Canadian Journal of Fisheries and Aquatic Sciences
Journal canadien des sciences halieutiques et aquatiques

**Using autonomous video to estimate the bottom contact
area of longline trap gear and presence-absence of sensitive
benthic habitat**

Journal:	<i>Canadian Journal of Fisheries and Aquatic Sciences</i>
Manuscript ID	cjfas-2016-0483.R1
Manuscript Type:	Article
Date Submitted by the Author:	14-Mar-2017
Complete List of Authors:	Doherty, Beau; Simon Fraser University, School of Resource and Environmental Management Johnson, Samuel; Simon Fraser University, School of Resource and Environmental Management Cox, Sean; Simon Fraser University, School of Resource and Environmental Management
Is the invited manuscript for consideration in a Special Issue? :	Canadian Fisheries Research Network
Keyword:	BENTHIC < Environment/Habitat, HABITAT < General, FISHING GEAR < General, CORALS < Organisms, COMMERCIAL FISHERIES < General

SCHOLARONE™
Manuscripts

Using autonomous video to estimate the bottom contact area of longline trap gear and presence-absence of sensitive benthic habitat

Beau Doherty¹, Samuel D N Johnson¹, Sean P Cox*¹

¹Quantitative Fisheries Research Group, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada

Beau Doherty

email: beaud@sfu.ca

Samuel D N Johnson

email: samuelj@sfu.ca

Sean P Cox*

email: spcox@sfu.ca

*Corresponding Author

Abstract

Bottom longline hook and trap fishing gear can potentially damage sensitive benthic areas (SBAs) in the ocean; however, the large-scale risks to these habitats are poorly understood because of the difficulties in mapping SBAs and in measuring the bottom-contact area of longline gear. In this paper, we describe a collaborative academic-industry-government approach to obtaining direct presence-absence data for SBAs and to measuring gear interactions with seafloor habitats via a novel deepwater trap camera and motion-sensing systems on commercial longline traps for Sablefish (*Anoplopoma fimbria*) within SGaan KInghlas - Bowie Seamount Marine Protected Area. We obtained direct presence-absence observations of cold-water corals (Alcyonacea, Antipatharia, Pennatulacea, Stylasteridae) and sponges (Hexactinellida, Demospongiae) at 92 locations over 3 commercial fishing trips. Video, accelerometer, and depth sensor data were used to estimate a mean bottom footprint of 53 m² for a standard Sablefish trap, which translates to 3 200 m² (95% CI = 2 400 - 3 900 m²) for a 60-trap commercial Sablefish longline set. Our successful collaboration demonstrates how research partnerships with commercial fisheries have potential for massive improvements in the quantity and quality of data needed for conducting SBA risk assessments over large spatial and temporal scales.

36 Introduction

37 Sensitive benthic areas (SBAs), such as cold-water coral and sponge communities, occur
38 throughout the world's oceans often providing three-dimensional habitat for fish and
39 invertebrate populations (Krieger and Wing 2002; Buhl-Mortensen et al. 2010; Stone et al.
40 2014). SBAs and associated communities are prone to damage when contacted by fishing gear
41 and recovery from such damage can take decades (Sainsbury et al. 1997; Williams et al. 2010;
42 Rooper et al. 2011). Spatial management strategies such as marine protected areas that
43 permanently close large areas to bottom-contact fisheries are increasingly used to limit or avoid
44 damage to SBAs in many parts of the world (Hourigan 2009; Wright et al. 2015). However, for
45 most remote parts of the deep ocean, there is little information about the locations, diversity,
46 abundance, and composition of SBAs, as well as the potential risks to these habitats from
47 bottom-contact fishing methods other than trawling. Without better information, misplaced
48 marine protected areas (i.e., both location and size) could have a dual effect of (1) shifting
49 fishing effort to more valuable, yet unprotected, SBA locations and (2) creating unnecessary
50 fishery economic losses or increases in fishing cost (Lagasse et al. 2015). These potential
51 consequences create strong incentives for the fishing industry to engage in new scientific
52 research aimed at mapping SBA distributions (e.g., Woodby et al. 2009; Rooper et al. 2014;
53 Lagasse et al. 2015), as well as forecasting potential fishery impacts to these habitats (e.g.,
54 Welsford et al. 2014b; Eigaard et al. 2015). Such research could better inform ecosystem-based
55 fisheries management that minimizes risks to bottom habitats, while allowing fisheries to
56 maintain access to fishing grounds where risks of damage are low.

It is reasonably well established that bottom trawling and dredging damage benthic communities by removing large amounts of sessile epifauna and dramatically altering certain benthic communities (Collie et al. 2000; Kaiser et al. 2006; Clark et al. 2015). We know much less about the potential impacts of bottom longline fisheries, even though these fisheries are more common and occur over a wider range of bottom habitats (Heifetz et al. 2009). In general, bottom longline gear (e.g., hook-and-line) is thought to be less damaging because of a much smaller bottom contact area, lighter weight, and relative stationarity on the seafloor (Hourigan et al. 2007; Pham et al. 2014); however, there is little scientific research available to test this assertion. Bottom longline gear using baited hooks or traps have potential to damage corals and sponges by landing on them when deployed or by dragging over them during retrieval (Eno et al. 2001; Stone 2006; Stone et al. 2014). Lateral movement of the mainline during dragging can create shearing forces that may break corals off at their base, while hooks, lines, and traps can entangle or crush freestanding corals during retrieval (Troffe et al. 2006; Durán Muñoz et al. 2011; Sampaio et al. 2012; Bo et al. 2014; Ewing and Kilpatrick 2014). On the other hand, the extent of dragging that occurs is likely influenced by particular circumstances of, for example, bottom bathymetry, hauling direction, wind, and currents (Eno et al. 2001; Stone 2006). Mainlines for some types of trap gear are also buoyant and may not even contact the bottom. Therefore, unlike trawls and dredges, the footprints from bottom longline gear involve more than a computation of *length x width* of a tow.

Scientific partnerships between academia, government, and the fishing industry have been used to assess bottom longline impacts on SBAs (Kilpatrick et al. 2011; Durán Muñoz et al. 2011; Sampaio et al. 2012). In this paper, we demonstrate a collaborative, technological

approach to improving the scientific information for assessing risks to cold-water corals and sponges from bottom longline trap fisheries. Through an academic-industry-government project, we developed and deployed a novel deepwater trap camera and motion-sensing system on commercial bottom longline trap fishing gear to collect direct observations of potential bottom impacts and benthic community composition.

Understanding the risks to SBAs from bottom longline fisheries requires four general types of information: (1) presence or presence-absence data for mapping suitable habitat for SBAs defined by presence of corals and sponges; (2) the effective bottom contact area or footprint of gear deployed within the fishing area; (3) the damage or mortality rate arising from gear contact with sensitive habitats or individual organisms; and (4) the recovery rates from damage (Rooper et al. 2011). Mapping habitat suitability for deepwater corals and sponges is challenging because direct observations are typically expensive and difficult to collect over large spatial scales and in remote areas of the deep ocean. By designing our cameras to work on commercial fishing gear, we are able to (1) vastly improve the input data to habitat suitability models for corals and sponges by using direct presence-absence data rather than the typical presence-only data (Hastie and Fithian 2013; Lagasse et al. 2015) and (2) provide a cost-efficient means of covering the large spatial scales needed to produce high-quality habitat suitability maps. Additionally, depth and accelerometer sensors on our camera systems allowed us to develop a simple algorithm for quantitatively estimating longline trap fishing footprints based on gear behaviour during set, soak, and hauling periods.

Role of industry-academic-government collaboration in deep-sea research

Between 2012 and 2015, bottom contact fisheries off British Columbia, Canada generated an average total landed value of CAD \$122 million with longline hook and longline trap fisheries for Halibut and Sablefish accounting for CAD \$66 million. Longline fisheries operate along most of the continental slope and shelf (Fig. 1), including within complex terrain (e.g., boulder outcrops, rocky reefs) that is inaccessible by bottom trawl (Sinclair et al. 2005; Wallace et al. 2015). This ability to fish a variety of terrain over a broad area increases the likelihood of bottom contact in areas where cold-water corals and sponges probably occur (Mortensen and Buhl-Mortensen 2004; Woodby et al. 2009).

In 2010, conservation groups in British Columbia questioned the Marine Stewardship Council's (MSC) certification of British Columbia's Sablefish fishery on grounds that there was no information about impacts of bottom longline fishing effort on vulnerable habitats (Furness et al. 2010). In response, Wild Canadian Sablefish, Ltd (WCS) joined with Simon Fraser University (S.P. Cox) and Fisheries and Oceans Canada (DFO Pacific Region) to design, build, and deploy an autonomous video camera and motion-sensing system capable of operating at extreme depths of 200 m - 1 800 m where Sablefish occur (Wyeth et al. 2007). The camera system, along with accelerometers and depth sensors, have been deployed annually on selected commercial fishing trips and on the annual stratified-random, fishery-independent Sablefish survey that is jointly funded by WCS and DFO (Wyeth et al. 2007).

In this paper, we report the first results from this collaborative academic-industry-government approach to improving the scientific information for protecting cold-water corals and sponges from bottom contact fishing at SGaan Kinghlas - Bowie (SK-B) Seamount, which is

part of the Bowie Seamount Marine Protected Area created in 2008 under Canada's Oceans Act. The Sablefish fishery by longline trap is the only fishing permitted within the SK-B marine protected area and is restricted to Zone 2 at depths below 457 m (DFO 2015; Fig. 1). Although Zone 2 is greater than 2 500 km² in area, the Sablefish fishery primarily operates at depths between 457 m and 1 500 m, resulting in a potential fished area of approximately 200 km². The scientific challenges of finding and protecting sensitive benthic areas at SK-B are indicative of challenges that are occurring, or are likely to occur in the future, in other areas as Canada aims to implement a large-scale marine protected area strategy (DFO 2005; Government of Canada 2014).

Materials and Methods

In this section we first describe (1) the camera system as developed for Sablefish trap gear, the sampling protocols, and collection of presence-absence data for deep-sea corals and sponges that is needed for habitat suitability modelling. We then describe (2) a new Bayesian method for estimating the bottom locations of the trap cameras and, finally, (3) an algorithm for estimating the bottom-contact area of bottom longline trap gear.

Autonomous video camera system and sampling protocol

The video component of the trap camera system uses a GoPro HD Hero® that produces 1080p video and 4 LED lights (Cree XLamp XM-L) that can generate up to 500 total lumens. The camera, lights, lithium-ion battery pack (Ultra Life UBBL24-FL), depth sensor, and tri-axial accelerometer are all contained within a 3.6 kg stainless steel housing rated to 1 500 m depth.

A custom circuit board and controller contained inside the housing allows programming the cameras to record video at both regularly timed intervals and using motion-activation thresholds via link to an accelerometer that moderates power delivery to the GoPro camera. The battery pack allows camera deployments up to 48-hours with 1-minute video recordings every hour.

Over the 2013-2015 period, we deployed the camera systems on commercial fishing traps for Sablefish at SK-B (Fig. 2) along with external accelerometers (Actilife wGT3x-BT monitors) and depth-temperature sensors (Sea-Bird SBE 39) (Table 1). A total of six trap camera systems were deployed individually in single traps as part of commercial bottom longline sets that each contained between 41 and 60 traps. The vessel position was recorded at the terminal ends of the set, with a linear distance between set endpoints ranging from 1.8 km to 4.0 km (median of 3.0 km). Cameras were programmed to record 1-minute video clips at 2-hour intervals while the trap was stationary on the bottom. Accelerometers within the camera housing system itself were used to trigger additional video recordings of trap movement during gear retrieval at impact forces greater than 0.6 g units. Depth-temperature sensors recorded at 10-second intervals. Traps are a conical design with a circular steel base (hoop) of 137 cm diameter extending to a smaller circular top 84 cm in diameter (Fig. 2). During fishing the traps are connected to stainless steel rings on a polypropylene groundline with approximately 60 kg chain anchors at each end to reduce groundline movement (Wyeth et al. 2007). Fishing sets at SK-B are normally deployed along the slopes of the seamount perpendicular to contour lines with one end of the set in shallow water and the other in deeper water. Gear retrieval typically

begins at the deep end of the set and attempts are made to minimize dragging by pulling the string of connected traps straight up off the bottom.

Video clips were reviewed to record observations of all species, benthic habitat, physical substrate, and gear substrate-interactions (Fig. 3). All epifauna were identified to the lowest taxonomic rank possible, which was typically the order or family level. Lower taxonomic identification of deepwater corals and sponges to genus or species was limited by: (1) a lack of close-up images required to identify distinguishing morphology; (2) views of specimens obstructed by traps, netting, boulders or other animals; (3) an absence of physical samples that are often needed to confirm identification to species level; and (4) the potential for observations of previously undescribed species (Cairns 2007; Austin et al. 2013; Reiswig 2015). Additional video still frames of coral and sponge observations and a list of the resources used for taxa identification are available in Doherty and Cox (2017).

Estimating trap landing locations

We used a Bayesian approach to estimate the bottom landing coordinates of Sablefish traps from 99 fishing sets at SK-B that were deployed with depth sensors. Discrete posterior probability distributions were produced on a square grid by combining trap surface-deployment coordinates, multi-beam bathymetry, and depth sensor data recorded during each set's soak time. We give symbols and notation for the location estimator in Table 2 with the full statistical model given in Table 3.

For each set i we recorded the total number of traps deployed, $N^{(i)}$, and the relative position $n^{(i)}$ of the camera trap (and depth sensor) along the deployment track

187 $(x_{START}^{(i)}, y_{START}^{(i)})$. We estimated the surface deployment coordinates $\mu^{(i)} = (\tilde{x}^{(i)}, \tilde{y}^{(i)})$ of the
 188 camera trap by taking a weighted average of the deployment track start and end locations
 189 (Table 3, equations 3.1-3.3). We assigned the median Sea-Bird depth measurement during the
 190 period that the trap was stationary on the seafloor as the observed landing depth $\hat{d}^{(i)}$.

191 For each set i we produced a 10 m by 10 m resolution Bayesian poster grid $P_{j,k}^{(i)}$ from a
 192 depth likelihood grid $L_{j,k}^{(i)}$ and spatial prior grid $p_{j,k}^{(i)}$ (Table 3, equations 3.4-3.8). The depth
 193 likelihood grid $L_{j,k}^{(i)}$ is computed using a normal density function with mean $\hat{d}^{(i)}$ and variance τ^2
 194 . The depth likelihood function (Table 3.6) assumes that for each 10 m by 10 m cell (j,k) ,
 195 deviations between the bathymetry $b_{j,k}^{(i)}$ for that cell and the observed depth $\hat{d}^{(i)}$ are normally
 196 distributed. We obtained bathymetry values for the depth likelihood grid from 10 m resolution
 197 multibeam bathymetry data for SK-B (Canadian Hydrographic Services, Halcro 2000). We set the
 198 variance of the observation error distribution as $\tau^2 = 1 \text{ m}^2$, based on our assumption that 99%
 199 of the true trap depths lie within 3 m of the observed depth reading $\hat{d}^{(i)}$. This assumption
 200 reflects our knowledge about the instrument's precision and the position of the accelerometer
 201 within the trap, as well as uncertainty about trap orientations, tidal changes, and wave actions
 202 affecting the precision of the depth readings.

203 The spatial prior grid is computed from a bivariate normal density with mean $\mu^{(i)}$ (i.e.,
 204 the initial deployment location) and covariance matrix Σ . We used the spatial prior distribution
 205 (Table 3.7) to penalise the distance of each grid cell's centre $\Theta_{j,k}^{(i)}$ from the estimated
 206 deployment location $\mu^{(i)}$. Deviations from the estimated deployment location are assumed to

have a diagonal covariance matrix Σ with $\Sigma_{1,1} = \Sigma_{2,2} = (\bar{L} / 6)^2$, where $\bar{L}$ is the mean length of a deployment track, calculated as the linear distance between deployment locations of anchors at the start and end of each set. We chose this covariance matrix based on the assumption that 99% of the bottom landing locations of the trap would occur within a circle centred at the deployment location with diameter equal to the length of an average set.

We performed all calculations for the Bayesian posterior grids using the raster package in the R statistical language (R Core Team 2015). The raster package enables grids to be manipulated arithmetically, allowing for bathymetry and spatial grids to be directly substituted for the variables in likelihood and prior functions (Table 3.6, 3.7) to produce likelihood and prior grids, as well as allowing for grids to be combined.

We quantified trap displacement from the deployment location using three metrics from the Bayesian posterior grid. First, we calculated the posterior mean distance of a trap from deployment location as:

$$\hat{\mu}^{(i)} = \sum_{(j,k)} P_{j,k}^{(i)} \cdot (100j^2 + 100k^2)^{1/2} .$$

Second, we computed the distance from the deployment location to the posterior mode, analogous to a maximum posterior density estimate. Finally, we estimated the distance to the posterior medoid, defined as the posterior grid cell with density greater than 0.0001 that was closest to the ordered pair of medians of the marginal easting and northing distributions.

Due to the large number of grid cells (62 500), a uniform probability distribution would assign a probability of 0.0016% to the event that the camera trap lands in any single 10 m square grid cell; therefore, we calculated uncertainty in displacement of traps from deployment

locations for each Bayesian posterior grid as the minimum required size of a square sub-grid centred at a given location and capturing 50% or 95% of the posterior distribution. We used the posterior mode and medoid as centres for the observations because the expected and median values often occur in areas of vanishingly small density.

Trap movement and bottom contact estimates

We used depth measurements, accelerometer data, and video recordings to classify different periods of trap movement and to estimate the bottom contact area of traps during gear retrieval for 2015 commercial fishing sets. Observations from 2013-2014 sets, as well as 3 sets from 2015, were excluded from analyses because time stamps from video recordings and motion-sensing equipment could not be reliably synchronized. We analysed 21 different commercial fishing sets from 2015 and focussed our analysis on the last hour of fishing when gear retrieval occurs because video observations showed that traps were stationary prior to the last hour. The last hour of the set was determined as the final 60 minutes for which depth sensor readings were below 5 m.

We developed an algorithm for classifying gear behaviour during 1-second intervals over the last hour (i.e., 3 600 seconds) of each set using the following measurements:

- depth sensor measurements (d_t),
- the depth change over 10-second intervals ($d_t - d_{t-10}$),
- acceleration (a_t),
- acceleration variance over 10-second intervals ($\sigma^2_{t(t+10)}$),

- and observed trap movement from 1-minute video.

Trap movement was classified as either "stationary", "dragging", or "suspended" (Figs. 4,5), using the following algorithm:

Step 1. Define start and end times for drag window:

a) Choose the start of the drag window as the first time step subject to (s.t.) any 1 of 3 conditions being true, i.e.,

$$t^{start} = \min \left\{ t \text{ s.t. } \begin{array}{l} |d_t - d_{t-10}| > 5 \text{ cm; or} \\ \log \sigma_{t(t+10)}^2 < -10g^2; \text{ or} \\ a_t > a_{video} \end{array} \right\},$$

where a_{video} is the camera's acceleration trigger threshold for recording videos during gear movement.

b) Choose the end of the drag window as the first time step subject to two conditions being simultaneously true:

$$t^{end} = \min \left\{ t \text{ s.t. } t > t^{start} \text{ and } (d_t - d_{t-10}) > 6 \text{ cm} \right\}.$$

Step 2. Determine the class $C_{(t-10):t}$ of trap behaviour over 10-second intervals for each t within the drag window:

$$C_{(t-10):t} = \begin{cases} \text{"stationary"} & d_t = d_{t-10} , \\ \text{"dragging"} & d_t \neq d_{t-10} . \end{cases}$$

Step 3. Set the classes of trap behaviour to $C_{1:(t^{start}-1)} = \text{"stationary"}$ for each t prior to the drag window and $C_{(t^{end}+1):3600} = \text{"suspended"}$ for each t after the drag window.

Video clips of dragging and suspended traps provided lower and upper bounds for the drag window. The difference between the start and end times of the drag window was considered the maximum potential dragging time.

We estimated the distance that a trap is dragged along the bottom by multiplying the estimated drag time by the estimated hauling speed (H) for each set, which we used to approximate the speed at which traps drag along the bottom. Haul speed was calculated using depth and time measurements during gear retrieval while the trap is suspended in the water column between 600 m and 200 m, i.e.,

$$H = \frac{(d_t < 600) - (d_t < 200)}{t_{600} - t_{200}}.$$

Where $d_t < 600$ and t_{600} are the first depth measurement and time during the trap retrieval above 600 m and $d_t < 200$ and t_{200} are the last depth measurement and time during the trap retrieval below 200 m.

We estimated the possible furrow width created by a dragging trap by individually dragging 54-inch (1.37 m) bottom diameter Sablefish traps along a sandy beach in 5 replicates of 5 m distance each (Fig. 6). Measurements of furrow width were taken at 0, 1, 2, 3, 4 and 5 m intervals along the tracks and averaged for each trial. The total bottom contact area of traps during fishing was estimated by multiplying the mean drag furrow width by the estimated trap

drag lengths for each set. An estimate of the bottom contact area for a typical 60-trap set was then obtained by multiplying the trap bottom contact area by 60 for each set.

Results

Direct observations of coral and sponge presence-absence

Deepwater corals or sponges were present at 26 locations and absent at 66 locations out of the 92 camera deployments that successfully obtained video of the bottom substrate at SK-B seamount (Table 4, Fig. 7). Gorgonian corals (Order Alcyonacea) were the most commonly observed and diverse group with at least 6 different species or taxonomic groups, including *Heteropolypus ritteri*, Isididae spp., *Paragorgia* spp., *Parastenella* sp., Primnoidae sp., and *Swiftia simplex*. We also observed sponges (Classes Demospongiae and Hexactinellida), seapens (Order Pennatulacea), hydrocorals (Family Stylasteridae) and black coral (Order Antipatharia) during camera deployments. The highest observed concentration of gorgonian corals was observed along the southwest and northeast flanks of the seamount. There were fewer locations with presence observations of sponges (7), sea whips (5), hydrocorals (3), and black corals (1) without any obvious consistency in their locations (Table 4, Fig. 7). Here we only show trap camera observations in 2 km by 2 km grid cells due to privacy restrictions associated with commercial fishing data, however the trap location estimator can provide higher spatial resolution for camera observations.

Trap location estimator

Fig. 8 provides an example of the components involved in the posterior grid computation for estimating trap location on the bottom. Fig. 8a shows the 10 m resolution multi-beam bathymetry for a 1.25 km² area surrounding the initial trap deployment location along with the depth likelihood function grid (Fig. 8b) given by the observed depth at the trap bottom location. The depth likelihood is then combined with the spatial prior grid (only the prior mean is shown as the intersection of dashed vertical and horizontal lines) to produce the final posterior grid (Fig. 8c), which in this case shows approximately 100 m northward displacement of the trap from its deployment location at the surface. Closer inspection of the posterior grid (Fig. 8d) shows that the posterior medoid location is on the very edge of the probability space, while the posterior mode lies within a larger region of reasonably high probability.

All three methods of estimating displacement from the deployment location are unimodal and highly left-skewed with an outlier at approximately 1200 m (Fig. 9). Based on the posterior mean estimator, expected displacement from the deployment location was greater than 200 m for all sets (median = 388 m; Fig. 9a), due to ridges of high likelihood extending along contours with the correct depth (see Fig. 8b). Displacements derived from the posterior mode estimator were closer to the surface deployment location (median = 203 m; Fig. 9b), while those derived from posterior medoids were in between the mean and mode (median = 265 m; Fig. 9c). Uncertainty in displacement from deployment locations, measured as squares that capture 50% of the posterior density, have side lengths of 430 m based on the modes and

329 390 m based on posterior medoids, while squares that capture 95% of the posterior density
330 have side lengths of 1 190 m (mode) and 1 150 m (medoid).

331 The maximum probability of a camera trap landing in a single 10 m square cell ranged
332 from 0.6% to 4.6% across all 99 sets. Depth of the set was not correlated with the distance
333 from deployment (Pearson $R^2 < 0.2$ based on posterior medoids).

334
335 **Bottom-contact area**

336 The results from the classification of trap movement and estimates of bottom contact
337 area are shown in Fig. 10 and Table 5. These statistics exclude one set where the trap was
338 wedged in a rock crevice that prevented any trap movement during retrieval, because this
339 behaviour was not observed in any of the other 92 sets with video observations. The estimated
340 drag window and drag time for the excluded set were 5.9 minutes and 0.4 minutes,
341 respectively. The mean estimated bottom contact area for a 54-inch trap was 53 m² (95% CI=
342 40-65 m²), which is nearly 36 times the static trap footprint of 1.47 m² (i.e., the bottom area of
343 the trap). Variability in the estimated drag times and drag lengths dominated bottom area
344 calculations compared to less variable haul speeds and drag widths (Fig. 10).

345 The start of the drag window is indicated by an increase in the acceleration variance and
346 increased magnitude of depth change (Figs 4,5). As gear retrieval continues, there is a
347 noticeable decrease in depth until eventually the trap moves vertically off the bottom and
348 becomes suspended in the water column (e.g., the end of the drag window). When this occurs,
349 there is usually a decrease in acceleration variance and a positive increase in the rate of depth
350 change (Figs. 4,5).

Video observations, depth and accelerometer data indicate that traps do not always drag continuously (Fig. 5) and that traps can start and stop dragging frequently during gear retrieval. The stationary intervals during the drag window were classified as such when the rate of depth change for a 10-second interval was zero (Step 2). This step of the classifying algorithm is important since deviations between the drag window and the estimated drag time can be substantial (Fig. 11). The estimated mean drag window (i.e., the period in which there is potential for the gear to drag along the seafloor) was 1.25 times longer than the estimated mean drag time (Table 5). The maximum difference between the drag window and drag time estimates was 9 minutes, where the drag window was nearly 2.9 times longer than the estimated drag time. If the drag window was used in the bottom footprint calculation, the mean footprint would be 4 000 m² instead of the 3 200 m² calculated using the estimated drag time, which would overestimate the contact area.

Video observations from trap cameras deployed at SK-B and during the Sablefish survey confirm that the polypropylene groundline remains suspended off-bottom; however, because the trap camera field of view is pointed at the substrate, there are limited groundline observations. The groundline is only visible when traps land upside down or are rotated during gear retrieval to allow a camera view of the water column and space above the traps. There were 33 sets at SK-B where the groundline could be viewed while under tension off the bottom when traps were moving along the seafloor. Note that these videos only provide a view of a small portion of the groundline that is directly above the trap.

371 Discussion

372 Contemporary fisheries are increasingly challenged to improve conservation of both fish
373 stocks and essential habitats as part of government and eco-certification requirements. (DFO
374 2010; Furness et al. 2010; Heupel and Auster 2013). Fisheries in Canada will also need to adapt
375 to a growing number of marine protected area (MPA) closures. The Government of Canada
376 recently re-affirmed commitments to protect 10% of coastal and marine waters by 2020 as part
377 of the Aichi Biodiversity Targets, with plans to implement half this area by 2017. For habitat
378 conservation, in particular, we lack the detailed knowledge about distribution, composition,
379 vulnerability, and habitat productivity necessary to effectively protect important deepwater
380 habitats. In this paper, we demonstrate how a collaborative academic-industry-government
381 approach to studying deepwater ocean habitats and the risks posed by longline trap fishing
382 gear could provide an improvement in our ability to design and implement protections for
383 sensitive benthic habitats. In particular, we obtained (1) high-quality presence-absence
384 observations for corals and sponges over a large area within the SK-B Seamount MPA and (2)
385 direct video observations of trap interactions with the seafloor, which we combined with
386 accelerometer and depth sensors to develop an algorithm for estimating the bottom contact
387 area of longline trap gear.

388

389 Understanding bottom contact area of longline trap gear

390 Video observations and accelerometer measurements confirm that Sablefish traps are
391 typically stationary once the gear has settled on the bottom and that the main interaction with
392 the seafloor occurs by traps over a short window of time when traps drag along the bottom

during the gear retrieval. For the fishing sets analysed at SK-B, gear retrieval usually begins at the deep end of the set and the short period of increasing depth sensor measurements observed during the drag window suggest that traps initially drag in the downslope direction during hauling. Video and accelerometer data also indicate that traps start and stop dragging frequently during gear retrieval, presumably because of stoppages to remove catch as traps reach the surface.

Our trap location estimator allows relatively accurate mapping of the fishing effort distribution on the seafloor, as well as the footprint within or near sensitive benthic habitats. Such information could be used to quantitatively determine longline trap gear footprints at the relatively fine-scale resolution needed to inform coral and sponge risk assessments at SK-B. The distribution of distances between deployment locations and estimated landing positions also provides valuable information that can be used to determine the appropriate area and buffers for closures designed to protect sensitive habitats. Delineating borders and different zoning for conservation areas in Canada can occur on a scale of 100 - 1000 m for many smaller scale (e.g., 0.6 - 475 km²) fishery closures designed to protect sponge (e.g., Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, Strait of Georgia Glass Sponge Reef Closures, Sambro Bank, Emerald Basin) and coral habitats (e.g., Northeast Channel Coral Conservation Area, Lophelia Coral Conservation Area, The Gully MPA, SK-B Seamount MPA Zone 1). Inaccurate spatial mapping and inappropriate buffer sizes in these kinds of closures may unnecessarily reduce fishing opportunities or reduce the effectiveness of closures designed to protect SBAs.

Estimates in this study are from a small sample size of fishing trips at SK-B seamount; trap footprint and deployment distances may differ for other fishing vessels, fishing conditions,

and fishing areas on the coast. For instance, the outlier displacement estimate of 1200 m from the deployment location may be the result of towing the gear or high currents during trap deployment. Further experiments under different fishing conditions will likely improve our ability to estimate how different environmental conditions and fishing characteristics influence gear displacement from drop locations, as well as different gear behaviour during retrieval. As part of that work, upgrades to our camera systems could automatically obtain GPS location data for the vessel at the trap camera deployment and surface retrieval, rather than using crude start and end deployment locations in the Bayesian spatial prior distributions.

Our approach to estimating gear movement can be adapted to other types of bottom longline fisheries (e.g., longline hook, other trap gear, and bottom trawls). This will allow a quantitative assessment of the cumulative impacts and comparison of footprints from different bottom-contact fisheries in overlapping areas (Welsford et al. 2014a). For example, our mean estimate of the footprint for a 60-trap longline Sablefish set ($3\,200\text{ m}^2$) is 6% of the mean footprint estimates for bottom longline hook sets ($55\,000\text{ m}^2$) in the Heard Island and McDonald Islands off Antarctica, based on a footprint width of 6.2 m and mean set length of 8.9 km (Ewing and Kilpatrick 2014; Welsford et al. 2014a). Estimates of footprint widths do not exist for the different BC longline hook fisheries (Fig. 1), and set lengths are shorter with median lengths of 3.0 km, 2.6 km, 2.4 km and 1.8 km for sets during 2006-2011 in the Sablefish trap, and Halibut, Schedule II and ZN longline hook fisheries, respectively (data from DFO groundfish database archived at the Pacific Biological Station in Nanaimo, BC). Bottom trawl footprint estimates vary based on the width of the trawl net and the length of the tow, and are much larger than longline hook and trap footprints. The mean trawl footprints per fishing event

estimated by Welsford et al. (2014a) ranged from 295 000 m² - 1 134 000 m² for 4 different vessels, based on footprint widths ranging from 100 - 160 m and mean tow lengths ranging from 2.9 - 7.6 km. Other metrics can also be used to compare the bottom impacts of different fishing gear, such as the footprint per hour of fishing (Eigaard et al. 2015) or catch per m² of bottom contact.

Our analysis focused on measuring the bottom contact area of traps, as our observations indicate this is the largest contributor to total bottom contact area of Sablefish longline trap fishing gear. The two anchors at terminal set ends are also in contact with the bottom (Fig. 2) and there is potential for occasional groundline bottom contact, but the footprint of these gear components is considered small relative to the trap footprint. There were two 1-minute video clips where the groundline was observed in close proximity to the bottom, suggesting that it is possible that the groundline may occasionally contact the bottom or entangle larger free-standing structures in certain fishing conditions (e.g., in areas with high rugosity or steep bathymetry), although this was not observed. Given the large variability in trap footprint estimates for different sets, there may be marginal benefits to quantifying anchor and groundline bottom contact for this particular gear.

Longline trap gear used in the B.C. Sablefish fishery appears to have properties that result in smaller footprints in comparison with other longline hook and trap gears. For example, as confirmed by video observations, extruded polypropylene groundline on Sablefish trap gear is buoyant even at extreme depths and rarely contacts the seafloor. Lack of bottom contact means that lateral movement of the groundline during retrieval is less likely to cause damaging shearing effects along the bottom as observed for groundlines used in longline hook fisheries

(Ewing and Kilpatrick 2014). In addition, conical traps with a circular base create narrower furrow widths during dragging compared to a square trap base of the same total area. The trap bridle connection at the top of a Sablefish trap causes traps to drag on their sides during retrieval resulting in a footprint width during dragging that is much less than the trap bottom diameter. In contrast, observed drag furrows created by box-shaped King crab pots on longlines in Alaska ranged from 2 m to 9 m (Stone 2006) for 2.4 x 2.4 m pots. We measured furrow widths created by dragging traps on a beach with wet sand to simulate the drag paths created during fishing operations; however, in situ observations of furrow widths could be obtained via video using camera configurations that provide unobstructed views of fishing gear (see Kilpatrick et al. 2011), or via scuba diving alongside traps retrieved in shallower water.

Next Steps - Understanding risks to seafloor habitats

The first two steps in evaluating specific fishery risks to deep-sea bottom habitats are (1) collecting data to map the locations of sensitive benthic areas and (2) calculating the seafloor area that is contacted by fishing gear. In this study we've described the methods and on-going data-collection that can provide this information by generating high-resolution habitat suitability maps and estimating the historical fishing footprint at SK-B. Additional information such as estimates of fishing mortality and recovery rates from damage, as well as methods to mitigate bottom-contact, are also important, but beyond the scope of this paper.

The trap location estimates provide more accurate coordinates for camera observations that can improve species distribution modelling. This is important because accurate mapping of SBAs will increase the effectiveness of management measures designed to protect bottom

habitats and can reduce lost fishing opportunities arising from large-scale fishing closures that include areas that may not actually contain SBAs. Typical species distribution models extract predictor variables from existing environmental data or oceanographic models (Rooper et al. 2014; Lagasse et al. 2015) based on the position of the observation even though there can be considerable uncertainty for observations collected during fishing activities. For example, the potential location of coral and sponge bycatch can span several km for data collected during bottom trawling. For the trap camera-based observations, the posterior mode or medoid estimates of trap locations provide the best location estimates given the data available, and can allow for more relevant selection of predictor variable locations used in model fitting. As an alternative to using a single grid-cell as a point-estimate of locations, the posterior density also provides a probability distribution that can be used to weight multiple grid cells when extracting predictor data from environmental raster layers.

Risks to habitat are not only influenced by the amount of gear that is deployed per year and the frequency that specific areas are contacted, but also by the cumulative effects over multiple fishing years and the recovery rates during the time between subsequent contact-events (Constable 2009). Our bottom footprint estimates can be used to identify potential at-risk SBAs within the SK-B Seamount MPA where high historical fishing intensity overlaps with areas of high probability for coral or sponge presence. For instance, we could use the historical trap deployment locations at SK-B along with the estimated contact area for each trap to estimate the frequency and cumulative trap gear contact for each patch of seafloor. Thus, the next step in understanding fishing bottom impacts is to estimate the mortality rate or damage to coral or sponge populations that occurs when fishing gear lands in a specific area, as well as

recovery rates from fishing damage. For example, Ewing et al. (2014) estimated the probability that individuals or colonies within the bottom contact-area of different fishing gears would experience no damage, sub-lethal damage or lethal damage, based on a variety of data sources such as life history, morphology and in-situ observations. Both High (1998) and Eno et al. (2001) observed cases where flexible corals bent during contact with traps and longlines and showed no apparent damage. Non-lethal damage such as lesions to gorgonian coenenchyme can allow for full recovery, however in some cases it may also increase the probability of lethal damage from future fishing events (Bavestrello et al. 1997; Ewing et al. 2014). Different species or groups of species will also have different recovery rates from fishing damage. Rooper et al. (2011) estimated intrinsic growth rates for corals and sponges in the Aleutian Islands were slow and that recovery from a large mortality of biomass could take several decades. More detailed studies on the life history of specific coral and sponge species that occur in SK-B could reduce parameter uncertainty and improve our ability to assess fishing risks to these habitats.

Our approach to estimating the bottom footprint of longline trap gear provides a method to estimate and compare the bottom-contact area of different fishing events, which, in turn, can be used to evaluate strategies aimed at minimizing fishing footprints and risks to SBAs. For example, it is likely that certain fishing characteristics (e.g., hauling speed, haul direction, catch, crew experience) combine with environmental conditions (e.g., depth, slope, rugosity, current, wind) to affect the size of the trap footprint. Thus, direct estimates of the fishing footprint can provide the data needed to test how alternative gear modifications (e.g., trap numbers, trap size, trap shape, bridle connections, groundline material) and hauling procedures could reduce bottom impacts. In this study, we only examined traps deployed in the

middle of the set, assuming the same footprint applied over the full set; however, it may be that traps at either end of the string may drag more or less than traps located in the middle.

Future research could deploy cameras, accelerometers, and depth sensors on multiple traps along the set to improve footprint estimates and understanding of gear behaviour. Furthermore, the small size and relatively low expense accelerometers (e.g., \$100 - \$250 USD), could be deployed much more broadly on commercial fishing sets to capture a wider range of our gear behaviour.

Conclusion

The deployment of cameras and motion-sensing equipment on commercial fishing gear, such as Sablefish traps, can provide regular observations of biological communities on the seabed as well as the information needed to estimate the bottom footprint of the gear. These direct observations provide valuable information needed to investigate strategies for reducing risks to sensitive bottom habitats, while still allowing fisheries access to valuable fishing grounds. Advances in technology and miniaturization create massive potential to expand this approach to larger spatial scales, which would allow greater fishing industry contributions toward mapping sensitive benthic areas and informing ecosystem-based management.

Acknowledgements

The authors thank Wild Canadian Sablefish Ltd (WCS) for their financial and in-kind support in all stages of this project from the initial design to field deployments and analysis. We especially thank the fishing masters who expertly deployed/retrieved camera traps on

547 commercial fishing sets. Additional funding was provided by the NSERC Canadian Fisheries
548 Research Network (S.P.C.), the NSERC Discovery Grants program (S.P.C.), NSERC Canada
549 Graduate Scholarship program (B.D.), and the Mitacs Accelerate Cluster Grants program (S.P.C.
550 and WCS). This project was also made possible by Fisheries and Oceans Canada Science staff K.
551 Anderson, A.R. Kronlund, L. Lacko, and M. Wyeth who assisted with camera design, data
552 collection, equipment preparation, and training of at-sea observers We also thank Jonathan
553 Martin and Nuytco Research Ltd. for their contributions to the design and manufacturing of the
554 deepwater camera system.

555

Draft

References

- Austin, W.C., Ott, B.S., Reiswig, H.M., Romagosa, P., and McDaniel, N.G. 2013. Two new species in the family Axinellidae (Porifera, Demospongiae) from British Columbia and adjacent waters. *ZooKeys* **338**: 11-28. doi: 10.3897/zookeys.338.5535.
- Bavestrello, G., Cerrano, C., Zanzi, D., and Cattaneo-Vietti, R. 1997. Damage by fishing activities to the Gorgonian coral *Paramuricea clavata* in the Ligurian Sea. *Aquat. Conserv.* **7**(3):253–262.
- Bo, M., Bava, S., Canese, S., Angiolillo, M., Cattaneo-Vietti, R., and Bavestrello, G. 2014. Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. *Biol. Conserv.* **171**:167–176.
- Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J., and Raes, M. 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. *Mar. Ecol.* **31**: 21–50. doi:10.1111/j.1439-0485.2010.00359.x.
- Cairns, S.D. 2007. Calcaxonian Octocorals (Cnidaria: Anthozoa) from Eastern Pacific Seamounts. *Proc. Calif. Acad. Sci.* **58**: 511–541.
- Clark, M.R., Althaus, F., Schlacher, T.A., Williams, A., Bowden, D.A., and Rowden, A.A. 2015. The impacts of deep-sea fisheries on benthic communities: a review. *ICES J. Mar. Sci.* doi:10.1093/icesjms/fsv123.
- Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *J. Anim. Ecol.* **69**(5):785–798.

- 576 Constable, A. 2014. A simulation model for evaluating management strategies to conserve
577 benthic habitats (vulnerable marine ecosystems) which are potentially vulnerable to impacts
578 from bottom fisheries. *In* Demersal fishing interactions with marine benthos in the Australian
579 EEZ of the Southern Ocean: An assessment of the vulnerability of benthic habitats to impact by
580 demersal gears. *Edited by* D.C. Welsford, G.P. Ewing, A.J. Constable, T. Hibberd, and R.
581 Kilpatrick. Australian Antarctic Division. pp. 247-255.
- 582 DFO. 2005. Canada's federal marine protected areas strategy. Fisheries and Oceans Canada.
583 Ottawa, Ontario.
- 584 DFO. 2010. Pacific region cold-water coral and sponge conservation strategy 2010-2015. Oceans
585 Program, Fisheries and Oceans Canada, Vancouver, BC.
- 586 DFO. 2015. Sablefish Commercial Harvest Plan. *In* Pacific Region Groundfish Integrated Fisheries
587 Management Plan. Version 1.3. pp. 1-25 appendix 7.
- 588 Doherty, B., and Cox, S. 2017. Data summary of trap camera video obtained during Sablefish
589 bottom longline trap fishing at SGaan Kinghlas - Bowie Seamount, 2014-2015. Can. Dat. Rep.
590 Fish. Aquat. Sci. 1276. Fisheries and Oceans Canada.
- 591 Durán Muñoz, P., Murillo, F.J., Sayago-Gil, M., Serrano, A., Laporta, M., Otero, I., and Gómez, C.
592 2011. Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic
593 ecosystem, north-east Atlantic. J. Mar. Biol. Assoc. U.K. **91**(4): 939–952.
- 594 Eigaard, O.R., Bastardie, F., Breen, M., Dinesen, G.E., Hintzen, N.T., Laffargue, P., Mortensen,
595 L.O., Nielsen, J.R., Nilsson, H.C., O'Neill, F.G., Polet, H., Reid, D.G., Sala, A., Skold, M., Smith, C.,

- 596 Sorensen, T.K., Tully, O., Zengin, M., and Rijnsdorp, A.D. 2015. Estimating seabed pressure from
597 demersal trawls, seines, and dredges based on gear design and dimensions. ICES J. Mar. Sci.
598 doi:10.1093/icesjms/fsv099.
- 599 Ewing, G., and Kilpatrick, R. 2014. Estimating the gear footprint of demersal trawl and longline
600 fishing gears used in the Heard Island and McDonald Islands fisheries. *In* Demersal fishing
601 interactions with marine benthos in the Australian EEZ of the Southern Ocean: An assessment
602 of the vulnerability of benthic habitats to impact by demersal gears. *Edited by* D.C. Welsford,
603 G.P. Ewing, A.J. Constable, T. Hibberd, and R. Kilpatrick. Australian Antarctic Division. pp. 176-
604 198.
- 605 Ewing, G., Hibberd, T., and Welsford, D. 2014. Assessing the resistance of vulnerable benthic
606 taxa to disturbance from demersal fishing in the HIMI region. *In* Demersal fishing interactions
607 with marine benthos in the Australian EEZ of the Southern Ocean: An assessment of the
608 vulnerability of benthic habitats to impact by demersal gears. *Edited by* D.C. Welsford, G.P.
609 Ewing, A.J. Constable, T. Hibberd, and R. Kilpatrick. Australian Antarctic Division. pp. 226-245.
- 610 Eno, N.C., MacDonald, D.S., Kinnear, J.A., Amos, S.C., Chapman, C.J., Clark, R.A., Bunker, F.S.P.,
611 and Munro, C. 2001. Effects of crustacean traps on benthic fauna. ICES J. Mar. Sci. **58**:11–20.
612 doi:10.1006/jmsc.2000.098.
- 613 Furness, R., Knapman, P., Nichols, J., and Scott, I. 2010. MSC assessment report for the
614 Canadian Pacific Sablefish (*Anoplopoma fimbria*) fishery. Moody International.
- 615 Government of Canada. 2014. Canada – British Columbia marine protected area network
616 strategy.

- 617 Halcro, K. 2000. July/August trip report: Pacific report, NOAA Ship Rainier, Kodiak Island area,
618 Bowie & Hodgkins seamounts. Canadian Hydrographic Service, Department of Fisheries and
619 Oceans, Institute of Ocean Sciences, Sidney, BC.
- 620 Hastie, T., and Fithian, W. 2013. Inference from presence-only data; the ongoing controversy.
621 *Ecography* **36**: 864–867. doi: 10.1111/j.1600-0587.2013.00321.x .
- 622 Heifetz, J., Stone, R.P., and Shotwell, S.K. 2009. Damage and disturbance to coral and sponge
623 habitat of the Aleutian Archipelago. *Mar. Ecol. Prog. Ser.* **397**: 295–303.
624 doi:10.3354/meps08304
- 625 Heupel, E., and Auster, P.J. 2013. Eco-labeling seafood: Addressing impacts to vulnerable
626 seafloor species, communities, habitats and ecosystems in data-poor regions. *Mar. Pol.* **38**: 8-
627 15.
- 628 High, W.L. 1998. Observations of a scientist/diver on fishing technology and fisheries biology.
629 Alaska Fisheries Science Center Processed Report 98-01, National Marine Fisheries Service,
630 National Oceanic Atmospheric Administration, Seattle, WA.
- 631 Hourigan, T. 2009. Managing fishery impacts on deep-water coral ecosystems of the USA:
632 Emerging best practices. *Mar. Ecol. Prog. Ser.* **397**: 333–340. doi: 10.3354/meps08278.
- 633 Hourigan, T.F., Lumsden, S.E., Dorr, G., Bruckner, A.W., Brooke, S., and Stone, R.P. 2007. Deep
634 coral ecosystems of the United States: Introduction and national overview. *In* The State of Deep
635 Coral Ecosystems of the United States. *Edited* by S.E. Lumsden, T.F. Hourigan, A.W. Bruckner,
636 and G. Dorr. NOAA Tech Memo CRCP-3. pp. 1-64.

- 637 Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. 2006.
638 Global analysis of response and recovery of benthic biota to fishing. *Mar. Ecol. Prog. Ser.* **311**:
639 1–14.
- 640 Kilpatrick, R., Ewing, G., Lamb, T., Welsford, D., and Constable, A. 2011. Autonomous video
641 camera system for monitoring impacts to benthic habitats from demersal fishing gear, including
642 longlines. *Deep-Sea Res. Pt. I.* **58**(4): 486–491.
- 643 Krieger, K.J., and Wing, B.L. 2002. Megafauna associations with deepwater corals (*Primnoa*
644 spp.) in the Gulf of Alaska. *Hydrobiologia* **471**: 83–90.
- 645 Lagasse, C.R., Knudby, A., Curtis, J., Finney, J.L., and Cox, S.P. 2015. Spatial analyses reveal
646 conservation benefits for cold-water corals and sponges from small changes in a trawl fishery
647 footprint. *Mar. Ecol. Prog. Ser.* **528**: 161–172. doi: 10.3354/meps11271.
- 648 Mortensen, P.B., and Buhl-Mortensen, L. 2004. Distribution of deep-water gorgonian corals in
649 relation to benthic habitat features in the northeast channel (Atlantic Canada). *Mar. Biol.* **144**:
650 1223–1238. doi: 10.1007/s00227-003-1280-8.
- 651 Pham, C.K., Diogo, H., Menezes, G., Porteiro, F., Braga-Henriques, A., Vandeperre, F., and
652 Morato, T. 2014. Deep-water longline fishing has reduced impact on vulnerable marine
653 ecosystems. *Sci. Rep.* **4**:4837. doi: 10.1038/srep04837.
- 654 R Core Team. 2015. R: A language and environment for statistical computing. R foundation for
655 statistical computing, Vienna, Austria.

- 656 Reiswig, H. 2015. First Lanuginellinae (Porifera, Hexactinellida, Rossellidae) from the NE Pacific
657 and first species of *Doconesthes* from the Pacific Ocean. *Zootaxa* **3920**(4): 572–578.
- 658 Rooper, C.N., Wilkins, M.E., Rose, C.S., and Coon, C. 2011. Modeling the impacts of bottom
659 trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands,
660 Alaska. *Continental Shelf Research* **31**: 1827–1834. doi:10.1016/j.csr.2011.08.003.
- 661 Rooper, C.N., Zimmermann, M., Prescott, M.M., and Hermann, A.J. 2014. Predictive models of
662 coral and sponge distribution, abundance and diversity in bottom trawl surveys of the Aleutian
663 Islands, Alaska. *Mar. Ecol. Prog. Ser.* **503**: 157–176. doi:10.3354/meps10710.
- 664 Sampaio, I., Braga-Henriques, A., Pham, C., Ocaña, O., De Matos, V., Morato, T., and Porteiro,
665 F.M. 2012. Cold-water corals landed by bottom longline fisheries in the Azores (north-eastern
666 Atlantic). *J. Mar. Biol. Assoc. U.K.* **92**(7): 1547–1555.
- 667 Sainsbury, K.J., Campbell, R.A., Lindholm, R., and Whitelaw, A.W. 1997. Experimental
668 management of an Australian multispecies fishery: examining the possibility of trawl-induced
669 habitat modification. *In* *Global Trends: Fisheries Management*. Edited by E.K. Pikitch, D.D.
670 Huppert, and M.P. Sissenwine. American Fisheries Society. pp. 107–112.
- 671 Sinclair, A.F., Conway, K.W., and Crawford, W.R. 2005. Associations between bathymetric,
672 geologic and oceanographic features and the distribution of the British Columbia bottom trawl
673 fishery. *In* *Annual Science Conference of the International Council for Exploration of the Sea*,
674 Scotland, UK, 20 September 2005. ICES CM 2005/L:25.

- 675 Stone, R.P. 2006. Coral habitat in the Aleutian Islands of Alaska: Depth distribution, fine-scale
676 species associations, and fisheries interactions. *Coral Reefs* **25**: 229–238. doi:10.1007/s00338-
677 006-0091-z.
- 678 Stone, R.P., Masuda, M.M., and Karinen, J.F. 2014. Assessing the ecological importance of red
679 tree coral thickets in the eastern Gulf of Alaska. *ICES J. Mar. Sci.* doi:10.1093/icesjms/fsu190.
- 680 Troffe, P.M., Levings, C.D., Piercey, G.E., and Keong, V. 2005. Fishing gear effects and ecology of
681 the sea whip (*Halipteris willemoesi* (Cnidaria: Octocorallia: Pennatulacea)) in British Columbia,
682 Canada: Preliminary observations. *Aquat. Conserv.* **15**: 523–533. doi:10.1002/aqc.685.
- 683 Wallace, S., Turris, B., Driscoll, J., Bodtker, K., Mose, B., and Munro, G. 2015. Canada's pacific
684 groundfish trawl habitat agreement: A global first in an ecosystem approach to bottom trawl
685 impacts. *Mar. Pol.* **60**: 240–248.
- 686 Welsford, D., Sumner, M., and Ewing, G. 2014a. Estimates of the multi-gear footprint of the
687 toothfish fishery at HIMI. *In* Demersal fishing interactions with marine benthos in the Australian
688 EEZ of the Southern Ocean: An assessment of the vulnerability of benthic habitats to impact by
689 demersal gears. *Edited by* D.C. Welsford, G.P. Ewing, A.J. Constable, T. Hibberd, and R.
690 Kilpatrick. Australian Antarctic Division. pp. 199-210.
- 691 Welsford, D., Ewing, G., Constable, A., Hibberd, T., and Kilpatrick, R. 2014b. Demersal fishing
692 interactions with marine benthos in the Australian EEZ of the Southern Ocean: An assessment
693 of the vulnerability of benthic habitats to impact by demersal gears. Australian Antarctic
694 Division. FRDC project 2006/042.

- 695 Williams, A., Schlacher, T.A., Rowden, A.A., Althaus, F., Clark, M.R., Bowden, D.A., Stewart, R.,
696 Bax, N.J., Consalvey, M., and Kloser, R.J. (2010). Seamount megabenthic assemblages fail to
697 recover from trawling impacts. *Mar. Ecol.* **31**(S1):183–199. doi:10.1111/j.1439-
698 0485.2010.00385.x.
- 699 Woodby, D., Carlile, D., and Hulbert, L. 2009. Predictive modeling of coral distribution in the
700 Central Aleutian Islands, USA. *Mar. Ecol. Prog. Ser.* **397**: 227–240. doi:10.3354/meps08358.
- 701 Wright, G., Ardron, J., Gjerde, K., Currie, D., and Rochette, J. 2015. Advancing marine
702 biodiversity protection through regional fisheries management: A review of bottom fisheries
703 closures in areas beyond national jurisdiction. *Mar. Pol.* **61**: 134–148.
- 704 Wyeth, M.R., Kronlund, A.R., and Elfert, M. 2007. Summary of the 2004 British Columbia
705 Sablefish (*Anoplopoma fimbria*) research and assessment survey. Can. Tech. Rep. Fish. Aquat.
706 Sci. 2694. Fisheries and Oceans Canada, Nanaimo, B.C.

Table 1. Summary of data collection requirements and the number of commercial sets at SK-B (e.g. sample sizes) included in the three different analyses.

Estimates/Observations	Sets	Years	Equipment
Coral and sponge presence/absence	92	2013-2015	Camera
Trap location	99	2013-2015	Depth sensor
Trap movement	20	2015	Depth sensor
			Accelerometer
			Cameras

1

Draft

2

Table 2. Symbol definitions for the trap location estimator and the trap movement classifier.

Symbol	Definition
Trap location estimator	
x	Eastings coordinate
y	Northings coordinate
$\Theta_{j,k}^{(i)}$	Trap location estimator grid cell centres for trap string i
$b_{j,k}^{(i)}$	Bathymetry data from cell (j,k) of grid for trap string i (m)
$\hat{d}^{(i)}$	Median depth measurement of trap string i while trap classified as stationary (m)
$x_{START}^{(i)}$	Eastings coordinate of start of deployment track for trap string i
$y_{START}^{(i)}$	Northings coordinate of start of deployment track for trap string i
$x_{END}^{(i)}$	Northings coordinate of end of deployment track for trap string i
$y_{END}^{(i)}$	Northings coordinate of end of deployment track for trap string i
$N^{(i)}$	Total number of traps deployed in set i
$n^{(i)}$	Ordinal number indicating position in set of trap containing SeaBird depth sensor
$\tilde{x}^{(i)}$	Estimated eastings coordinate of SeaBird deployment location
$\tilde{y}^{(i)}$	Estimated northings coordinate of SeaBird deployment location
τ^2	Depth measurement error variance
Σ	Covariance matrix for spatial prior distribution
$\bar{l}$	Mean length of a trap deployment track

$L_{j,k}^{(i)}$ Likelihood function value at grid cell reference (j,k) for set i

$p_{j,k}^{(i)}$ Prior probability at grid cell reference (j,k) for set i

$P_{j,k}^{(i)}$ Posterior probability at grid cell reference (j,k) for set i

Trap movement classifier

d_t Depth sensor measurements at 10 second intervals

a_t Acceleration (g) at 1 second intervals

a_{video} Camera acceleration trigger threshold for motion-activated video recording

$\sigma_{t(t+10)}^2$ Acceleration variance over 10-second interval using 10 Hz acceleration

3

4

5

6

Table 3. Statistical model for computing the grid of posterior probabilities for trap camera locations.

Deployment Location	
(3.1)	$\tilde{x}^{(i)} = x_{START}^{(i)} + \frac{n^{(i)}}{N^{(i)}} \left(x_{END}^{(i)} - x_{START}^{(i)} \right)$
(3.2)	$\tilde{y}^{(i)} = y_{START}^{(i)} + \frac{n^{(i)}}{N^{(i)}} \left(y_{END}^{(i)} - y_{START}^{(i)} \right)$
(3.3)	$\mu^{(i)} = (\tilde{x}^{(i)}, \tilde{y}^{(i)})$
Grid Cells	
(3.4)	$(j, k) \in \{-124, -123, \dots, 124, 125\}^2$
(3.5)	$\Theta_{j,k}^{(i)} = (\tilde{x}^{(i)} + 10j, \tilde{y}^{(i)} + 10k)$
Likelihood Grid	
(3.6)	$L_{j,k}^{(i)} = \mathcal{L}^{(i)} \left(\Theta_{j,k}^{(i)} \mid \hat{d}^{(i)}, \tau^2 \right) = \frac{1}{\sqrt{2\pi\tau^2}} e^{-\frac{(b_{j,k}^{(i)} - \hat{d}^{(i)})^2}{2\tau^2}}$
Prior Grid	
(3.7)	$p_{j,k}^{(i)} = p \left(\Theta_{j,k}^{(i)} \mid \mu^{(i)}, \Sigma \right) = \frac{1}{2\pi\sqrt{ \Sigma }} e^{-\left(\Theta_{j,k}^{(i)} - \mu^{(i)} \right)^T \Sigma^{-1} \left(\Theta_{j,k}^{(i)} - \mu^{(i)} \right)}$
Posterior Grid	
(3.8)	$P_{j,k}^{(i)} = \frac{L_{j,k}^{(i)} \cdot p_{j,k}^{(i)}}{\sum_{(j,k)} L_{j,k}^{(i)} \cdot p_{j,k}^{(i)}}$

7

8

Table 4. Presence(P)-absence(A) frequencies by sampling year, and total frequencies and percentages over all years from 92 video sample sites during May 2013-2015 Sablefish fishing trips at SK-B Seamount.

Observations	2013	2014	2015	2013-2015		
	P-A	P-A	P-A	P-A	% P	%A
Gorgonian corals (Order Alcyonacea)	3-9	9-45	6-20	18-74	20	80
Sponges (Phylum Porifera)	4-8	3-51	0-26	7-85	8	92
Sea whips (Order Pennatulacea)	1-11	2-52	2-24	5-87	5	95
Hydrocorals (Family Stylasteridae)	1-11	2-52	0-26	3-89	3	97
Black corals (Order Antipatharia)	1-11	0-54	0-26	1-91	1	99
Corals or sponge	6-6	12-42	8-18	26-66	28	72

Table 5. Summary statistics for trap movement and bottom contact area estimates from longline trap fishing sets at SK-B seamount in 2015. N=5 for path width estimates and 20 for all other statistics.

Metric	Mean	95% CI	Range
Drag window (min)	8.72	6.65 - 10.79	1.42 - 15.52
Drag time (min)	6.97	5.23 - 8.71	1.08 - 14.00
Haul speed (m·s ⁻¹)	0.75	0.72 - 0.78	0.64 - 0.89
Drag length (m)	310	238 - 383	44 - 610
Drag path width (m)	0.17	0.15 - 0.19	0.15 - 0.20
Single trap footprint (m ²)	53	40 - 65	7.4 - 104
Footprint for 60-trap set (m ²)	3 200	2 400 - 3 900	400 - 6 200

10

Figure Captions

Fig. 1. Average annual effort density of bottom longline hook and trap sets (2006-2011) for BC coastal groundfish fisheries and the SGaan K'inghlas-Bowie Seamount (SK-B) Marine Protected Area. The SK-B Zone 1 area (top 457 m contour) is closed to all fishing.

Fig. 2. Close-up configuration of the camera housing, external accelerometer, and depth-temperature sensor in a commercial Sablefish trap (top left). The trap's front mesh panel has been cut out to provide unobstructed field of view (top right). The bottom diagram displays the different components of the fishing gear and configuration for a 3-km long bottom longline Sablefish trap set with 59 traps (traps 2-28 and 32-58 not shown).

Fig. 3. Video still images collected from trap cameras during commercial fishing of a) Bamboo coral (Family Isididae) and substrate with dense coverage of brittle stars, b) *Swiftia simplex* (larger specimen) and small white hydrocoral (Family Stylasteridae), and c) *Parastenella sp.* serving as habitat for shrimp and basket stars. Trap mesh is visible in images a) and c).

Fig. 4. Example of observations used to classify trap movement during the last hour of bottom longline trap fishing for a case where the trap is estimated to have dragged during the entire drag window (e.g. drag window = drag time). Raw accelerometer and depth data are shown in (a) and (b) and algorithm output for classifying trap movement in (c).

Fig. 5. Example of observations used to classify trap movement during the last hour of bottom longline trap fishing for a case where the trap is estimated to have been stationary for multiple intervals during drag window (e.g. drag window $\neq$ drag time). Raw accelerometer and depth data are shown in (a) and (b) and algorithm output for classifying trap movement in (c).

Fig. 6. Drag paths (top) created by dragging a Sablefish commercial trap with 54-inch (1.37 m) bottom diameter along a sandy beach, and example path width measurement (bottom).

Fig. 7. Presence-absence (pres-abs) video sample sites in 2 km x 2 km grid cells for (a) Alcyonacea, (b) Porifera, (c) Pennatulacea and (d) Other (Antipatharia or Stylasteridae) from trap camera deployments during May 2013-2015 fishing trips at SK-B. The coloured cells are grid cells with presence observations during at least 1 camera deployment in that cell, while white cells indicate that the specified taxa was absent (i.e. 0 presence observations) for all video samples within that cell. Numbers indicate video sampling sites in the grid cell with presence and absence observations (presence-absence). For example, a value of 1:2 in (a) indicates 1 video sample site where Alcyonacea was present and two video sample sites where Alcyonacea was absent.

Fig. 8. Trap location estimator components for a single set of traps. (a) 1.25 km by 1.25 km subset of the multi-beam bathymetry grid, (b) the depth likelihood function, (c) the Bayes posterior grid, and (d) a zoomed 0.4 km by 0.4 km subset of (c). Intersection of the dashed lines

indicates the prior mean location based on the estimated deployment location $(\tilde{x}, \tilde{y})$. Shading in panels (b), (c) and (d) indicates likelihood or probability density, with darker cells indicating higher density. Panels (c) and (d) indicate the posterior mode (circle) and medoid (diamond) trap location estimates.

Fig. 9. Empirical distributions ($n = 99$ sets) of three estimates of the posterior (a) mean, (b) mode, and (c) medoid distance from the estimated deployment location of camera traps. The dashed lines indicate the median values of each distribution.

Fig. 10. Distributions ($n = 20$ sets) of (a) estimated drag times of camera traps, (b) mean haul speed between 200 m and 600 m depths for camera traps, (c) estimated drag lengths for camera traps, and (d) estimated bottom contact areas for a 60-trap bottom longline set using an average drag width of 17.0 cm (SE 0.8).

Fig. 11. Classified drag window (i.e. period where there is potential for dragging), and estimated drag times for 20 sets. Sets rank number is ordered by increasing drag time estimates. Set numbers 19 and 15 correspond with sets shown in Figs. 4 and 5, respectively.

Fig. 1. Average annual effort density of bottom longline hook and trap sets (2006-2011) for BC coastal groundfish fisheries and the SGaan Kinghlas-Bowie Seamount (SK-B) Marine Protected Area. The SK-B Zone 1 area (top 457 m contour) is closed to all fishing.

Fig. 2. Close-up configuration of the camera housing, external accelerometer, and depth-temperature sensor in a commercial Sablefish trap (top left). The trap's front mesh panel has been cut out to provide unobstructed field of view (top right). The bottom diagram displays the different components of the fishing gear and configuration for a 3-km long bottom longline Sablefish trap set with 59 traps (traps 2-28 and 32-58 not shown).

Fig. 3. Video still images collected from trap cameras during commercial fishing of a) Bamboo coral (Family Isididae) and substrate with dense coverage of brittle stars, b) *Swiftia simplex* (larger specimen) and small white hydrocoral (Family Stylasteridae), and c) *Parastenella sp.* serving as habitat for shrimp and basket stars. Trap mesh is visible in images a) and c).

Fig. 4. Example of observations used to classify trap movement during the last hour of bottom longline trap fishing for a case where the trap is estimated to have dragged during the entire drag window (e.g. drag window = drag time). Raw accelerometer and depth data are shown in (a) and (b) and algorithm output for classifying trap movement in (c).

Fig. 5. Example of observations used to classify trap movement during the last hour of bottom longline trap fishing for a case where the trap is estimated to have been stationary for multiple intervals during drag window (e.g. drag window $\neq$ drag time). Raw accelerometer and depth data are shown in (a) and (b) and algorithm output for classifying trap movement in (c).

Fig. 6. Drag paths (top) created by dragging a Sablefish commercial trap with 54-inch (1.37 m) bottom diameter along a sandy beach, and example path width measurement (bottom).

Fig. 7. Presence-absence (pres-abs) video sample sites in 2 km x 2 km grid cells for (a) Alcyonacea, (b) Porifera, (c) Pennatulacea and (d) Other (Antipatharia or Stylasteridae) from trap camera deployments during May 2013-2015 fishing trips at SK-B. The coloured cells are grid cells with presence observations during at least 1 camera deployment in that cell, while white cells indicate that the specified taxa was absent (i.e. 0 presence observations) for all video samples within that cell. Numbers indicate video sampling sites in the grid cell with presence and absence observations (presence-absence). For example, a value of 1:2 in (a) indicates 1 video sample site where Alcyonacea was present and two video sample sites where Alcyonacea was absent.

Fig. 8. Trap location estimator components for a single set of traps. (a) 1.25 km by 1.25 km subset of the multi-beam bathymetry grid, (b) the depth likelihood function, (c) the Bayes posterior grid, and (d) a zoomed 0.4 km by 0.4 km subset of (c). Intersection of the dashed lines indicates the prior mean location based on the estimated deployment location $(\tilde{x}, \tilde{y})$. Shading in panels (b), (c) and (d) indicates likelihood or probability density, with darker cells indicating higher density. Panels (c) and (d) indicate the posterior mode (circle) and medoid (diamond) trap location estimates.

Fig. 9. Empirical distributions ($n = 99$ sets) of three estimates of the posterior (a) mean, (b) mode, and (c) medoid distance from the estimated deployment location of camera traps. The dashed lines indicate the median values of each distribution.

Fig. 10. Distributions ($n = 20$ sets) of (a) estimated drag times of camera traps, (b) mean haul speed between 200 m and 600 m depths for camera traps, (c) estimated drag lengths for camera traps, and (d) estimated bottom contact areas for a 60-trap bottom longline set using an average drag width of 17.0 cm (SE 0.8).

Fig. 11. Classified drag window (i.e. period where there is potential for dragging), and estimated drag times for 20 sets. Sets rank number is ordered by increasing drag time estimates. Set numbers 19 and 15 correspond with sets shown in Figs. 4 and 5, respectively.