Application of Line Transect Methods to Surveying Demersal Communities with ROVs and Manned Submersibles

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ABSTRACT

The traditional method of estimating the abundance of demersal fishes is the swept-area trawl method. This method has many biases and is limited to smooth bottom. The Southwest Fisheries Science Center is developing innovative stock assessment methodology to improve population estimates of important fishery resources in the U. S. Exclusive Economic Zone (EEZ). Manned submersibles or ROVs, equipped with both still and video cameras will be used to record images along sea-floor transects. This method will allow for sampling of areas unavailable to traditional methods (e.g. rocky substrate). Line transect estimates from the survey vehicle will be compared to traditional trawl estimates on trawlable substrate. Density estimates obtained from samples stratified by depth and bottom roughness will be used to make population estimates using stratum areas quantified by multibeam surveys. Integrating habitat specific estimates of fisheries resources with multibeam data will provide a new application for existing NOAA multibeam sonar data, as well as previously unattainable precision in fishery assessment. Survey data will provide in situ evidence of habitat use by fishery resources. The analysis of trawl tracks will document the effect of man's activities (trawling) on this habitat.

INTRODUCTION

Management of demersal fish species is based on a combination of fishery dependent data obtained from catch sampling to provide information on the relative change in population size, and fishery independent data obtained from surveys to provide information on the absolute population size. Fish from catch sampling are aged and this age-structured information can be analyzed through cohort [1] or stock synthesis [2] analysis to give an accurate picture of how population size changes from one year to the next.

Unfortunately it cannot give an indication of how close the actual population is to a threshold value of overfishing. Therefore absolute population estimates from fishery independent data are needed to anchor the relative trend obtained from the fishery dependent data.

Currently trawl surveys using nets similar to those used in the commercial fishery are the primary source of fishery independent data used in demersal fish management but these surveys have several serious problems. The most serious problem is that the mean values from trawl surveys have very large variances which tend to be related to the mean, with means and variances both increasing together rather than being independent [3]. This results in confidence intervals around means that range from 50 to 100% for flatfish species and that are greater than 100% for rockfish species, *Sebastes* spp. [4]. As a result, all but the most severe changes in population size are masked by these large confidence intervals. Methods that have been commonly used to deal with this variability are transformations using either the negative binomial [3] or the delta [5] distribution. Data transformed using these distributions more closely follow the observed mean to variance relationship, however the large confidence intervals and variances remain. Other problems with trawl survey data are uncertainties due to fish behavior (avoidance and off-bottom migration), the area swept by the trawl and fish escapement through the net.

Here we describe two new methods of making absolute population estimates from fishery independent data, observer transects and video transects. The observer transects are made from manned submersibles and the video transects are made from both manned submersibles and remotely operated manned vehicles (ROV). The advantages and disadvantages of both transect types are specified and compared to the currently used trawl surveys.

METHODS

Sampling Design

Isobath The traditional method of sampling demersal fishes has been with trawl samples taken at discrete depths. Samples have been taken systematically with depth (every 100 m) or stratified randomly with depth. In reality the samples are not taken along the isobath. The course of the ship while the trawl is on the bottom is determined by the direction of the wind and the seas. Unless the bottom is very flat or the isobaths are parallel to the direction of the seas, the trawl will sample across the isobaths.

Transects along isobaths replicate trawling and maximize information about within strata heterogeneity. This approach has two disadvantages. If distributions of species are strongly determined by depth and the transect happens to fall on a boundary, the sample may be highly biased. From a practical standpoint it is very difficult to maneuver a manned submersible or ROV along the isobath. This is especially true along steep terrain when the pilot cannot see the bottom. The amount of time actually viewing the substrate is reduced when the vehicle maneuvers across steep ravines.

Gradient Making transects up slope has the advantage of crossing important gradients (depth, light, oxygen) on each dive. Each observation provides information on distribution and abundance of organisms with respect to depth[6]. For that reason it is critical to record depth constantly in order to facilitate later analysis. Abundance data may be post-stratified by depth to address questions concerning abundance within a given depth range.

A second advantage is efficient use of dive time. Since the pilot can see the substrate at all times, the effective survey time is maximized. Because the preferred orientation of the vehicle (both ROV and manned submersible) is tilted upward the amount of time in visual contact with the substrate is maximized. Surveying up slope also makes use of time that would be allocated to returning to the surface from a horizontal transit.

Configuration of Vehicles

It is beyond the scope of this paper to provide a comprehensive discussion of all of the manned submersible and ROV designs and accessory equipment available. The following section summarizes some attributes of manned submersibles and ROVs that pertain to their use in fisheries oceanography.

Manned submersible The configuration of manned submersibles is quite variable, but typically the pilot and observer(s) occupy a pressure hull along with a large quantity of equipment including life support systems. This compartment is contained within a larger structural frame that supports the batteries, flotation, variable ballast system, etc. Manned submersibles typically have two means for directly viewing the ocean outside the pressure hull, small circular view ports (11 cm diameter; e.g. Alvin, Pisces, Turtle) or an entire pressure hull manufactured from transparent material (Johnson Sea-link, Deep Rover). In manned submersibles with small view ports, the scientist/observer's view is normally very limited. For obvious reasons, the pilot's view is forward, and far superior to that of the scientist/observer. Both the pilot and observer have external lights that illuminate their fields of view. The acrylic view ports present a magnified image, confounding one's ability to estimate the size of objects in view. In manned submersibles with acrylic pressure hulls, the pilot and observer have a tremendous field of view. However, due to the shape of the pressure hull, the apparent size of objects is somewhat reduced.

ROV The configuration of ROVs for fishery research requires that every effort is made to collect and record the maximum amount of visual information. Details of these requirements will be discussed in various sections below. Briefly these requirements are high resolution video cameras, adequate lighting, and minimal loss of picture clarity in transmission. Only fiber optic tethers meet the last requirement. To survey fish at depths below about 400 m, a tether management system is necessary. The ROV must monitor and record information about altitude, camera angle, zoom and focus to provide data on the size of the field of view from the video camera. Laser spots, discussed below, provide a convenient way to spatially calibrate the video system.

Requirements for Video

Traditionally, video has been used to record movements and a continuous record of the dive's activities. Although video cameras and recorders serve this purpose well, their wider application has been limited by poor resolution and the difficulty of identifying organisms from tapes. With the increasing availability of high resolution cameras and recording media, video has become a viable alternative to still photographs for ecological studies.

Identification of organisms from visual cues is a difficult task. Standard taxonomic information (meristic characters such as dentition, number of gill rakers, fin ray counts, etc.) are not readily available. In addition, we have observed that live specimens do not look like dead or preserved specimens. Illustrations or pictures of dead fish in identification guides are often misleading. Thus, identification of live organisms from images requires experience and the greatest obtainable resolution in order to maximize the certainty of identification. For this reason and because of the power of continuous observation, high resolution video cameras and video recorders are the media of choice.

Camera There are a wide variety of video cameras and recording formats available; most of which have been utilized on manned submersibles and ROVs. Until very recently, the most commonly used video camera had resolutions of about 300 lines. In recent

years, a number of higher resolution cameras and recording formats have become available at reasonable prices. Most video cameras today are based on solid state charge coupled devices (CCD). Cameras are available with one, two, and three CCDs. Single chip cameras are available with 400 lines of resolution. Two chip cameras with resolution of 500 lines are made specifically for the S-VHS recording format. Three chip cameras are made for broadcast quality applications and have resolutions up to 600 lines. These cameras output composite video, S-video or BetaCam component signals. With multiple chip cameras the light is split by prisms to 2 or 3 chips each of which has a different filter. Hence multiple chip cameras have much lower sensitivity than single chip cameras.

Recording formats are the limiting factor in video systems. No recording format equals the resolution of the highest resolution camera. The most common recording format in North America is VHS which has a resolution of 230 lines. S-VHS and Hi-8 recorders reproduce 400 lines of resolution. Both S-VHS and Hi-8 separate chromanance from luminance and record each on separate tracks to increase the signal to noise ratio. BetaCam reproduces 350 lines of resolution but the quality of the color image is far superior to S-VHS or Hi-8.

Lighting High resolution images require adequate lighting and color balance. Video cameras with three CCDs require more light than single chip cameras. Broadcast quality video cameras such as those based on the Sony DCX 3000 require 25 lux at F1.6. To obtain good color up to 2 meters from the camera, at least 3000 watts of light or 52,000 lumens is required[7]. Since red wavelengths are absorbed strongly in sea water, the light should be biased toward those wavelengths. Sodium scandium lamps produce light from 330 to 700 nm with the maximum in the orange wavelengths (590 nm)[8]. These lamps are ideally suited for color video. To reduce common volume scattering (backscatter), the lamps should be positioned away from the optical axis of the camera.
Lasers With the addition of lasers mounted parallel to the camera axis the size of organisms can be determined. Two lasers allow the scaling of organisms [9] and three lasers define the plane of view [10] with fixed focal length lenses. The addition of a fourth laser at an angle will provide this information for zoom lenses at any focal length. Using an image processing system and a real time frame grabber it will be possible to calibrate each video frame and to calculate the area covered by the transect (Daniel Davis, MBARI, pers. comm.).

Requirements for Still Photography

Camera Still cameras have been used extensively in the study of benthic biology to gather information on abundance and pattern in the distribution of megafauna [11,12] Megafauna are defined operationally as those animals, including fishes, large enough to be counted and identified in photographs of the sea floor [11,13]. A wide variety of still cameras with a variety of lenses have been used on manned submersibles and ROV's in both single and stereo modes. Stereo photographs can be used to measure distances within the field of view, and allow a tremendous amount of information to be gleaned from a single pair of photographs. However, stereo photogrammetry is not an efficient means for analyzing a large number of photographs where only a limited amount of information will be extracted from each frame (e.g. identity and counts of fish). A typical 35 mm sea camera consists of a chassis, film mechanism with electronic controller, and lens, all enclosed within a deep-sea pressure housing. The use of 70 mm film will result in a recording of more detail on the film at some costs to the user which include an increase in the size of the camera, and a decrease in the ease of processing. A common lens used in deep-sea cameras is a water-corrected 28 mm lens (Nikkor). For many applications, the widest angle lens is desirable, because it reduces the distance between the subject and the lens, thereby minimizing the loss of light due to attenuation and the loss of resolution due to particulate matter in the water.

Lighting and film Photographs of the sea floor at all but the shallowest depths are illuminated by strobe lights. Due to the severe absorption of light by water and to the scattering of light by particulate matter in the water, the amount of light required to illuminate a small area of sea floor is considerable. As is the case with video lighting, the quality of the light field that finally illuminates the image is dependent on many factors in addition to the output of the source. The type of reflectors and positioning of the strobe in relation to the camera are critical to optimal illumination. For example, illumination of particles in the water between the camera and object being photographed will greatly degrade the image. This problem has been termed common volume scattering. If the camera and strobe can be separated, this problem is minimized. The interplay between the amount of illumination and the speed of the film will determine the aperture at which photographs are taken. There are a number of new color, and black & white negative films (e.g. Fuji f-series motion picture film) that offer high speed alternatives to the more commonly used color transparency films (e-6 process).

Data logging To maximize the amount of information obtained from video surveys, all of the pertinent information must be recorded in the proper context. Depth, altitude, and position should be recorded at all times and be integrated with time or time codes on video tape.

Analysis of Still Photographs

Quadrat A common approach to estimating the abundance of animals is to count the number of individuals within a known size area or quadrat. This sampling technique is well suited to the analysis of the type of non-overlapping, still photographs, commonly obtained with towed camera systems [11,14]. Photographs obtained from ROVs and manned submersibles fall into two major categories; vertical and oblique. In vertical

photographs, the axis of the camera is at a right angle to the sea floor, and distances and areas are uniform throughout the entire photograph. In oblique photographs the camera angle is inclined below the horizontal, and the scale within the photographs changes with distance from the camera (Figure 1). For this reason, oblique photographs may be more difficult to interpret quantitatively than vertical photographs. For example, the error in estimating the sizes of objects and areas increases quasi-exponentially with distance from the camera [15]. The scale within a photograph is typically determined by superimposing a grid of appropriate dimension. Grids are either drawn empirically from underwater photographs of scale markers on the sea floor or determined from photogrammetric principles as applied to deep-sea photographs. In the photogrammetric approach, a grid of the camera's field of view is determined from several critical variables: 1) the height of the camera off the sea floor, 2) the inclination of the camera's optical axis, and 3) the camera's angle of view (Figure 1). Specific details concerning assumptions and methods for constructing measuring grids for oblique photographs can be found in the literature [15,10].

In most photographic surveys of the sea floor, the probability of detecting an organism is not equal over the entire field of view. This can be the case for both vertical and oblique photographs although the problem is usually more pronounced in the latter. Visibility of animals on the sea floor depends on a variety of factors, including characteristics of the lighting (e.g. amount of backscatter), orientation of a given animal and its reflectivity, as well as the relief of

the sea floor. To minimize bias due to difficulties in detecting animals within photographs, it has been suggested that the usable area within a photograph (= quadrat size) should be determined a posteriori [15,16].

Here we will briefly discuss this problem for the case of "forward-looking" oblique photographs, however this method can be applied in a radial fashion to vertical photographs. Data, collected as part of a larger study on slope-dwelling fishes off central California, will be used to illustrate detection functions for selected species of fish with potentially different appearances: Sebastolobus spp., a 10 to 80 cm scorpaenid fish, Microstomus pacificus, a 20 to 40 cm flatfish, and Eptatretus spp. a hagfish which was photographed both resting on the substrate and occupying burrows with only their snouts visible [17]. A computerized digitizing system was used to record the size and location of fish within a photograph [15,16]. The data were pooled from a series of still photographs taken with a towed camera sled.

Taxa-specific patterns in visibility were examined by an analysis of the probability of detection at increasing perpendicular distance from the camera sled's transect center line and longitudinal distance from the camera along the transect center line. In the case of perpendicular distance, the data were grouped into 13 intervals. The variation of probability density with perpendicular distance is shown in Figure 2 for all 4 fish taxa. Each bar in the histogram represents the probability of detection within a parallel "lane" on the sea floor, beginning 120 cm ahead of the camera sled (10x920 cm).
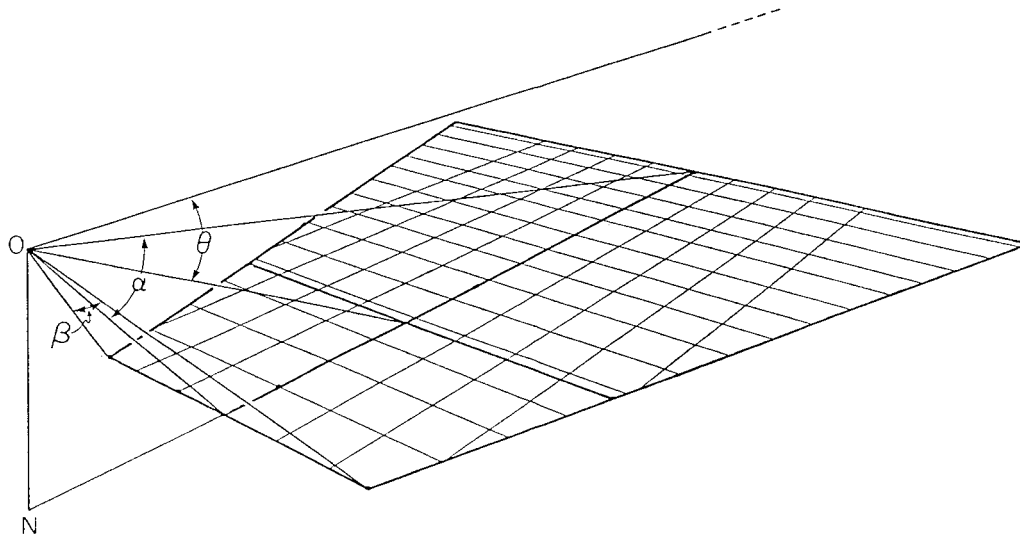

Figure 1. Representation of a perspective view of the sea floor where α and β correspond to the camera's horizontal and vertical angles of view, and θ is the inclination of the axis of the camera. The position of the camera lens is marked by O and the line o,n is the height of the camera above the substrate.
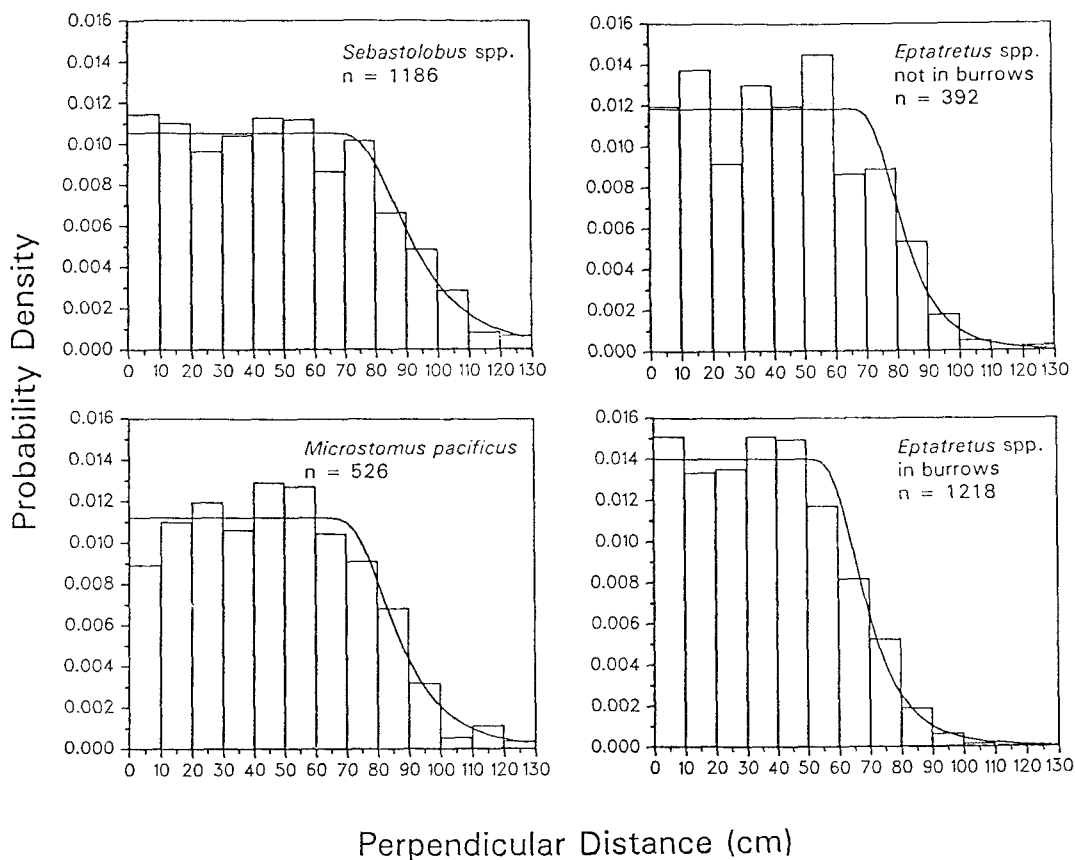
Perpendicular Distance (cm)

Figure 2. Observed probability of detection (bars) as a function of perpendicular distance (cm) from the trackline for 3 species of fish and hazard-rate model fitted to the data.

The line plotted over each histogram is the detection function for the hazard-rate model [18], and its importance will be discussed in the next section. Fish were visible out to a maximum perpendicular distance of 130 cm. Probability of detection was relatively constant out to a perpendicular distance of about 70 cm for *Sebastolobus*, *Microstomus*, and *Eptatretus* on the substrate after which it declined monotonically. For *Eptatretus* occupying burrows, a break in the probability of detection occurs at about 50 cm. These perpendicular distances define the usable "width" of quadrats for each species.

A similar approach can be used to define the taxa-specific limit for a quadrat in the direction moving out from the camera sled or in the "longitudinal direction". Probability of detection versus longitudinal distance (20 intervals) is plotted for the same four taxa of fish in Figure 3. Longitudinally, fishes were visible to distances in excess of 400 cm, but the longitudinal distance over which the probability of detection was constant varied between types of fish: 180 cm for

Sebastolobus and *Microstomus*, 120 cm for *Eptatretus* on the substrate and 60 cm for *Eptatretus* in burrows. The extension of the usable area of sea floor along the transect center line varied by a factor of up to 3.

The perpendicular and longitudinal detection functions may be combined to derive the following taxa-specific quadrat sizes:

Fish Taxa	Quadrat Size (m²)
Sebastolobus spp. thornyhead	2.5
Microstomus pacificus Dover sole	2.5
Eptatretus spp. hagfish on substrate	1.7
Eptatretus spp. hagfish in burrows	0.6

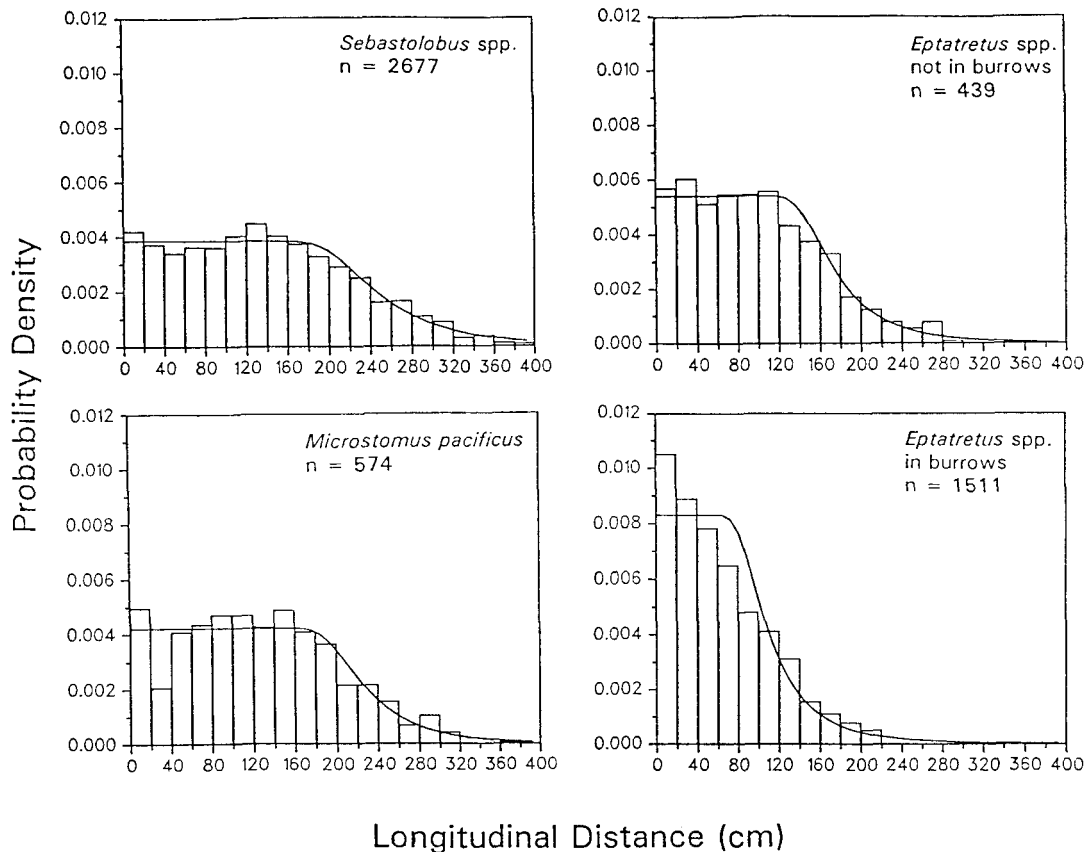**Longitudinal Distance (cm)**

Figure 3. Observed probability of detection (bars) as a function of longitudinal distance (cm) from the trackline for 3 species of fish and hazard-rate model fitted to the data.

Analysis of Video

In the previous section, we demonstrated the use of quadrat sampling in the analysis of non-overlapping still photographs. In contrast, overlapping still photographs or continuous video footage taken along a transect center line require an alternative approach to sampling. Strip and line transect methods were developed to analyze data where an observer, or in our case, a camera, continuously records counts of animals along a transect center line or transect [19,20,21].

Strip transect In strip transect sampling, the probability of detecting a fish is assumed to be constant over some width (perpendicular distance) of the transect that was determined either before or after the survey. If we assume that detection functions derived from still photographs (Figure 2) approximate those for video footage, then there appears to be a strip within which the probability of detection is constant. However, as we have observed in the previous section, data collected beyond the point where the detection function declines is not included in the analysis. The choice of whether or not to use strip or line transect methods depends in part on the shape of the detection function and whether or not it is practical to collect perpendicular distance or radial distance with the corresponding angle. If it is not practical to collect distance data, and there is reason to believe that the detection function has a broad shoulder (e.g. on the basis of preliminary data) an investigator may choose to use strip rather than line transect sampling. However if there is significant detection probability outside of the area where detection is 100%, then strip transect methods consistently underestimate true population size [22,23,24] This is the situation of an observer counting organisms from a manned submersible. If data on the perpendicular distance is available, then line transect sampling is probably preferable.

Line transect In line transect sampling, the visibility of an organism is assumed to decline with its perpendicular distance from the transect center line. For each animal,

694

the perpendicular distance or radial distance and corresponding angle off the transect center line are recorded (perpendicular distance can be estimated from radial distance and angle). The probability of detection versus distance off the transect center line is modeled, and the resulting function is used to estimate an effective strip width. There are a number of critical assumptions in line transect sampling: 1) the probability of detecting an organism on the transect center line is unity, 2) organisms are randomly distributed, 3) organisms are moving slow with respect to the camera, 4) each count is independent and no organism is counted more than once, and 5) distances and angles are measured without error [19]. Line transect sampling has been used in a limited number of instances to census objects on sea or lake floors [24,25,26].

We will use the still camera data from the previous section as an example of the application of line transect sampling in the analysis of data from camera surveys of demersal fishes on the sea floor. It should be noted that the distribution of "sightings" of fish in photographs only approximates the case of analyzing continuous video footage.

In line transect sampling, the density of organisms can be estimated by the following equation:

$$D = n\ f(0)/2L$$

where n is the total number of organisms counted, and L is the length of the transect. The parameter f(0) is related to the probability of detecting an organism on the transect center line by the following equation;

$$f(x)=g(x)/a$$

where

$$g(x)=Pr(object\ observed|x)$$

and x is the perpendicular distance from the transect center line and

$$a=1/f(0)$$

is one half the effective strip width [19].

A number of models have been used to analyze line transect data (e.g. Fourier series, hazard-rate; [18]). We have used the hazard-rate model to predict effective strip widths for the four cases represented in Figure 2. The probability density functions are similar in shape, but differ in the effective strip width. For *Eptatretus* occupying burrows, effective strip width was narrower than for the other 3 cases. For *Microstomus pacificus*, the probability of detection does not decrease monotonically with distance from the transect center line, but shows a peak at 50 cm. This suggests that this species is moving in response to the camera sled. If video rather than still photography had been used it would have been possible to observe this behavioral response. In video transects with the ROV, we have observed *Microstomus pacificus* moving in response to the approaching ROV.

CONCLUDING REMARKS

Observer and video transects provide an opportunity to analyze the association of fishes with physical and biological features in their environment. This can be either an association with physical features, such as habitat type and substrate, or with biological features, such as prey complexes. Observer and video transects contain extremely valuable qualitative data that often is very important in forming hypotheses about the processes which control community structure. The information about the biology of these organisms obtained from these surveys should help explain their distributions and therefore reduce the large variances of their population estimates.

There are different operational considerations for *in situ* surveys (either observer or video transects), and for trawl surveys. Each method has some advantage over the other.

Observer transects have some advantages over video transects such as 1) a wider field of view, 2) the human eye has better resolution and is more sensitive at low light levels than the camera, 3) human observers have a much greater depth of field and bionocular vision, and 4) most important, with observer transects there is immediate interaction between the viewing and decision making process. However, the cost of observer data obtained with manned submersibles is much higher than video data obtained from an ROV.

Video surveys obtained from either manned submersibles or ROVs provide a permanent record of organisms and their associations with the substrate. Video data is ideally suited for analysis using line transect techniques.

Trawls typically integrate a larger area of sea floor for a given expenditure of time. In addition trawls provide specimens that are essential for additional studies such as reproduction and feeding. However, trawling is limited to smooth substrate and population estimates based on samples from only one habitat may be erroneous. When used in conjunction with video transects, trawl caught specimens can be invaluable in confirming identifications.

SUMMARY

Visual line transect estimates of fish populations have great potential for fisheries management, both for reducing the very large variances around the population estimates and for providing qualitative data that is important in forming hypotheses about how these communities work. The reliability of these systems must be improved. ROV video transects are the most useful method because of the large sample size required and because the cost of observer line transects are prohibitive, when large, manned submersibles are used. Some trawl component of surveys may be necessary to provide sample material and ground truth referencing.

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