada (Wareham and Edinger, 2007; Baker et al., 2012a). Using fisheries observer and Fisheries and Oceans Canada survey data from that region, Wareham and Edinger (2007) reported *K. grayi* (synonym: *K. ornata*: Deichmann, 1936; van der Land, 1994) in depths from 195 to 1,262 m. Baker et al. (2012a) reported *K. grayi* often co-occurred with *Acanthogorgia armata* and *Anthomastus* spp. at relatively shallow depths with boulders and cobbles. *K. grayi* was associated with steep topography and semi-consolidated mudstone in a submarine canyon off Nova Scotia (Mortensen and Buhl-Mortensen, 2005). Large gorgonians (including *K. grayi*) were recorded as bycatch in multiple fisheries spanning trawl sets (*Pandalus borealis*, *Reinhardtius hippoglossoides*, and *Sebastes* spp. fisheries), crab pots, longlines (*R. hippoglossoides* and *Hippoglossus hippoglossus* fisheries), and gillnets (*R. hippoglossoides* and *Sebastes* spp. fisheries) off

Newfoundland between 2004 and 2005 (Edinger et al., 2007), illustrating the vulnerability of *K. grayi* to fishing disturbances.

We employed remotely operated vehicle (ROV) transect data collected in three canyons off the Grand Banks to examine quantitatively the influence of depth, bottom type, canyon, and trawling intensity on *K. grayi* abundance, height, and condition at small spatial scales.
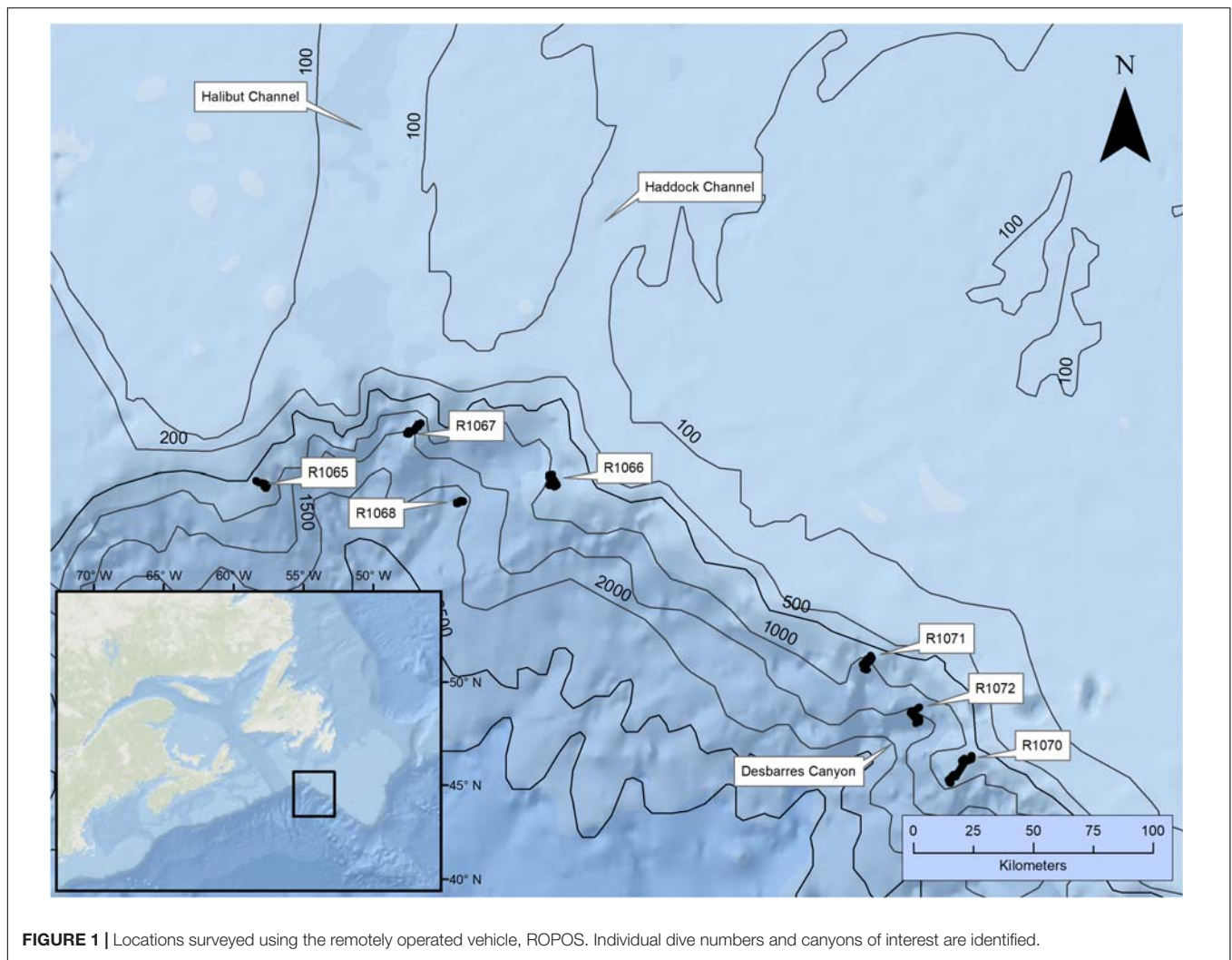
MATERIALS AND METHODS

Video Surveys

We explored three submarine canyons on the slopes of the Grand Banks south of Newfoundland: Halibut Channel, Haddock Channel, and Desbarres Canyon (**Figure 1**) with the ROV, Remotely Operated Platform for Ocean Science (ROPOS) (CSSF, 2010). The southerly flowing, cold Labrador Current and the northerly flowing, warm Gulf Stream both influence the three canyons. Fishers frequently target the areas using trawlers directed at *Sebastes* spp. and various flatfish, usually at depths shallower than 1000 m (Kulka and Pitcher, 2001; Edinger et al., 2007; Koen-Alonso et al., 2018). Trawl surveys in these areas indicate the presence of abundant and diverse cold-water coral taxa (Edinger et al., 2007).

Remotely Operated Platform for Ocean Science performed video surveys from *CCGS Hudson* during seven dives between July 16 and 24, 2007 (see Baker et al., 2012a,b, for details). The ROV was equipped with lasers placed 10 cm apart to indicate scale. Depth, date, time, altitude (distance above bottom), temperature, and position were logged at 1-s intervals (though sporadic problems with the logger resulted in several long periods with no temperature data).

Based on known distributions of corals in relation to bathymetry, we planned 1-km transects at 200-m depth intervals along depth contours between 2200 and 600 m and along contours every 100 m in waters shallower than 500 m (Baker et al., 2012a,b). We standardized transects by maintaining the ROV as close to the bottom as possible, at a constant slow speed (approx. 0.2–0.5 m s^{-1}) while tilting the camera down slightly on a wide-angle view in order to image the seafloor and water column directly above. Between pre-selected transects, we explored the area with ROPOS, capturing still images and video of interesting features, and collecting voucher specimens to validate visual identification.

Video Processing

Using the program ClassAct Mapper (Benjamin, 2007), we recorded continuous geo-referenced data describing bottom type, ROV mode, trawl marks, and corals. We identified all corals to the lowest possible taxonomic level (typically species) and measured colony height and diameter of *K. grayi* to the nearest 5 cm using the lasers for scale. Whenever possible, we quantified the general condition of colonies using two descriptors: proportion of colony dead and overall status. We estimated the proportion of each colony that appeared dead to the nearest 5%, using the lasers for scale. The overall status of each *K. grayi* colony was scored as "normal" (the colony appeared

FIGURE 1 | Locations surveyed using the remotely operated vehicle, ROPOS. Individual dive numbers and canyons of interest are identified.

upright), "broken" (the colony or pieces of the colony appeared detached), or "tipped" (the colony was tilted and laying against another object, such as the substrate). If a colony was both broken and tipped, we classified it as broken.

We characterized bottom type every second by primary (most abundant) substrate and secondary (next most abundant) substrate, with optional additional comments. Bottom types included (1) outcrop (vertically exposed bedrock and consolidated Quaternary sediment), (2) boulder (>25 cm), (3) cobble (5–25 cm), (4) gravel (0.2–5 cm), or (5) mud-sand (fine-grain) sediments (Thrush et al., 2001).

We defined "transect-mode" as any portion of the video when the ROV followed the prescribed methodology for transects (described above), regardless of whether the transect was planned. All other ROV behaviors were combined as "Other" (Baker et al., 2012a,b).

Data Analysis

Flatfish and *Sebastes* spp. in the area are typically fished using bottom trawls. Commercial trawl-doors off Newfoundland

spread approximately 116 m for flatfish trawlers and 95 m for *Sebastes* spp. trawlers. Therefore, using ArcGIS 9.3 (ESRI, 2008), we created circular 100-m buffers around each observed trawl mark location. We then calculated the frequency with which each second of video coincided with a buffer to determine the potential trawling intensity at each second (~location).

Our analysis considered the effect of average temperature, bottom type, depth, canyon, trawl intensity (Trawl), and their interactions. However, because of strong collinearity in average temperature and depth, we removed average temperature from consideration (furthermore, 72% of the colonies had no associated temperature records). When necessary, we $\log_{10}$-transformed Trawl in our models to adjust for non-linearity (logTrawl), and chose all final models through backward selection using likelihood ratio tests to remove insignificant terms.

Abundance

We examined patterns in *K. grayi* colony abundance observed when the ROV was in transect-mode by splitting transects into 10-m segments (=sample unit) and summing the number of live

K. grayi colonies (<100% dead) in each segment. Regardless of abundance, large, hard substrates likely influence *K. grayi* distribution (Baker et al., 2012a). Therefore, we used the largest size category in each 10-m segment to classify bottom type in that segment. We used mean depth of each 10-m segment as "depth" and maximum number of trawl mark buffers coinciding with any point in the segment as the Trawl value for that segment. Given low sample sizes, we chose to remove the 10-m segments in mud-sand, outcrops, or depths > 1000 m. Because the data were zero-inflated we chose a hurdle (zero-altered) model. A hurdle model consists of two parts: a binomial generalized linear model (GLM) to model presence/absence, combined with a count model for values greater than zero (Zuur et al., 2009). Because our count data were overdispersed, we implemented a truncated negative binomial GLM count model using the *Pscl* package (Jackman et al., 2011) in *R* (RDevCoreTeam., 2012).

Height

We used all video (regardless of ROV mode) to examine patterns in *K. grayi* colony height, treating each *K. grayi* colony as a sample unit. Low sample size led us to remove Desbarres Canyon and mud-sand data. A gamma GLM with identity link produced the best explanatory model for patterns in height of *K. grayi*.

Condition

We examined all video for patterns in *K. grayi* condition, again removing Desbarres Canyon and mud-sand data because of low sample size, and assessed status using two approaches: proportion dead and overall status (normal, broken, or tipped).

Values of zero ($n = 5037$) and 1 ($n = 317$) strongly skewed the proportion dead, and common transformations used for proportional data (e.g., arcsine and logit) therefore did not improve our ability to meet model assumptions. As a result, we categorized all colonies with any dead portions as "dead/partially dead," thereby creating a binary response variable: dead/partially dead (1) or alive (0). We used a binomial GLM to examine patterns in live versus dead/partially dead colonies, and a multinomial logit model to examine overall status (normal, broken, or tipped).

RESULTS

We surveyed approximately 105 km (90 h) of seafloor, and recorded a total of 5031 10-m segments using all dives and depth categories (see Baker et al., 2012a,b). We observed 5770 *K. grayi* colonies, most in Halibut Channel ($n = 4341$) and Haddock Channel ($n = 1427$), and only two colonies in Desbarres Canyon (**Table 1**).

We recorded 167 trawl marks (**Table 2**), spanning all canyons and depths from 377 to 821 m. A total of 1086 *K. grayi* colonies occurred within at least one 100-m trawl buffer zone; the greatest number of buffers coinciding with a *K. grayi* colony was 13 ($n = 8$).

Abundance

Overall, we enumerated 3765 live *K. grayi* colonies while the ROV was in transect mode, 2820 of which occurred in 10-m segments. Of the 1422 10-m segments used in our model, a total of 440 segments contained *K. grayi*. The median of counts greater than zero in a 10-m segment was 3 and the maximum of 43 occurred at 573 m within segments with boulders in Halibut Channel (Dive R1067).

TABLE 1 | Number of *Keratoisis grayi* colonies and status observed during ROV surveys off the Grand Banks, Newfoundland in 2007.

Canyon	Dive	# Observed	# Normal	# Broken	# Tipped	# Dead/Partially Dead	# Alive
Halibut Channel	R1065	192	154	19	9	19	150
Haddock Channel	R1066	1427	1090	184	57	213	1117
Halibut Channel	R1067	4149	3738	140	131	164	3773
Haddock Channel	R1068	–	–	–	–	–	–
Desbarres Canyon	R1070	2	1	1	0	1	1
Desbarres Canyon	R1071	–	–	–	–	–	–
Desbarres Canyon	R1072	–	–	–	–	–	–
	Total	5770	4983	344	197	397	5041

TABLE 2 | Number of trawl marks observed by depth and dive during ROV surveys off the Grand Banks, Newfoundland in 2007.

Dive	300–400 m	400–500 m	500–600 m	600–700 m	700–800 m	800–900 m
R1065	–	–	–	5	4	1
R1066	–	1	26	52	–	1
R1067	–	2	–	–	–	–
R1068	–	–	–	–	–	–
R1070	3	6	33	18	–	–
R1071	1	2	11	1	–	–
R1072	–	–	–	–	–	–
Total	4	11	70	76	4	2

Bottom type ($p < 0.0001$), Trawl ($p = 0.018$), and the interaction of Depth and Canyon ($p < 0.0001$) were significant predictors of *K. grayi* presence within a 10-m segment (**Table 3**). *K. grayi* colonies were significantly more likely to be present as Trawl increased (**Figure 2**). The probability of *K. grayi* presence in habitats with boulders was significantly greater than in cobble ($p < 0.0001$) and gravel ($p < 0.0001$), but cobble and gravel habitats did not differ significantly from each other ($p = 0.053$).

The interaction of Depth and Bottom type was a significant predictor of *K. grayi* counts greater than zero ($p = 0.004$) (**Table 3**), and as trawl intensity (logTrawl) increased counts of *K. grayi* decreased ($p < 0.0001$). Trawling intensity appeared to have the greatest negative influence on *K. grayi* counts during the first trawl (**Figure 3**). Depth greatly influenced counts in habitats with cobble, which was less obvious in habitats with boulders and gravel (**Figure 3**).

Height

We determined height (median = 30 cm) confidently for 4654 *K. grayi* colonies. The tallest colony (215 cm) occurred in a segment with cobble in the absence of trawling at 776 m in Halibut Channel.

Depth ($p < 0.0001$), logTrawl ($p < 0.0001$), and the interaction of Canyon and Bottom type ($p < 0.0001$) were significant predictors of *K. grayi* height (**Table 3**). We found a significant negative relationship between *K. grayi* colony height and logTrawl, and a significant positive relationship between height and depth. The predicted height of *K. grayi* increased by 0.07 m for each 1 m increase in depth. In Halibut Channel, the largest colonies occurred in habitats with boulders, in contrast with Haddock Channel where the largest colonies occurred in habitats with cobble and boulders (**Figure 4**).

Condition

Over 75% of the *K. grayi* colonies we recorded appeared healthy (**Table 1**).

LogTrawl ($p = 0.0001$) and the interaction of Canyon and Depth ($p < 0.0001$) were significant predictors of a *K. grayi*

colony with dead portions ($n = 5428$) (**Table 3**). As logTrawl increased, so did the probability of recording a colony with dead portions (**Figure 5**). Depth strongly influenced the probability of dead portions in *K. grayi* in Haddock Channel, but not Halibut Channel. The probability of dead portions in a *K. grayi* colony in Haddock Channel was highest in the shallowest depths (**Figure 5**).

Canyon ($p < 0.0001$), Depth ($p = 0.004$), and logTrawl ($p < 0.0001$) were significant predictors of *K. grayi* overall status ($n = 5513$) (**Table 3**). As trawl intensity increased, the probability of a healthy *K. grayi* colony decreased (**Figure 6**) and the probability of a broken colony increased ($p < 0.0001$) (**Figure 6**). We found no significant relationship between logTrawl and probability of a tipped colony ($p = 0.848$). Healthy *K. grayi* were more likely and broken coral less likely in Halibut Channel ($p < 0.0001$) compared to Haddock Channel. We found no significant difference between canyons when comparing the probability of a tipped colony ($p = 0.313$). As depth increased, the probability of a tipped *K. grayi* colony decreased ($p = 0.003$) (**Figure 6**). We found no significant relationship between the probability of a broken colony and depth ($p = 0.155$).
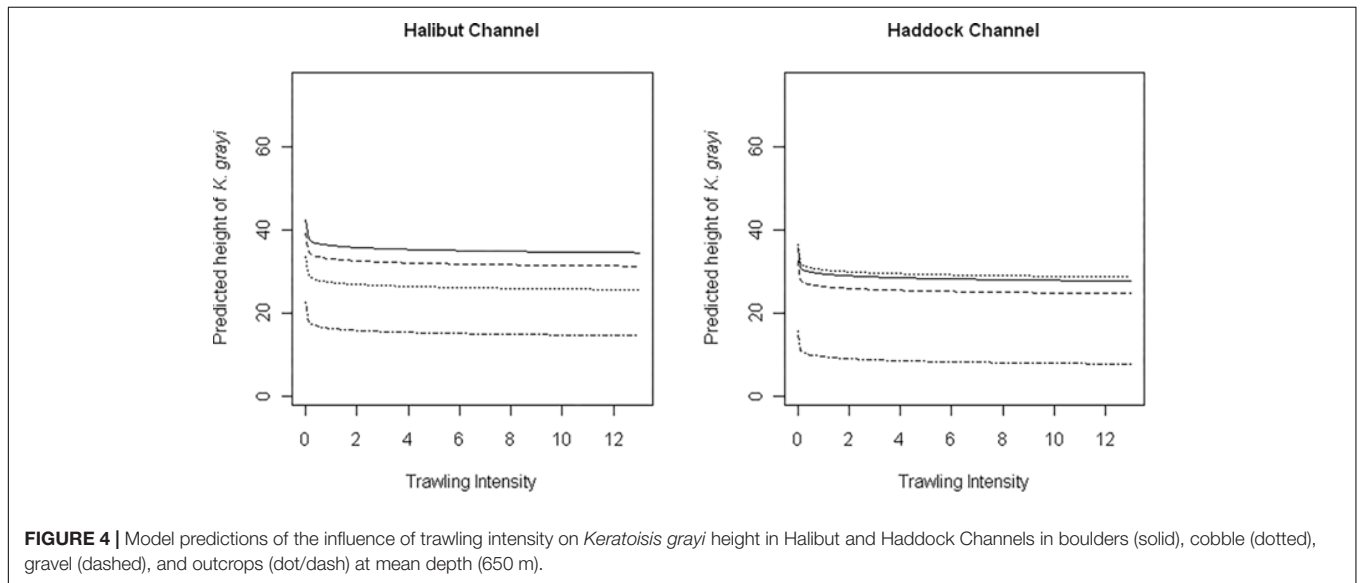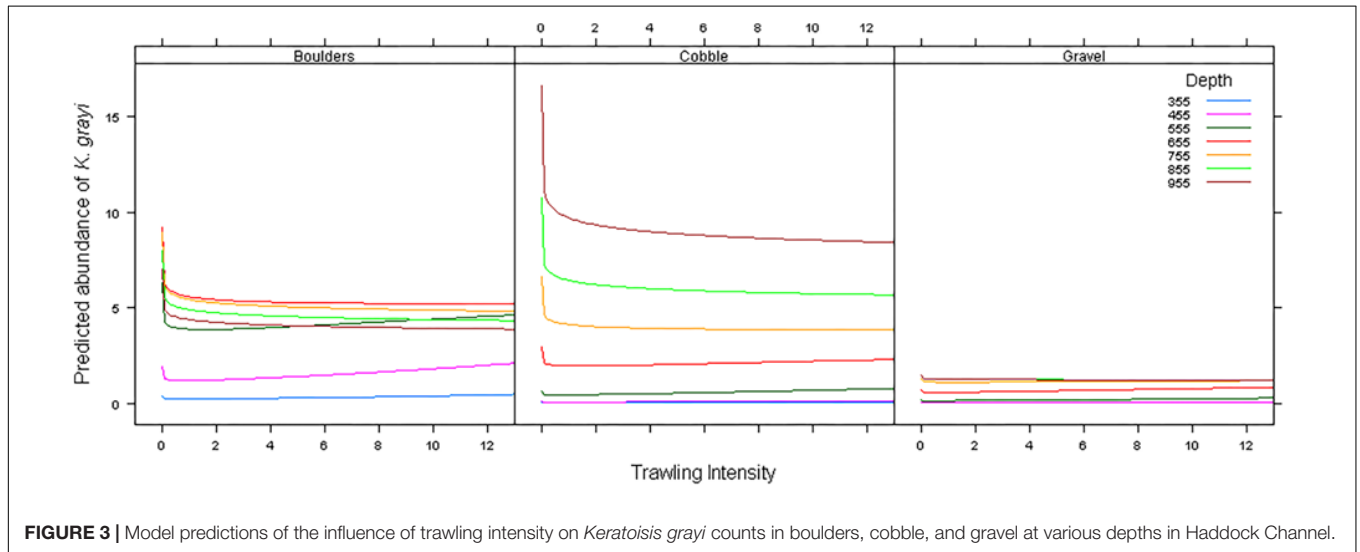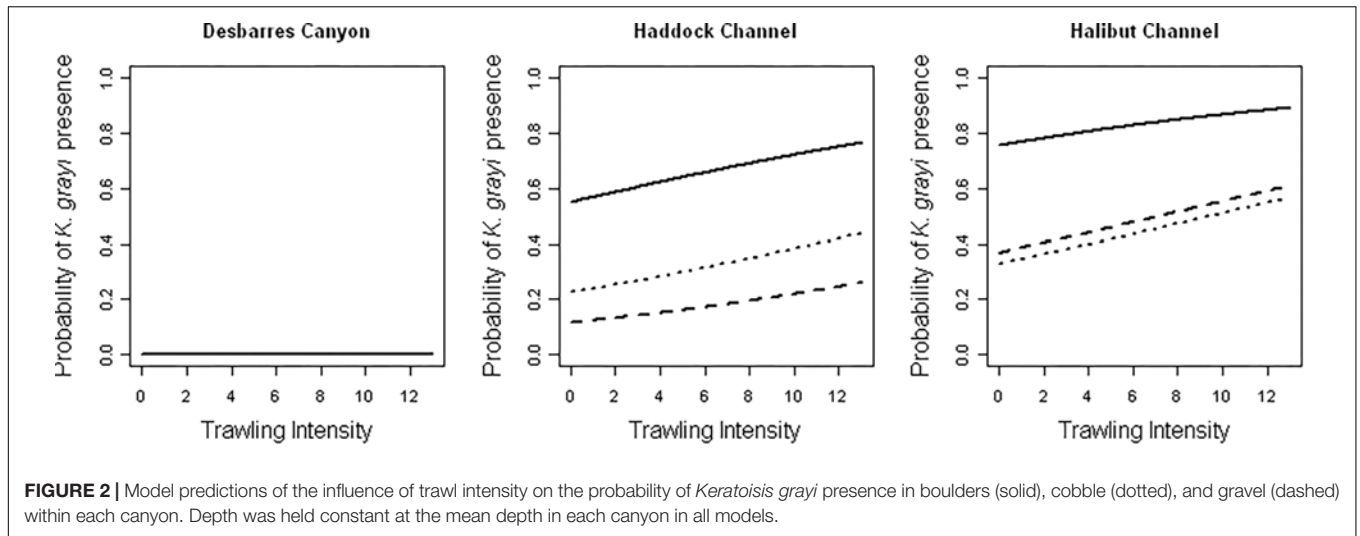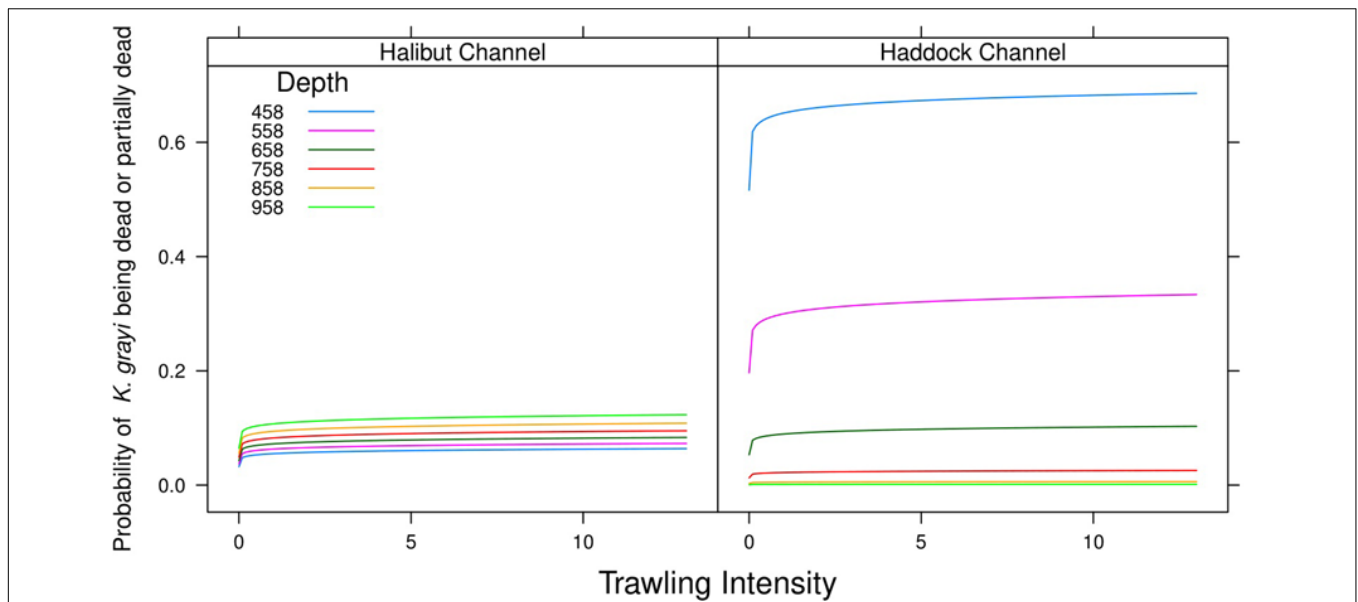
DISCUSSION

Abundance

Keratoisis grayi colonies were significantly more likely to occur in boulder areas, than cobble or gravel. This species requires hard substrate for attachment, therefore, boulders presumably create more available stable habitat for attachment than smaller substrata, such as gravel or cobble. In The Gully, off Nova Scotia, *K. grayi* also associate with large, hard substrate (consolidated mudstone) (Mortensen and Buhl-Mortensen, 2005), and off California and Oregon bamboo corals were only observed on rock substrate (Yoklavich et al., 2018).

We found significant interactions when modeling both presence and counts of *K. grayi*. The significant Depth × Canyon interaction in predicting counts and presence of *K. grayi* indicates a between canyon difference in *K. grayi* presence and abundance at a given depth, implying that while depth is important, other environmental factors that differ between canyons likely also influence *K. grayi* distributional patterns. Other factors that co-vary with depth may account for differences in *K. grayi* between bottom types. For example, current regime may change with depth and contribute to bottom type. Multiple environmental factors, such as current velocity, temperature, sedimentation rates, slope, and food availability that likely influence presence and abundance (but not measured in the present study) may differ between depths and/or canyons and therefore help to explain these interactions (Roberts et al., 2009; Watanabe et al., 2009). Future ROV studies could include additional methodologies and sampling (e.g., Digital Terrain Modeling, CTD samples, and planktonic samples) to examine other likely contributors to coral health and abundance.

TABLE 3 | Significant terms in models predicting abundance, height, and status of *Keratoisis grayi* colonies from ROV surveys off the Grand Banks, Newfoundland.

Response	Model terms	*p*-value
Abundance: presence/absence	Bottom type	<0.0001
	Trawl	0.0178
	Depth × Canyon	<0.0001
Abundance: counts	$\log_{10}$Trawl	<0.0001
	Depth × Bottom type	0.0036
Height	$\log_{10}$Trawl	<0.0001
	Depth	<0.0001
	Canyon × Bottom type	<0.0001
Probability of having dead portions	Canyon × Depth	<0.0001
	$\log_{10}$Trawl	0.0001
Overall status	Canyon	<0.0001
	Depth	0.0037
	$\log_{10}$Trawl	<0.0001

FIGURE 2 | Model predictions of the influence of trawl intensity on the probability of *Keratoisis grayi* presence in boulders (solid), cobble (dotted), and gravel (dashed) within each canyon. Depth was held constant at the mean depth in each canyon in all models.

FIGURE 3 | Model predictions of the influence of trawling intensity on *Keratoisis grayi* counts in boulders, cobble, and gravel at various depths in Haddock Channel.

FIGURE 4 | Model predictions of the influence of trawling intensity on *Keratoisis grayi* height in Halibut and Haddock Channels in boulders (solid), cobble (dotted), gravel (dashed), and outcrops (dot/dash) at mean depth (650 m).

FIGURE 5 | Model predictions of the influence of trawling intensity and depth on the probability of dead/partially dead versus live *Keratoisis grayi* in Halibut Channel and Haddock Channel.
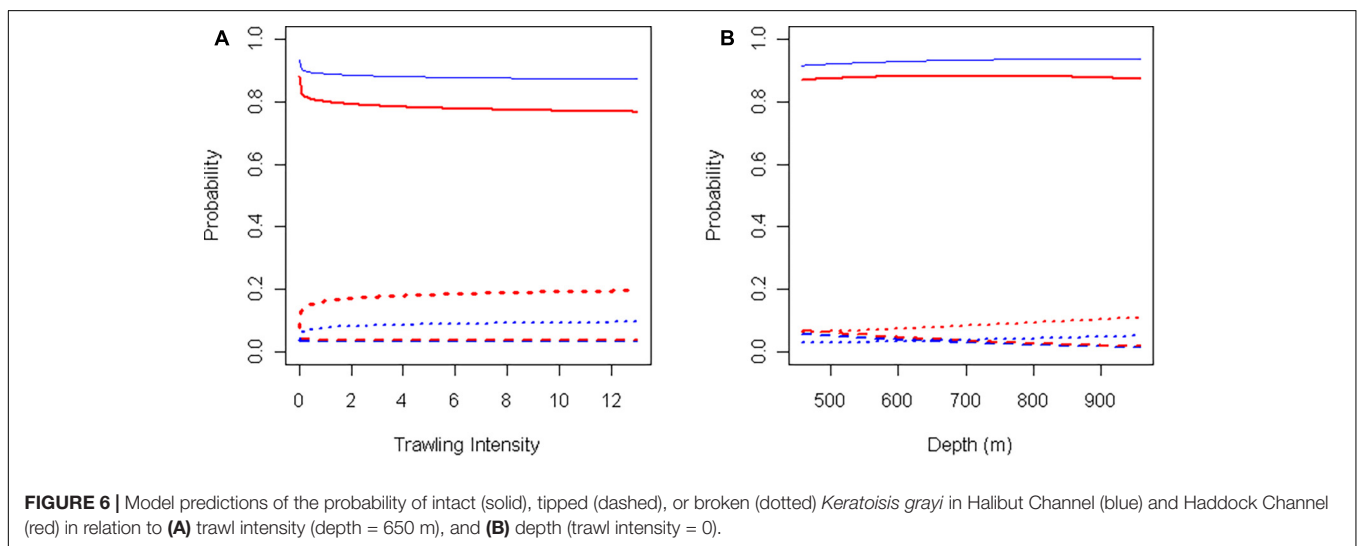
FIGURE 6 | Model predictions of the probability of intact (solid), tipped (dashed), or broken (dotted) *Keratoisis grayi* in Halibut Channel (blue) and Haddock Channel (red) in relation to **(A)** trawl intensity (depth = 650 m), and **(B)** depth (trawl intensity = 0).

Height

Colony height increased significantly with bottom depth, a pattern previously reported for bubble gum coral, *Paragorgia arborea,* in the Northeast Channel off Nova Scotia (Watanabe et al., 2009). Thresher (2009) found slower radial growth rates in bamboo corals collected in deeper waters and at lower temperatures, suggesting much longer growth periods without disturbance for deeper, taller corals than shallower, faster growing colonies.

Our models predicted that the largest bamboo coral colonies occur on boulders in Halibut Channel and boulders and cobble in Haddock Channel (acknowledging a significant positive interaction between canyon and bottom type). We suspect that the larger surface area of boulders offers a more stable surface as colonies grow in size, thus allowing a colony to grow larger before tipping and overturning the stone (Tunnicliffe and Syvitski, 1983).

As with coral abundance patterns, size, and growth rates may link to a variety of environmental factors that likely vary with depth and differ between canyons. These factors include, but are not limited to, currents, strontium/calcium ratios, surface productivity, calcium carbonate, and organic content (Weinbauer et al., 2000; Thresher, 2009).

Condition

The majority of *K. grayi* observed in both Halibut and Haddock Channels were healthy (80%) and fully living (78%). Dead/partially dead colonies of *K. grayi* were more prevalent at

shallower depths in Haddock Channel than Halibut Channel, and colonies in Haddock Channel were broken more often and generally less intact compared to those in Halibut Channel. Trawling could explain this difference. Although we attempted to account for trawl intensity in our models, we may have underestimated areas of past trawling if our survey path did not intersect the trawl-door furrow. We observed a total of 80 trawls marks in Haddock Channel, compared to only 12 in Halibut Channel, and the Haddock Channel survey site is relatively close to locations where >100% of the area was trawled at least 1 year between 1980 and 2000 (Kulka and Pitcher, 2001). Therefore, in our survey areas, trawling pressure in Haddock Channel likely exceeded that in Halibut Channel and the poorer health of *K. grayi* in Haddock Channel may reflect fishing damage not captured with our methodologies. This interpretation would also explain the absence of significant differences in probability of tipped colonies between canyons. The physical force of a trawl would likely break or tip and break a colony, rather than tip a colony without breakage (Sainsbury et al., 1992; Krieger, 2001). Alternatively, many of the variables that likely differ between canyons and affect size and abundance (e.g., current velocity, sedimentation rates, and temperature), may also impact overall *K. grayi* condition and contribute to the canyon-related patterns.

Numerous mechanisms can tip and break colonies, sometimes overturning the attachment substrate (Tunnicliffe and Syvitski, 1983). For example, longlines or gillnets may hook corals (Krieger, 2001). Therefore, we cannot identify the direct mechanism responsible for the colonies that were tipped and/or broken in our video.

Trawling Impacts

Our results clearly illustrate the negative influence of trawling on the size, condition, and number of *K. grayi* off Newfoundland. However, *K. grayi* were also more likely to occur in trawled areas, perhaps because fishers target areas with high densities of fish, which could coincide with coral presence (Husebo et al., 2002; Costello et al., 2005; Stone, 2006). But corals that persist in trawled areas are more likely to exhibit damage, breakage, smaller size, and reduced abundance. These findings confirm other studies on trawling effects on vulnerable epifauna. For example, Yoklavich et al. (2018) considered only half of the bamboo corals healthy in a heavily trawled area, and observed bamboo corals sheared off at the base, and linear swaths of broken and/or dead colonies. Freese (2001) found an immediate 16% reduction in sponge density post trawling, a 21% reduction 11 months post trawling, and damaged to almost half of the sponges (46.8%) that remained in three trawl paths. Trawled seamounts exhibited significantly reduced cover of *Solenosmilia* thickets compared to seamounts that were never trawled, with significantly higher density of large gorgonians and black corals with broken stems on seamounts with active trawling (Althaus et al., 2009). One study in the Gulf of Alaska estimated that 27% of corals in a trawl net path were detached and 50–90% of these corals were missing polyps (Krieger, 2001). Damaged corals may be more susceptible to predation (Malecha and Stone, 2009), infection and disease and,

ultimately, mortality (Krieger, 2001), with reduced reproductive (Henry et al., 2003; Malecha and Stone, 2009), and feeding abilities (Krieger, 2001), and slower growth rates (Meesters et al., 1994). For example, *Tritonia diomedea* actively fed on sea whips lying on the seafloor after simulated trawl disturbance (Malecha and Stone, 2009).

Our predictive models clearly corroborate previous research illustrating the significant damage caused by the first pass of a trawl. In each model, we found the largest incremental effect of trawling with the smallest number of trawls (illustrated by initial slopes in **Figures 3–6**). On the continental shelf of Australia, a single pass of a trawl removed 90% of the large epibenthic organisms in the trawl path (Sainsbury et al., 1992). A single trawl pass in the Gulf of Alaska significantly removed or damaged emergent epifauna (Freese et al., 1999). Van Dolah et al. (1987) found significantly reduced barrel sponge abundances and octocorals and stony corals broken at the base after only a single trawl pass.

Our findings use observations collected with an ROV and quantitative methods to add to the growing research demonstrating clear impacts of trawling on deep-sea ecosystems (e.g., Watling and Norse, 1998; Freese, 2001; Althaus et al., 2009; Norse et al., 2012; Clark et al., 2016; Yoklavich et al., 2018). Slow-growing and long-lived octocorals, such as *K. grayi* will require considerable time to recover from disturbances (Roberts et al., 2009), if even possible, and other taxa in the deep sea may depend on octocorals (Buhl-Mortensen et al., 2010). Collectively, these findings raise significant concerns regarding trawling impacts and sustainability of deep-sea ecosystems. Therefore, we believe protection of corals, associated taxa, and their ecosystems requires closing large areas of the seafloor to destructive fishing gear. In areas that remain open to trawling (and other fishing practices), ensuring appropriate fisheries management in an ecosystem context requires accountability and transparency (Weaver et al., 2011).

In conclusion, we used quantitative methods to clearly illustrate the negative influence of trawling on *K. grayi* counts, size, and status. Our findings also suggest fishers may preferentially, though unintentionally, target areas with *K. grayi*, underscoring the urgency of this conservation threat. Therefore, our research adds to growing evidence for the need to protect large seabed areas from bottom trawling. Such protected areas will help to reduce the overall footprint of fishing and initiate recovery efforts for deep-sea corals and associated marine fauna.

DATA AVAILABILITY

The datasets generated for this study can be found in the author's GitLab site: https://gitlab.com/krista.baker/keratoisis.

AUTHOR CONTRIBUTIONS

KB, PS, RH, EE, VW, and KG contributed to the concept and initial study design. KB and VW performed the video analysis. KB

and DF performed the statistical analyses and interpretation. KB wrote the first draft of the manuscript. All authors contributed to the manuscript revisions. KB, PS, EE, VW, and KG have read and approved the submitted version of the manuscript. RH approved a previous, but very similar, version of the manuscript.

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