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A towed camera sled for estimating abundance of juvenile flatfishes and habitat characteristics: Comparison with beam trawls and divers

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Abstract

An inexpensive towed video camera sled was developed to provide abundance estimates for juvenile flatfishes and other benthic taxa, and to characterize habitat features. The camera sled was compared with beam trawls and diver survey methods in Yaquina Bay, Oregon, and in bays of Kodiak Island, Alaska. In Yaquina Bay the camera sled with a tickler chain (to induce flatfish movement) yielded density estimates for juvenile flatfish (English sole, *Pleuronectes vetulus*) that were equivalent to those of the divers, but greater than with a 1 m beam trawl or the camera sled without a tickler chain. Crab (*Cancer magister*) density estimates were similar between the divers and the camera sled (with or without the tickler chain), but were underestimated with the beam trawl. In Kodiak, densities of juvenile flatfish (northern rock sole, *Lepidopsetta polyxystra*) were similar between the camera sled with a tickler chain, divers, and a 2 m beam trawl. Density estimates from the camera sled were obtainable for flatfish as small as 20 mm. Habitat features, such as empty bivalve shells, were underestimated with the beam trawl compared with the divers and the camera sled. These results demonstrate the effectiveness of an inexpensive, simple to operate, towed camera sled in surveying abundance and habitat associations of juvenile flatfishes, crabs, and other taxa.
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Keywords: survey technique; video; fish; habitat

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1. Introduction

Effective methods for surveying demersal fish distributions and abundance are critical for assessing changes in populations, community structure, and recruitment patterns. Trawls are the traditional gear used to survey demersal fishes, and small (1–3 m) beam trawls have been the preferred gear for juvenile flatfishes (Kuipers, 1975; Gunderson and Ellis, 1986; Kuipers et al., 1992; Rozas and Minello, 1997). However, trawl collections underestimate fish density (Wennhage et al., 1997; Munro and Somerton, 2002) and provide little information on habitat characteristics and complexity. In contrast, divers can count fish directly and document habitat associations. While diver surveys have been conducted primarily for reef fish studies, Walton and Bartoo (1976) recognized the potential advantages of visual transects in sand bottom habitats, and developed a flatfish sampler that could be used by divers to rake fish out of the sediment for counting and size estimation. However, divers remain limited by depth and time restrictions.

Increasingly, underwater camera systems mounted on submersibles, remotely operated vehicles (ROVs), and towed platforms or sleds have been developed to view fishes in their associated habitats and to obtain

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a permanent record of the survey area (Uzmann et al., 1977; Felley et al., 1989; Lough et al., 1989; Adams et al., 1995; Gregory and Anderson, 1997; Diaz et al., 2003). Norcross and Mueter (1999) adapted ROVs for use in locating juvenile flatfishes by attaching tickler chains to induce flatfish movement. While the ROVs proved effective for estimating juvenile flatfish densities and characterizing habitat types, these systems are expensive and require special training to maintain and operate.

Development of better and more easily accessible methods for assessing distribution of juvenile flatfish and other cryptic demersal species is necessary for improved identification of essential habitat and better understanding of recruitment-related processes. The objective of this study was to develop and test an inexpensive underwater camera sled, suitable for deployment from a small boat, and compare its utility, relative to diver and beam-trawl surveys, in quantifying the abundance of economically important juvenile flatfishes, crabs, and habitat features.

2. Materials and methods

2.1. Study sites

Survey comparisons were conducted in August, 2002, at five sites in Yaquina Bay, Oregon, a known nursery for English sole (*Pleuronectes vetulus*) (Boehlert and Mundy, 1987; Rooper et al., 2003), and at four sites in two embayments along the northeast coast of Kodiak Island, Alaska, which provide nurseries for northern rock sole (*Lepidopsetta polyxystra*) (Norcross et al., 1997). At each site, one transect line was positioned in an area of low bottom relief with sand/mud substrate, and the length and orientation of each transect were selected to minimize changes in habitat characteristics while maximizing distances for gear comparisons and numbers of flatfish observed. In Yaquina Bay (44°37′ N, 124°02′ W) transect lines were 30 m in length and were oriented parallel to the depth contour. Bottom temperatures ranged from 9.4 to 12.2 °C and depths ranged from 3 to 5 m. The Yaquina sites were located inshore from the dredged channel of the bay, but were subject to moderate flow (~ 50 cm s^{-1}) during maximum tidal current. Two of the Kodiak sites were located off Holiday Beach (57°41′ N, 152°27′ W) in Middle Bay and two were in Pillar Creek Cove (57°49′ N, 152°25′ W) in Monashka Bay. At Holiday Beach, transect lines were 100 m in length and oriented parallel to the depth contour. At Pillar Creek Cove, transects lines were 200 m in length and were perpendicular to the depth contour. Bottom temperatures at the Kodiak sites ranged from 8.3 to 10.0 °C. At Holiday Beach, depths ranged from 12 to 13 m, while at Pillar Creek Cove they ranged from 5 to 15 m. There was minimal current (<10 cm s^{-1}) at the Kodiak sites.

2.2. Survey gear and approach

A 5.2 m skiff was used to deploy gear in Yaquina Bay, and the 9.1 m charter boat F/V *Miss O* was used in Kodiak. At each site a transect line was anchored tautly on the bottom and marked at the ends with surface floats. This provided for boat and diver orientation. The survey techniques were conducted at each transect in a rapid sequence ordered by increasing impact on the substratum and fish community: divers, camera sled without tickler chain (Yaquina Bay sites only), camera sled with tickler chain, and beam trawl. This approach was justified by preliminary observations made by divers that juvenile flatfish and Dungeness crabs moved only short distances (typically <2 m) upon disturbance. Furthermore, there was minimal overlap in the narrow paths (≤ 1 m) travelled by the camera sled and divers. To reduce possible effects of tidal current on species abundance and composition, all surveys were conducted at a site within 2 h of high tide in the Yaquina Bay, with the exception of one site when the use of the towed gear was delayed until 5 h after the high slack tide. This precaution was deemed unnecessary for the Kodiak Island sites, where tidal currents were minimal; however, the survey sequence was completed within 2 h at each location.

The camera sled (Fig. 1) was fabricated with 3.8 cm diameter aluminium pipe (sled dimensions: $L=114.3$ cm, $W=67.3$ cm, $H=41.9$ cm). Aluminium flanges ($L=29$ cm, $W=4$ cm), with holes drilled every 3.7 cm, welded to the top front of the frame allowed the attachment points of the bridle to be adjustable for better balance of the sled as depth and scope changed. Four lead-weights (1.36 kg each) taped to the lower sled frame ensured solid contact with the bottom. After results from the Yaquina Bay comparisons showed that estimates of flatfish density were significantly lower when the camera sled was not equipped with a tickler chain, it was tested only with a tickler chain at the

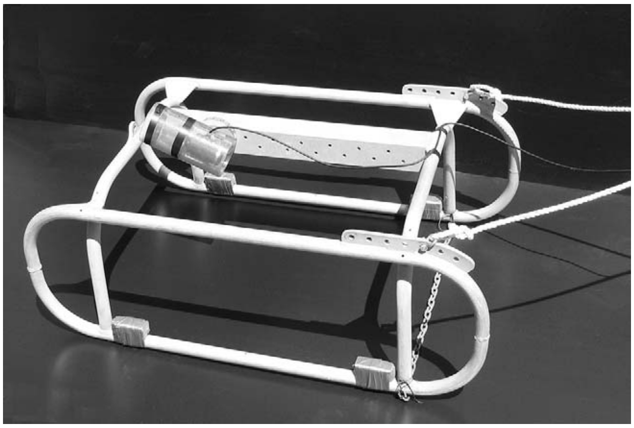

Fig. 1. Camera sled with tickler chain.

Kodiak sites. The tickler chain (2.5 cm diameter links, galvanized steel) was attached with twine to the front vertical struts. This provided a weak link in the event of striking an obstruction. The total weight of the camera sled with the camera and weights was 19 kg.

The underwater camera was an Aqua-Vu ZT-120 (Nature Vision, Inc, Brainerd, MN) equipped with a temperature sensor and 37 m long cable leading to a small black-and-white monitor on deck. The video image with temperature stamp was captured with a Sony digital video camera recorder (DCR-PC110) for later analysis. The camera housing was a 23 cm length of clear acrylic pipe (10 cm diameter). The housing was mounted on an aluminium beam ($L = 76$ cm, $W = 7.6$ cm) running lengthwise between the top horizontal struts of the sled. Holes drilled at 7.5 cm intervals along the beam enabled forward/aft adjustment of the camera. The vertical angle of the camera was adjusted by rotating the camera housing against the beam. For the surveys described in this paper, the camera lens was positioned 55 cm from the front vertical struts where the tickler chain was attached and set at an angle of 35° from horizontal; this positioning maximized the field of view while keeping the tickler chain, when present, visible at the bottom of the image. This provided a maximum forward view of 3.2 m. This oblique view was 0.67 m wide at its base and 2.5 m at the top. The total field of view was 5.0 m^2. However, juvenile flatfishes were predominately encountered directly in front of the tickler chain where the width of view was 0.67 m, so counts were confined to this swath and this width was used as the effective gear width. The cost of fabricating the camera sled and outfitting it with the underwater camera was approximately US$2000.

The camera sled was deployed by hand at one end of each transect line and towed (60 cm s^{-1}, average speed) along one side of the transect line to the opposite endpoint. This was immediately followed by a tow along the other side of the transect line. Flatfishes observed in each video record were counted. The smallest flatfish that could be counted with certainty were ≥ 20 mm total length (TL), as estimated by comparison with the known dimensions of the links in the tickler chain. This was similar to the smallest flatfish consistently observed by the divers and captured in the beam trawls. In Yaquina Bay few large flatfish were observed and all juvenile flatfish were combined for analysis. Like English sole, Dungeness crabs (*Cancer magister*) utilize northeastern Pacific estuaries as nursery grounds (Stevens and Armstrong, 1984; Gunderson et al., 1990; Stone and O'Clair, 2001), and were abundant in certain locations in Yaquina Bay. Therefore, counts were also made for Dungeness crabs. This provided another economically important taxon for comparison of survey techniques. In Kodiak, the flatfish were divided into two size classes, <60 and >80 mm TL, which represent age-0 and age-1+ rock sole, respectively, based upon length–frequency distributions in August (Hurst and Abookire, unpublished data). Although accurate length measurements were not possible with the camera and diver survey methods, they were not required for age class distinctions because of obvious size separation (e.g. mean TL of age-0 = 42 mm, age-1+ = 97 mm in August, 2004, Hurst and Abookire, unpublished data). Empty bivalve shells were consistently present at the Kodiak sites. Survivorship of juvenile rock sole is enhanced by selectively utilizing habitat with emergent structure, including shell (Stoner and Titgen, 2003; Ryer et al., 2004). Therefore, empty bivalve shells >5 cm diameter were quantified along with the fish.

For the diver counts, two divers swam simultaneously along either side of the transect line, pushing a 1 m length of 2 cm PVC pipe over the sediment surface to gauge transect width and to induce movement of flatfish out of the sediment. Care was taken not to double-count flatfish or crabs that moved from one side of the transect line to the other, or moved ahead and resettled along the transect line. Divers stopped to record counts at 3 m intervals along the 30 m transects, at 5 m intervals along the 100 m transects, and at 25 m intervals along the 200 m transects. This gave divers opportunity to record counts without the risk of missing fish while making notes. Intervals were increased with increased transect length to ensure timely completion of the transect. Swimming speed of the divers was 5–10 cm s^{-1}.

In Yaquina Bay, a 1 m beam trawl (1.0 m effective fishing width, 3 mm mesh codend, 3 mm mesh net body) with a single tickler chain positioned 20 cm in front of the trawl footrope was used (modified from Kuipers, 1975). A 2 m plumb-staff beam trawl (1.8 m effective fishing width, 3 mm mesh codend, 10 mm mesh net body) with a single tickler chain positioned 20 cm in front of the footrope was used in Kodiak (modified from Gunderson and Ellis, 1986). Average towing speed was 60 cm s^{-1}. Two tows were conducted consecutively along either side of a transect line. English sole comprised 95% of the flatfish counts in Yaquina Bay beam trawls, and northern rock sole were 95% of the flatfish catch in Kodiak.

2.3. Statistical analysis

For each site, the two counts for each survey technique from a transect line were considered non-independent samples due to their proximity, and averaged to increase accuracies of estimates made with each gear type. Each value was then standardized to count per 100 m^2 based upon the effective width of the gear (divers = 100 cm, camera sled = 67 cm, 1 m beam trawl = 100 cm, 2 m beam trawl = 180 cm) and transect length (Yaquina = 30 m, Kodiak = 100 or 200 m). Data were log-transformed to achieve homogeneity of variance and analyzed among sites within each location using an unreplicated two-way analysis of variance (ANOVA) (Sokal and Rohlf, 1981). Where significant differences occurred ($p < 0.05$), post-hoc multiple comparisons (Tukey HSD) were performed (Zar, 1984).

3. Results

In Yaquina Bay, density estimates of juvenile flatfishes made with the camera sled with a tickler chain were generally equivalent to, or exceeded those made with the other survey methods (Table 1, Fig. 2a). Juvenile flatfish densities estimated from the tickler chain-equipped camera sled were comparable to those from the diver surveys, and both of these were greater than density estimates produced by the chainless-sled surveys (Tukey HSD, $p < 0.05$). In addition, density estimates from the tickler chain-equipped camera sled were greater than those made from the 1 m beam trawl. There were also differences among survey methods for estimates of crab densities in Yaquina Bay (Table 1, Fig. 2b). Crab estimates were similar between the divers and the camera sled, both with and without a tickler, while estimates from all three were significantly greater than those from the 1 m beam trawl (Tukey HSD, $p < 0.05$, Fig. 2b). Site differences in densities occurred only in the crab density estimates (Table 1).

At the Kodiak Island sites, density estimates from the divers, the tickler chain-equipped camera sled, and the 2 m beam trawl were similar for both age-0 and age-1+ flatfishes (Table 1, Fig. 3a,b). However, the survey methods yielded significant differences in shell density estimates (Table 1, Fig. 3c). The diver and the camera sled surveys produced higher shell densities than the beam trawl (Tukey HSD, $p < 0.05$). Significant differences in densities among sites were found for age 1+ flatfish and shells (Table 1). The largest shells included horse clams (*Tresus capax*) and surf clams (*Mactromeris polynyma*).

Table 1
Results from two-way ANOVA on log-transformed density estimates comparing survey types by site

	df	SS	MS	*F*	*p*
Yaquina Bay					
Flatfish					
Survey type	3	20.39	6.80	10.81	0.001
Site	4	2.09	0.52	0.83	0.531
Survey type × site	12	7.54	0.63		
Crabs					
Survey type	3	14.82	4.94	9.14	0.002
Site	4	13.77	3.44	6.37	0.006
Survey type × site	12	6.49	0.54		
Kodiak					
Age-0 flatfish					
Survey type	2	0.57	0.28	1.81	0.242
Site	3	1.21	0.40	2.57	0.150
Survey type × site	6	0.94	0.16		
Age-1+ flatfish					
Survey type	2	0.02	0.01	0.08	0.926
Site	3	2.52	0.84	7.99	0.016
Survey type × site	6	0.63	0.11		
Shells					
Survey type	2	5.44	2.72	39.63	0.000
Site	3	11.76	3.92	57.11	0.000
Survey type × site	6	0.41	0.07		

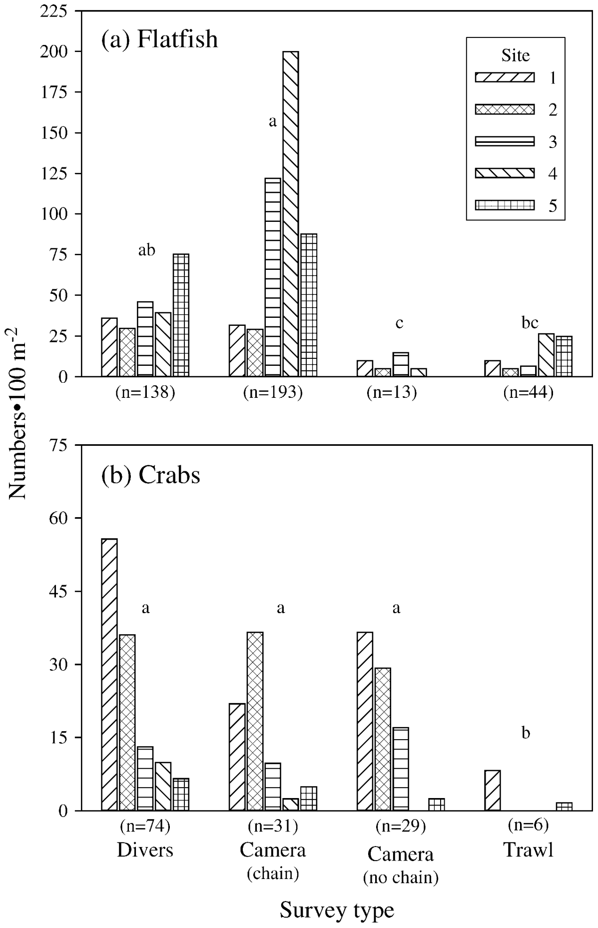

Fig. 2. Densities of juvenile flatfish (a) and crabs (b) at five sites in Yaquina Bay, Oregon as estimated by divers, camera sled without and with tickler chain, and 1 m beam trawl. Estimates were calculated by standardizing the actual number counted (*n*) along each transect to number 100 m^{-2} based on the width of the gear and the actual length of each transect. Estimates for survey types with the same letter were not significantly different based on Tukey multiple comparison tests following two-way ANOVAs without replication.

4. Discussion

The camera sled developed and tested in this study was inexpensive, simple to operate, and proved to be a very effective means for surveying juvenile flatfishes, Dungeness crabs, and their habitats. Flatfishes as small

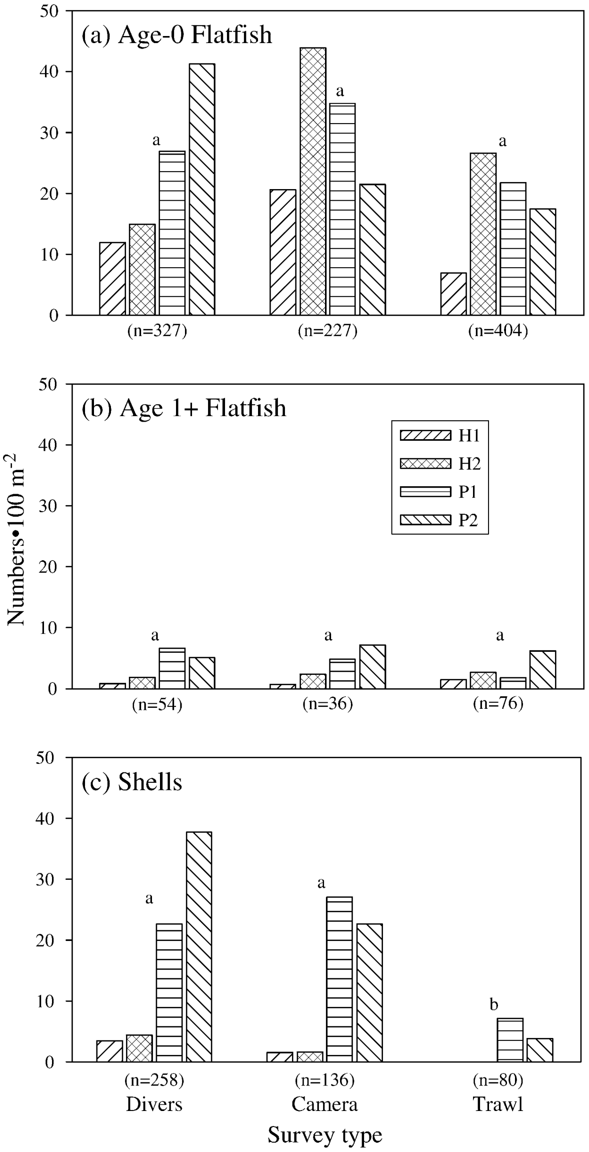

Fig. 3. Density of age-0 flatfish (a), age 1+ flatfish (b), and empty bivalve shells (c) at two sites along Holiday Beach (H1, H2) and at two sites in Pillar Creek Cove (P1, P2), along the coast of Kodiak Island, Alaska, as estimated by divers, camera sled with tickler chain, and 2 m beam trawl. Estimates were calculated by standardizing the actual number counted (*n*) along each transect to number 100 m^{-2} based on the width of the gear and the actual length of each transect. Estimates for survey types with the same letter were not significantly different based on Tukey multiple comparison tests following two-way ANOVAs without replication.

as 20 mm TL were well quantified when a tickler chain was used in camera view, equalling or exceeding the performance of divers and beam trawls. Larger flatfishes (>80 mm TL) and crabs could be surveyed effectively with or without a tickler chain. Other fishes, seastars, hermit crabs, jellyfish, shrimps, anemones, and sea pens could be quantified from video tapes. The camera sled was non-destructive to mobile organisms, and the sled's runners and tickler chain caused little damage to substrate and sessile invertebrates.

The key advantages of the camera sled compared with other survey methods investigated in this study were the accuracy of flatfish quantification made possible by replaying videotapes at slow speed, combined with the efficiency of a towed gear system that requires limited deployment time and has unrestricted tow duration. While other studies (e.g. Thresher and Gunn, 1986; Fowler, 1987; Cheal and Thompson, 1997; Samoilys and Carlos, 2000), along with ours, show that diver surveys can provide good estimates for fish density, limitations and sources of error include diver experience (Kulbicki and Sarramégna, 1999), variations in diver swim speed (Lincoln Smith, 1988; Watson et al., 1995), and time and depth restrictions. None of these are concerns with a towed camera. However, accurate identification of small flatfish species is difficult with camera sled and diver surveys, making lack of collections the main weakness of these methods. There was also a risk of counting the same fish more than once for both the camera sled and divers. However, the video recording from the camera sled facilitated tracking fish locations, thereby decreasing this risk. Although the forward view of a diver was potentially greater than that of the fixed camera, it was effectively similar since the diver needed to consistently limit attention to the area directly ahead of the tool used to disturb the flatfish.

Environmental conditions limiting accuracy of density estimates for a towed camera system are bottom roughness, natural light, and turbidity. Other types of towed underwater camera systems have been designed for manoeuvrability over high-relief bottoms (e.g. Goeden, 1981; Barker et al., 1999), but they are more complicated to operate and not well-suited for locating and quantifying cryptic or burying species. For this study, natural light was sufficient for viewing the bottom, and lights could easily be attached to the camera sled for surveys at greater depth. Water turbidity can be a larger problem in visual surveys, both with cameras or divers. However, in this study, the fishes of primary interest were observed directly in front of the tickler chain, and turbidity was not a severe problem until horizontal visibility fell below about 30 cm.

Camera sled performance was observed in various habitat types in Yaquina Bay and near Kodiak. While the camera sled performed best on low-relief sand or mud substrata, it was also capable of negotiating biogenic depressions, sand waves, and cobbles. The tickler chain lost contact with the substratum in areas with high vertical relief (>30 cm) created by sea cucumber mounds (*Paracaudina chilensis*), but subsequent modifications of the tickler chain by adding additional lengths of chains dangling from the main chain helped to correct this problem. The sled system could be used without a tickler chain on cobble bottom, on hard bottom with relatively low relief, and in short seagrass, but not in more rugged terrain or stands of kelp. A tickler chain would not be necessary for quantifying large, mobile, and non-cryptic taxa, such as age-1 + flatfishes and crabs, and for dedicated habitat studies.

While all of the gear types compared in this study were easily deployed from a small boat, they differed in their efficiencies for covering large areas and their complexity of use. Divers can count fish accurately and can record bottom features with either written notes or a video camera; however, diving is costly in terms of both time and effort. Also, divers are limited to small areas of survey coverage because of bottom time and depth restrictions, whereas beam trawls and the camera sled can be towed for long periods of time, and at depths limited only by the amount of tow rope or cable that can be handled. We have used the camera sled successfully to 35 m depth with a longer cable in clear water. Our towed camera system can be deployed quickly and easily by one person, and can be used to cover extensive areas of the bottom. However, analysis of videotape can be time consuming, depending upon the amount of information being extracted.

Despite the time needed for analysis, videotapes from camera surveys provide an ideal tool for studying fine- to broad-scale habitat associations for the surveyed taxa. Demersal fishes, including juvenile flatfishes, are often associated with habitat features such as sand waves, shells, drift algae and other biogenic structures (Auster et al., 1991; Norcross and Mueter, 1999; Stoner and Titgen, 2003). Survey methods that can include such microhabitat information along with quantification of a variety of taxa are valuable for analysis of habitat utilization. While algae and invertebrates are often captured in trawls as bycatch, observational or acoustic techniques are needed to quantify habitat features such as bedform and the structural context and scale of the bottom. In this study, densities of empty bivalve shells were accurately estimated with the camera sled and by the divers, but severely underestimated with beam trawls. With subsequent analyses of video coverage over various habitats, we have developed methods for quantifying habitat features that produce three types of data. We note: (1) general features of the sea bottom (e.g. flat, rippled, sand waves, and biogenic mounds); (2) score the density of biogenic features such as worm tubes, shell hash, and algal mats; and (3) count individual structures, such as shells, invertebrates, and algal clumps. Integration of the video recordings with navigational instrumentation supplies positional information that may then be incorporated into geographic information systems (GIS) for spatially explicit analyses on various spatial scales dependent upon the intensity of video coverage. Subsequent analyses can include predictive modelling of the spatial distribution of flatfishes and other taxa using habitat information not available in traditional collections of fishes with nets. The spatial analysis capabilities combined with the low cost and operational simplicity of the camera sled provides numerous advantages over ROVs and submersibles and makes it ideal for use by researchers with limited funds or technical support.

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