Chapter 20
Using the Seabed AUV to Assess Populations of Groundfish in Untrawlable Areas

M. Elizabeth Clarke, Nick Tolimieri, and Hanumant Singh

Abstract Near-bottom groundfish communities were surveyed in the waters off California and Oregon using the Seabed autonomous underwater vehicle (AUV) at depths ranging from 100 to 500 m. These surveys were designed to test the utility of the Seabed AUV in surveying groundfish and their associated habitat. The long-term goal of these tests is to fill the need for cost-effective, non-extractive, fishery-independent surveys in untrawlable areas. During nine dives we collected information on the species composition, abundance, and size of many groundfish species, and over 30,000 images were collected from the optically calibrated camera. Habitat classification on a fine spatial scale was easily accomplished and allowed habitat associations of many species to be determined. An assessment of one of the most easily identifiable species, rosethorn rockfish *Sebastes helvomaculatus*, also showed that the size composition of this species varied over habitat types. These surveys were the first using the Seabed AUV to survey fishes in these habitats and provided insights for sample design and enhancements that would optimize the AUV for future operational surveys.

Keywords Autonomous underwater vehicle, AUV · fishery-independent surveys · groundfish · underwater imaging

20.1 Introduction

Fishery-independent surveys of groundfish populations provide the basic information needed for monitoring and assessing fish stocks. These assessments are a key component of the scientific advice to decisions makers for management of groundfish.

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In fisheries research, fishery-independent data are becoming increasingly important in the light of growing concerns about the availability and applicability of fishery-dependent data. Fishery-dependent data are of limited utility in monitoring populations when catch limits are very restrictive. It is therefore apparent that there is a need to invest in additional indices of abundance. It is also important in light of the limited catch available for some overfished species that new methods that are non-extractive should also be developed.

Traditionally groundfish have been surveyed primarily from vessels using the same extractive methods similar to those used in the capture fisheries. On the west coast most of the surveys for groundfish have been conducted using bottom trawl gear. This gear cannot be effectively deployed in rocky habitat, and these rugged areas are the primary habitat of many groundfish species. Currently a bottom trawl survey is the primary fishery-independent source of information for stock assessments (Keller et al. 2006). This survey is conducted annually from the Mexican border to the Canadian border in water depths between 50–1200 m. Over 700 stations are randomly selected in designated strata and are occupied in trawlable areas. The survey area is subdivided into approximately 12,000 cells that are 1.5 × 2.0 nm. Each of four vessels is randomly assigned a set of 180 cells. While this survey provides comprehensive information in areas accessible by bottom trawls much of the area is likely untrawlable (Zimmermann 2003).

In general the assumption is made that bottom trawl surveys represent to some degree untrawlable areas. In some cases the observed trawl densities of fish biomass are expanded to both trawlable and untrawlable grounds. If in untrawlable areas the groundfish species composition, size composition, and biomass are unknown, in the bottom trawl survey estimates may result in inaccurate estimates of fish biomass. Thus, if the densities differ between the trawlable and untrawlable grounds, then the density observed from the trawl samples would not be expected to be representative of the population density. This situation is most problematic if the distribution of fish on trawlable and untrawlable grounds is density-dependent (Fretwell and Lucas 1970) or if the size distribution between untrawlable and trawlable areas varies considerably. Autonomous underwater vehicles (AUVs) are relatively small, untethered, unmanned, self-propelled vehicles able to carry a variety of sensors along preprogrammed mission trajectories. AUVs have already been employed as a survey platform to detect fish in midwater using acoustic methods (Fernandes et al. 2000, 2003). Studies have also shown that these electric powered platforms may have minimal fish avoidance (Fernandes et al. 2000, 2003; Griffiths et al. 2001). A unique bottom tracking AUV, the Seabed, has been used to monitor coral reef habitat (Armstrong et al. 2006). We are attempting to further develop the Seabed as a tool to conduct non-extractive surveys of groundfish. This particular AUV we believe has great potential because its unique bottom hugging capability makes it particularly appropriate for this task (Singh et al. 2004).

In this paper we discuss the capabilities of the AUV, the results of initial tests with the current AUV, and recommend improvements that are needed to use this AUV as an operational tool.

20.2 Methods and Results

In the fall of 2005, the Seabed AUV was deployed off the research vessel *Thomas G. Thompson* to assess the potential for AUVs to conduct surveys in untrawlable areas. The Seabed AUV is a multihull, hover-capable vehicle, which, unlike traditional torpedo-shaped AUVs, is capable of working extremely close to the seafloor while maintaining very precise altitude (3 ± 0.05 m) and navigation (1 m) control (Fig. 20.1). Its small footprint coupled with its 2,000 m depth rating makes it an ideal platform for conducting surveys at the continental shelf and upper slope depths deployed from on ships ranging from standard oceanographic vessels to smaller fishing vessels of opportunity.

The Seabed was utilized at three different locations on the west coast of the United States over the course of 14 days. These areas included Daisy Bank (two dives) and Coquille Bank (one dive) off the coast of Oregon and St Lucia Bank (six dives) off the coast of Central California (Fig. 20.2). During these dives over 30,000 images were collected from the optically calibrated camera. On average each image viewed an area of 3.02 m^2 (±0.32 S.D.).

The suite of sensors on board the AUV include 1.2 megapixel 12-bit high dynamic-range camera and associated strobe, a 230 kHz Delta-T multibeam imaging system, a 1.2 MHz Acoustic Doppler Current Profiler (ADCP), fluorometers, a pumped CTD, and methane sensor. Typical mission durations for the current vehicle allow it to run with its suite of sensors for 6–8 h covering distances of up to 10–15 km on a single dive.

The AUV, which can run at speeds between 0.3 and 1 m/s, was programmed to run at minimum speed and to maintain a fixed distance from the bottom of 2.5 m. The initial position of the AUV was determined by shipboard GPS. Measurements of velocity over the bottom, heading, altitude, pitch, roll, and integrated position

Fig. 20.1 The Seabed AUV

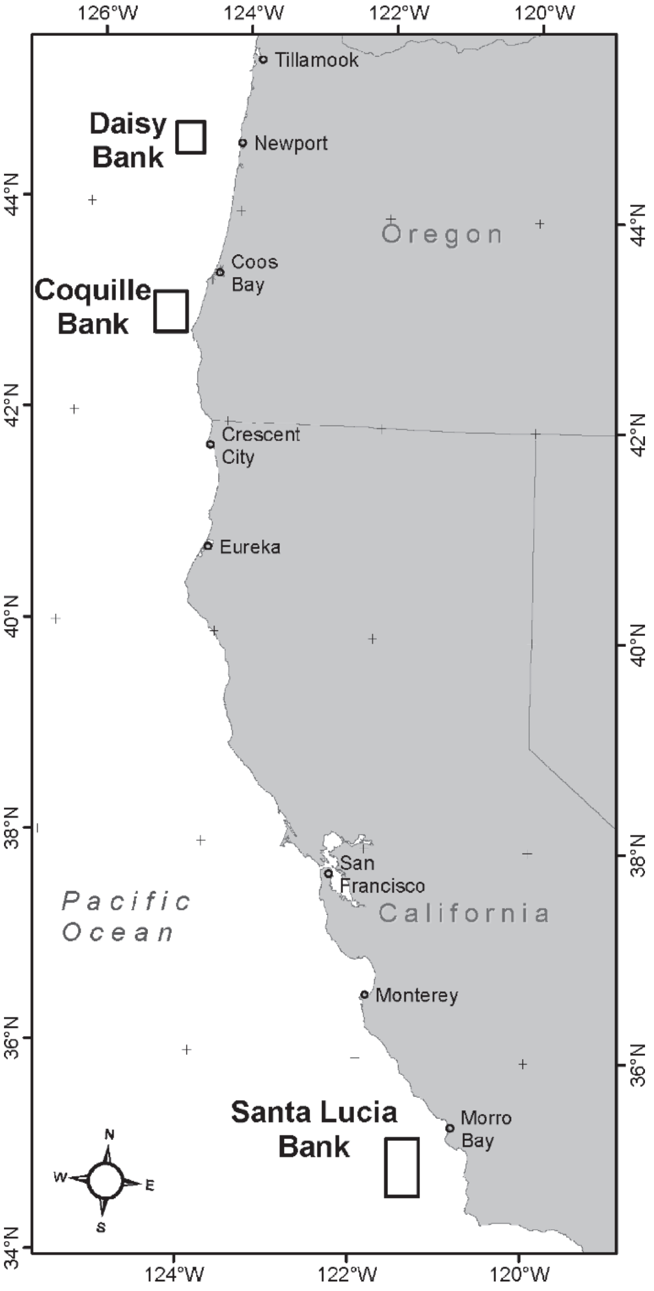

Fig. 20.2 Locations of study sites

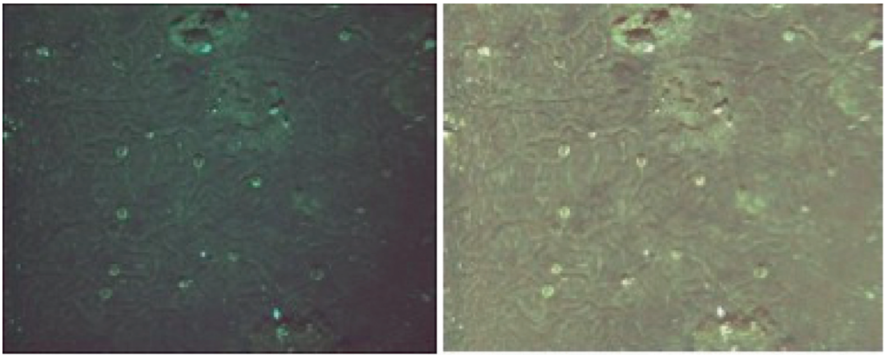

Fig. 20.3 *Left*: Original image of burrowing irregular urchins (*Spatangoida* sp.). *Right*: The same image after color compensation. The high dynamic range camera on board Seabed allows us to compensate for the nonlinear attenuation of light underwater to obtain high-resolution imagery with high color fidelity

are provided by a 1.2 MHz ADCP. More information on the Seabed components, controls, and navigation are listed in Singh et al. (2004).

The sensors, the AUV, and its associated systems are all vertically integrated. Thus the imagery can be easily color-corrected (Fig. 20.3), merged with the navigation and attitude data, photomosaicked, and then analyzed for species counts, sizes, and distributions with an easy to use Graphical User Interface (Ferrini and Singh 2006).

20.2.1 General Sampling Protocol

At Daisy and Coquille Banks the AUV ran similar survey tracks (Figs. 20.4 and 20.5). On each dive, the AUV completed four transects, each approximately 0.5 km in length. The first transect was run within the center of the rocky habitat or within the center of the proposed closed area, as appropriate. The second transect was run within the rocky habitat (or closed area) but along the margin of that habitat. The third and fourth transects were run in the soft sediment (or outside the proposed closed area) with one transect along the margin and one farther from the rocky area (or closed area). This design allowed us to examine the effects of habitat type and edge effects. Along each transect the AUV took approximately 600 photo quadrats (frames, $3.0\,m^2 \pm 0.32$ S.D.). From each transect, we analyzed 200 randomly chosen frames (see below).

For the dives at St Lucia Bank, the AUV tracks differed from those at Daisy and Coquille Bank (Fig. 20.6) because of different overall sampling objectives. At St. Lucia Bank we were primarily concerned with collecting data inside and outside of proposed trawl closure areas. Dive 15 followed a track line similar to those at Daisy and Coquille Bank but with three transects within the proposed closed area and three outside. Dive 10 was in rocky habitat also crossing the boundary of the closed area with one transect inside and one transect outside. Dive 11 was inside

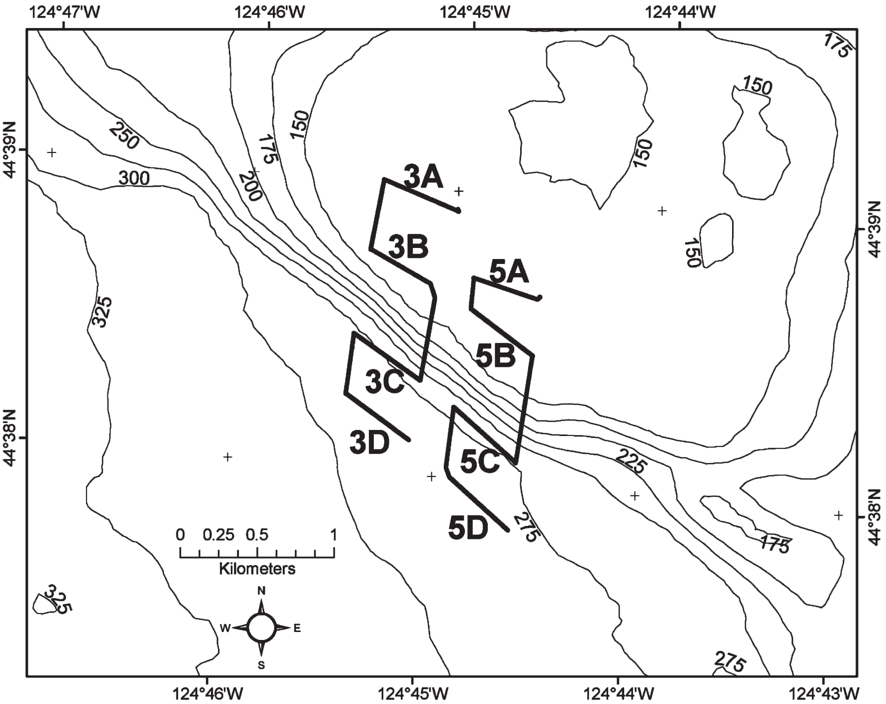

Fig. 20.4 AUV survey lines for two dives at Daisy Bank. Within each dive the four labeled, parallel lines were data collection transects. The three parallel lines at 90° are transit lines where data were not collected. The first two lines (A and B) are within rocky habitat; the second two lines (C and D) are at the base of the bank in sediment

the closed area in rocky habitat and Dive 12 was outside of the closed area in rocky habit. Dive 16 was within the closed area in soft sediment. Dive 14 was an exploratory dive conducted in an area where petrale sole *Eopsetta jordani* were reported to occur at high density.

In many cases, especially at Daisy and Coquille Banks, habitat is confounded by depth because the soft sediment areas were deeper than the adjacent rocky area. In a fisheries sense, this is not a problem. Trawl surveys frequently sample the softer sediments around these rocky outcrops. Clearly we would like to know whether sampling in the trawlable area next to an untrawlable area gives us good information about populations on the rocky areas.

20.2.2 Subsampling Schemes

In order to determine the best method for analysis of the large number of images collected, we evaluated several subsampling schemes by conducting power analyses

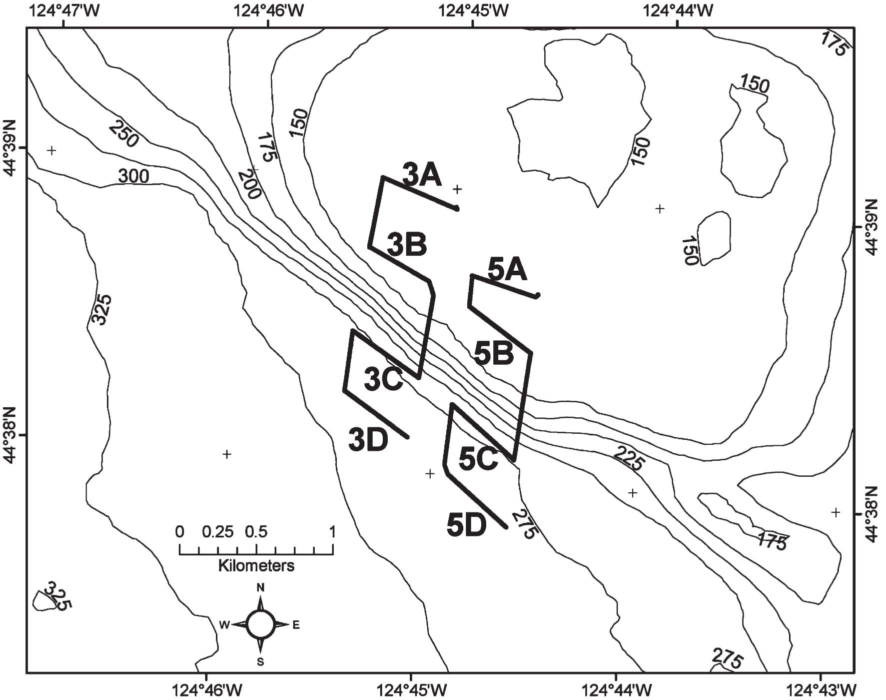

Fig. 20.5 AUV survey lines for one dive at Coquille Bank. Within the dive the four labeled, parallel lines were data collection transects. The one long line between the labeled lines is a transit line where data were not collected. The first two lines (7A and 7B) are within rocky habitat; the second two lines (7C and 7D) are at the base of the bank in sediment

on a subsample of the data from Daisy and St Lucia Banks prior to completing the complete analysis of the frames. We considered three alternatives: (1) divide the main transect into three randomly placed but nonoverlapping subtransects 100 frames long, and analyze all frames to generate a total count for each subtransect; (2) as above, but analyze only 50 alternate frames, and (3) analyze 90 random frames from each full transect treating each frame as a replicate. In this sampling regime, the main transect (with four per dive) was considered a location (e.g., center of the rocky area or margin of the rocky area). For both cases (1) and (2), $n=3$ for each location, while in case (3), $n=90$. In case (1) double counts were deleted since frames overlapped and individual fish could be counted twice.

For the power analysis, we examined differences between Daisy Bank and St Lucia Bank in terms of the number of rockfish *Sebastes* spp. (six 100-frame sections from Daisy Bank and three 100-frame sections from St. Lucia Bank). Since the data were counts, we used log-linear models (generalized linear models with log-link and Poisson distribution).

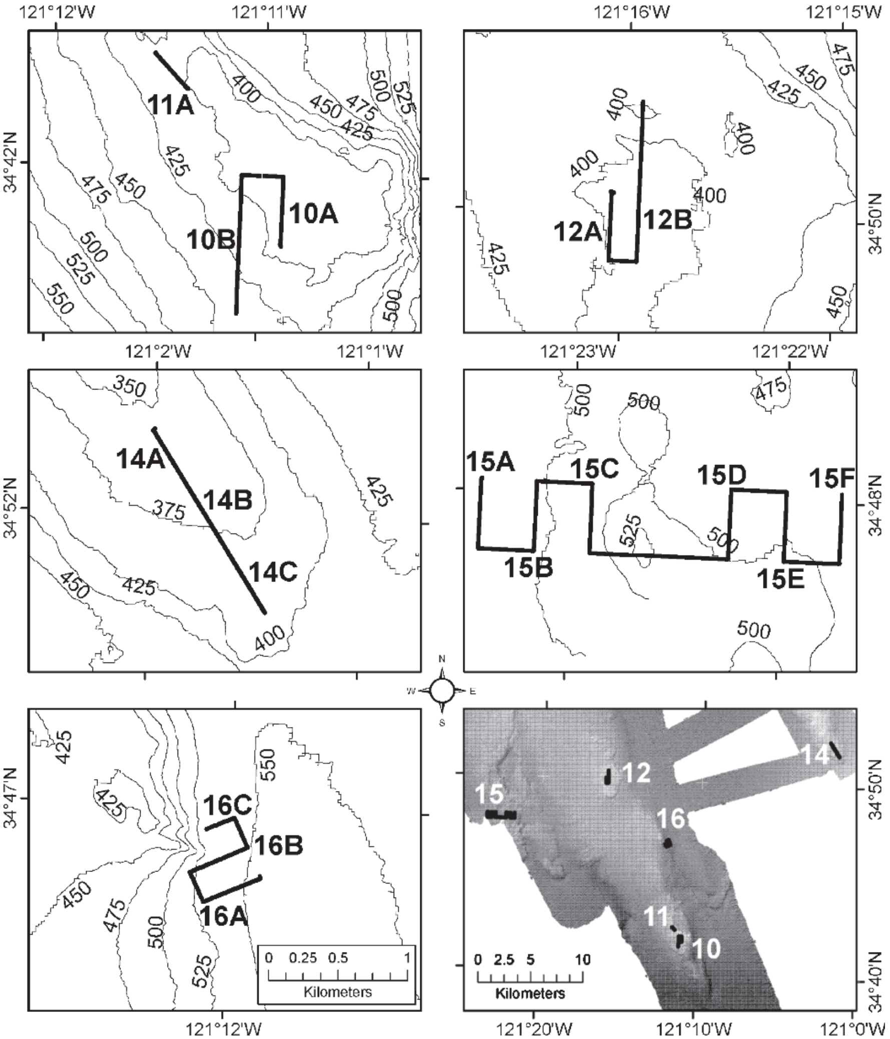

Fig. 20.6 AUV survey lines for dives at St. Lucia Bank. Within the dives 10, 12, 15, and 16, the labeled, parallel lines were data collection transects. The lines between the labeled lines are transit lines where data were not collected. Dives 11 and 14 were exploratory dives in unique habitats and sampling was conducted in one continuous line. The lower right panel shows the locations of all sampling sites on sun-illuminated bathymetry

We estimated the statistical power of the GLM tests following Willis et al. (2003) who provide a conversion from standard power analysis, which assumes homogeneity of variance, to the Poisson situation where variance equals the mean and the data may also be overdispersed such that $\sigma^2 = \phi\mu$, where ϕ is the overdispersion parameter.

Table 20.1 Sample size needed to detect various multiplicative effect sizes. Note that for the two methods, the replicate is a 100-frame section of a 0.5 km long main transect (considered a location). Thus while 46 subtransects would be required to detect a 50% difference (effect size of 1.5) in the number of fish between two sites using the all frames approach, this would require analyzing 4,600 frames

Method	ϕ (overdispersion parameter)	Desired effect size		
		×1.25	×1.5	×2.0
All frames in a section of a subtransect	21.38	164 subtransects (16,400 frames)	46 subtransects (4,600 frames)	15 subtransects (1,500 frames)
Alternate frames in a section of subtransect	14.74	135 subtransects (6,750 frames)	38 subtransects (1,900 frames)	12 subtransects (600 frames)
Random frames selected from an entire transect (location)	2.4	1,435 frames	403 frames	124 frames

An approximate upper bound on type II error rate is given by the value β obtained as the probability of having standard normal quantile z_β given by:

$$z_\beta = \frac{\log(k)}{\sqrt{\frac{\phi}{n\mu_1}\frac{k+1}{k}}} - z_{\alpha/2}$$

where k is the ratio of the two means $k=\mu_2/\mu_1$ and μ_1 is the smaller of the two means. The lower bound on power is then $1-\beta$. As usual, n is the sample size. The standard normal quantile exceeds the value z_β with probability β. The value α is the type I error rate (here 0.05) such that $z_{\alpha/2}=z_{0.025}=1.96$. It is relevant to note that overdispersion and low mean abundance in the smallest of the means being compared reduces power.

Results of the power analysis suggested that analyzing individual, random frames was a more effective approach for two reasons (Table 20.1). First, analyzing individual, random frames results in a higher sample size for the same level of effort ($n=90$ versus $n=3$ per location). Second, the other two methods resulted in highly overdispersed data (indicating clumping). Ideally the overdispersion parameter should be equal to 1.0, but values less that 3.0 are generally considered acceptable.

20.2.3 Species Identification

In many cases the success of identification of species using remote optical methods is dependent on species-specific morphological characteristics and markings being identifiable from a photograph. In the case of the images from the Seabed AUV, the identification of fish species is dependent on the analyst's ability to discern these characteristics from an overhead view of the organism. Flatfish and skates are particularly easy to identify from this view (Fig. 20.7). Certain rockfish such as *Sebastes helvomaculatus*, rosethorn rockfish, and *S. diploproa*, splitnose rockfish, have morphology or markings that along with the known bathymetric and geographic distributions make them easily identifiable from the overhead images at least over portions of their ranges. Members of species groups such as thornyheads, *Sebastolobus* spp. can be identified but shortspine *Sebastolobus alascanus* and longspine thornyheads *S. altivelis* generally cannot be distinguished from each other. For marine invertebrates, where there are specific morphological characteristics and markings that are easily identifiable from the overhead view the identification of these invertebrates to a particular taxonomic or morphologic level and in many cases to species is possible. One benefit of the vertical images is that the spatial relationships between fishes and invertebrates and associated habitats are easily viewed and quantified (Fig. 20.8).

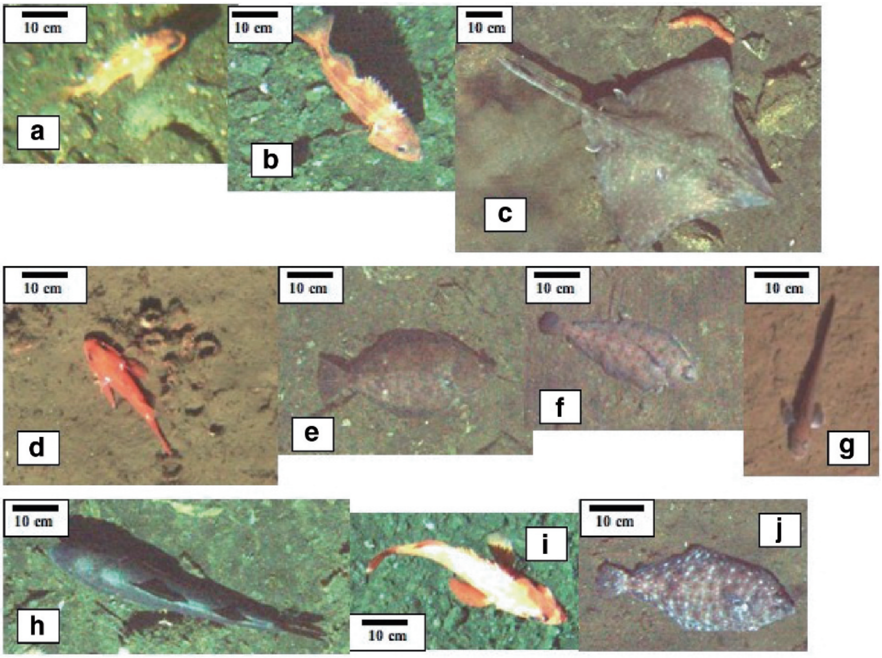

Fig. 20.7 Typical groundfish identifiable from AUV images. (**a**) Rosethorn rockfish off Oregon, *Sebastes helvomaculatus*; (**b**) blackgill rockfish, *S. melanostomas*; (**c**) longnose skate, *Raja rhina*; (**d**) thornyhead, *Sebastolobus spp.*; (**e**) petrale sole, *Eopsetta jordani*; (**f**) rex sole, *Glyptocephalus zachirus*; (**g**) bigfin eelpout, *Lycodes cortezianus*; (**h**) sablefish, *Anoplopoma fimbria*; (**i**) splitnose rockfish, *S. diploproa*; (**j**) Dover sole, *Microstomus pacificus*

Fig. 20.8 Blackgill rockfish *Sebastes melanostomus* and “vase” sponge

20.2.4 Monitoring of Habitat Associations

The habitat was classified and the number of rockfish were counted at each of 8 transects on Daisy Bank, 4 transects on Coquille Bank and 17 transects on St. Lucia Bank. Habitat was classified using a simplified two-letter classification scheme (after Hixon et al. [1991] and Stein et al. [1992]) where the first letter indicates the primary substrate type (50% of substrate or greater) and the second letter indicates the secondary substrate type (greater than 20% but less than 50% of the substrate type). In this scheme the letter R indicates rock ridge, F indicates flat rock, B indicates boulder, C indicates cobble, P indicates pebble, S indicates sand and M indicates mud. Rockfish were counted with the assistance of the Graphical User Interface developed for this purpose (Ferrini and Singh 2006) (Fig. 20.9). This revealed that rockfishes were much more abundant on transects where the percentage of rocky habitat was the highest and lowest where mud and sand predominated (Fig. 20.10).

20.2.5 Size Composition of Rosethorn Rockfish

An analysis of the size composition of one of the most easily identified species, rosethorn rockfish, *S. helvomaculatus*, was conducted on dives that occurred on Coquille and Daisy Bank. This analysis was limited to Daisy and Coquille Banks

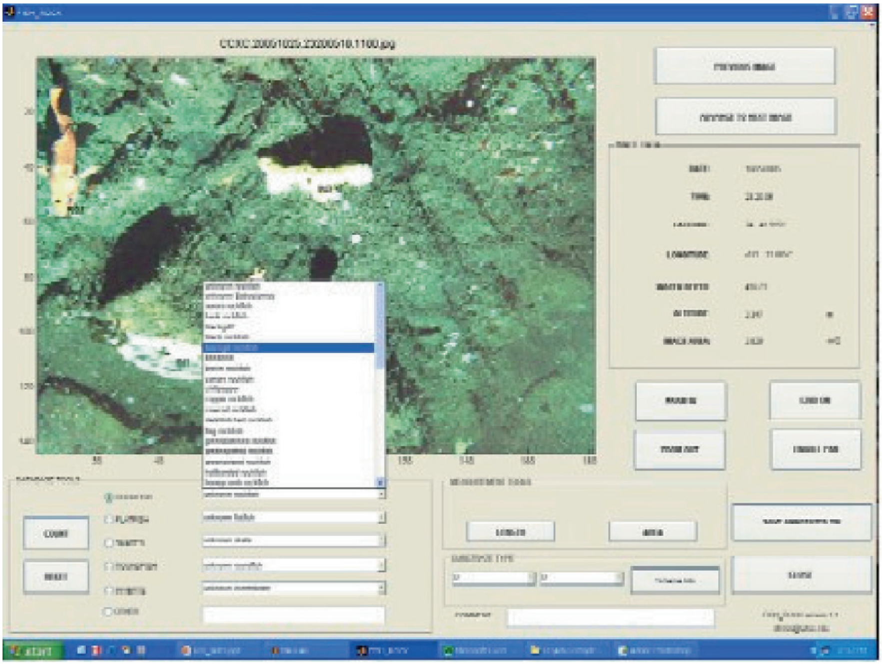

Fig. 20.9 An example of the Graphical User Interface (GUI) that was used to easily analyze images collected by the Seabed AUV

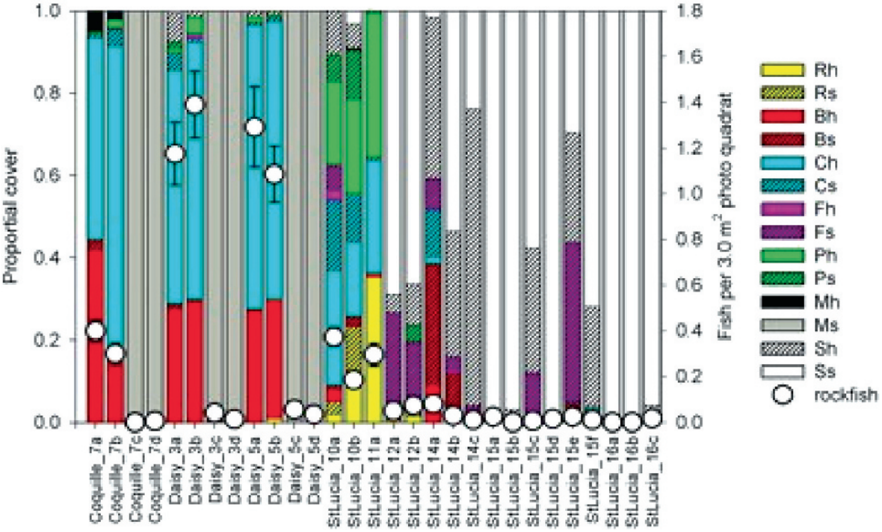

Fig. 20.10 Relationship between rockfish and associated habitat type on 4 transects on Coquille Bank, 8 transects on Daisy Bank and 17 transects on St. Lucia Bank (where R = rock ridge, F = flat rock, B = boulder, C = cobble, P = pebble, S = sand, M = mud, and an upper case letter indicates that greater than 50% was classified as that type and lower case indicates that greater than 20% but less than 50% was classified as that habitat type)

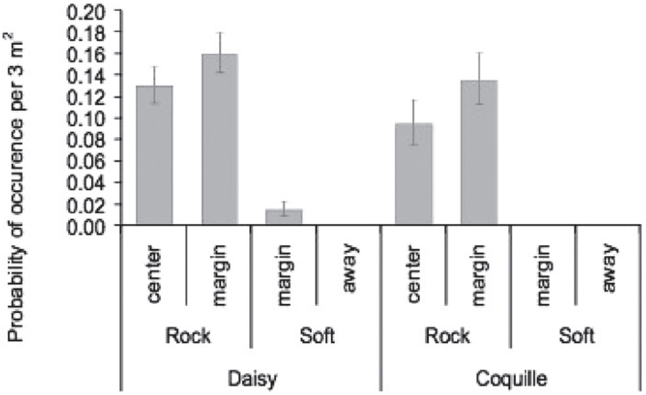

Fig. 20.11 Density of rosethorn rockfish *Sebastes helvomaculatus* in four habitats at Daisy and Coquille Banks. Because rosethorn were either present (one fish) or absent in the photoquadrats, data were analyzed using a logistic regression model. Probability of occurrence is qualitatively similar to density

because in more southerly areas rosethorns could be easily confused with several other species (Yoklavich et al. 2000). Rosethorn are typical of the deep rock habitat (Love and Yoklavich 2006), and adults also use transitional areas between rock and mud (Love et al. 2002). For four transects (200 random quadrats per transect), all of the rosethorn rockfish were counted and their body size in grams estimated from length measurements using published length–weight relationships (Love et al. 2002). The habitat (transect not the individual frame) on which each fish was found was categorized as either rocky or soft and as either on the edge or the center of those habitats. More rosethorn were found on rocky habitat than on adjacent soft sediment (Fig. 20.11). But larger fish and more biomass were found on the reef margin than in the center (Figs. 20.12 and 20.13). Only large fish ever ranged off of the rocky areas.

20.3 Discussion

The primary focus of this research was to determine the utility of a bottom-tracking AUV as a tool for assessing the abundance of groundfish in and around rocky, untrawlable areas. The advantages routinely described in surveys with AUVs versus Remotely Operated Vehicles (ROVs) were apparent in this application (Bingham et al. 2002). The Seabed AUV tether-free maneuvering ability and near-bottom performance were significant assets when surveying in rocky areas. Furthermore, the deploying vessel was freed after deployment to conduct other operations such as high-resolution multibeam sonar mapping of the sea floor and water column oceanography. This led to increased efficiency in the use of research vessel time.

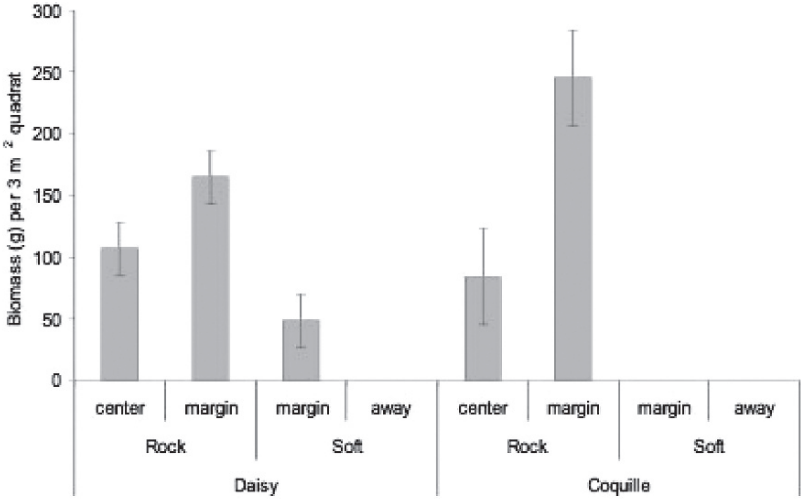

Fig. 20.12 Biomass of rosethorn rockfish *Sebastes helvomaculatus* in various habitats on Daisy and Coquille Bank

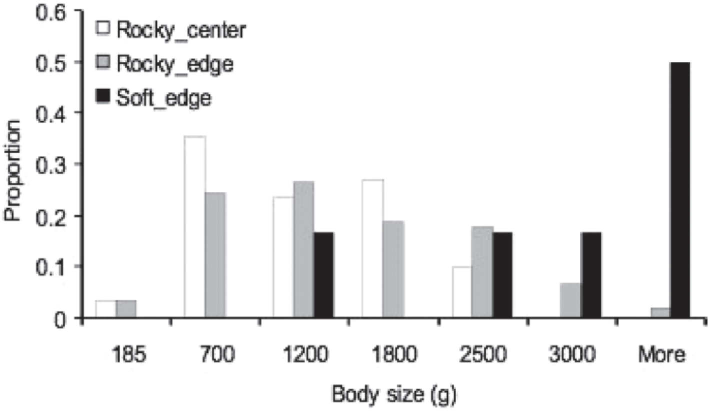

Fig. 20.13 Size of individual rosethorn rockfish *Sebastes helvomaculatus* in rocky versus soft habitat

The lack of tether also avoided problems such as entanglements. The lack of the tether did have the disadvantage that unlike with tethered vehicles (ROVs) no images could be viewed in real time. However, the unique ability of the vehicle to drive at a fixed distance from the bottom was a clear advantage over many other platforms. Not only were observations simplified since the distance from the bottom was not constantly changing but the ability to maintain a fixed altitude from the bottom even in rocky areas allowed the vehicle to avoid collisions. In addition, the difficulty in target identification and verification associated with acoustic surveys from AUVs (Fernandes et al. 2003) was not evident here. However, for some species we have yet to develop clear characters that allow identification from an overhead view. Therefore, one of the next steps needed is to develop keys of local species from an overhead view. For some species the addition of a side or forward-looking oblique camera will give a view similar to that seen from other human-occupied submersibles and ROVs and will aid in identification.

An enormous amount of data is collected during AUV deployment. The image storage and processing can be a bottleneck in the data analysis. However, our analysis of the various subsampling schemes shows that there are efficient ways to subsample our data that retain appropriate power while minimizing the number of frames that must be examined. Nonetheless, the specific subsampling protocol used here should not be considered definitive as we continue to investigate other possibilities. Tools also have been developed to improve the efficiency in the analysis of the images (Ferrini and Singh 2006). Future automation of the analyses will help make the AUV an even more powerful tool. We are currently developing automated target recognition tools to scan frames and separate those that contain fish and subsequently categorize those fish into general groups.

The patterns that we see in regards to the habitat utilization of groundfish are similar to those described for deep water habitats in our region (Love and Yoklavich 2006). It is clear that in addition to information on fish abundance and general habitat utilization, categorizations of fine scale habitat utilization by fish and invertebrates and the spatial relationships between fish and invertebrates are possible. In future analyses these finer scale patterns of habitat utilization will be examined and may provide insights into fish habitat relationships.

Finally, this tool unlike many other traditional survey tools allows easy analysis of size distributions of fish on fine scales. The fish and invertebrates can be measured directly unlike indirect methods necessary when using technologies such as acoustics. Our analysis shows that there are fine scale patterns in size that may be masked when survey tools that integrate over fairly large spatial scales are used. It is evident that understanding these fine scale size distributions may be critical to intercalibrating the information collected with trawls and information collected during surveys in rocky habitat.

The Seabed AUV has great potential as a direct observation tool to estimate the density of benthic fishes in high relief areas that are not accessible by other tools. In addition, differences in fish densities and sizes between trawlable and untrawlable areas can be observed that may have implications for the estimation of abundance of groundfish.

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