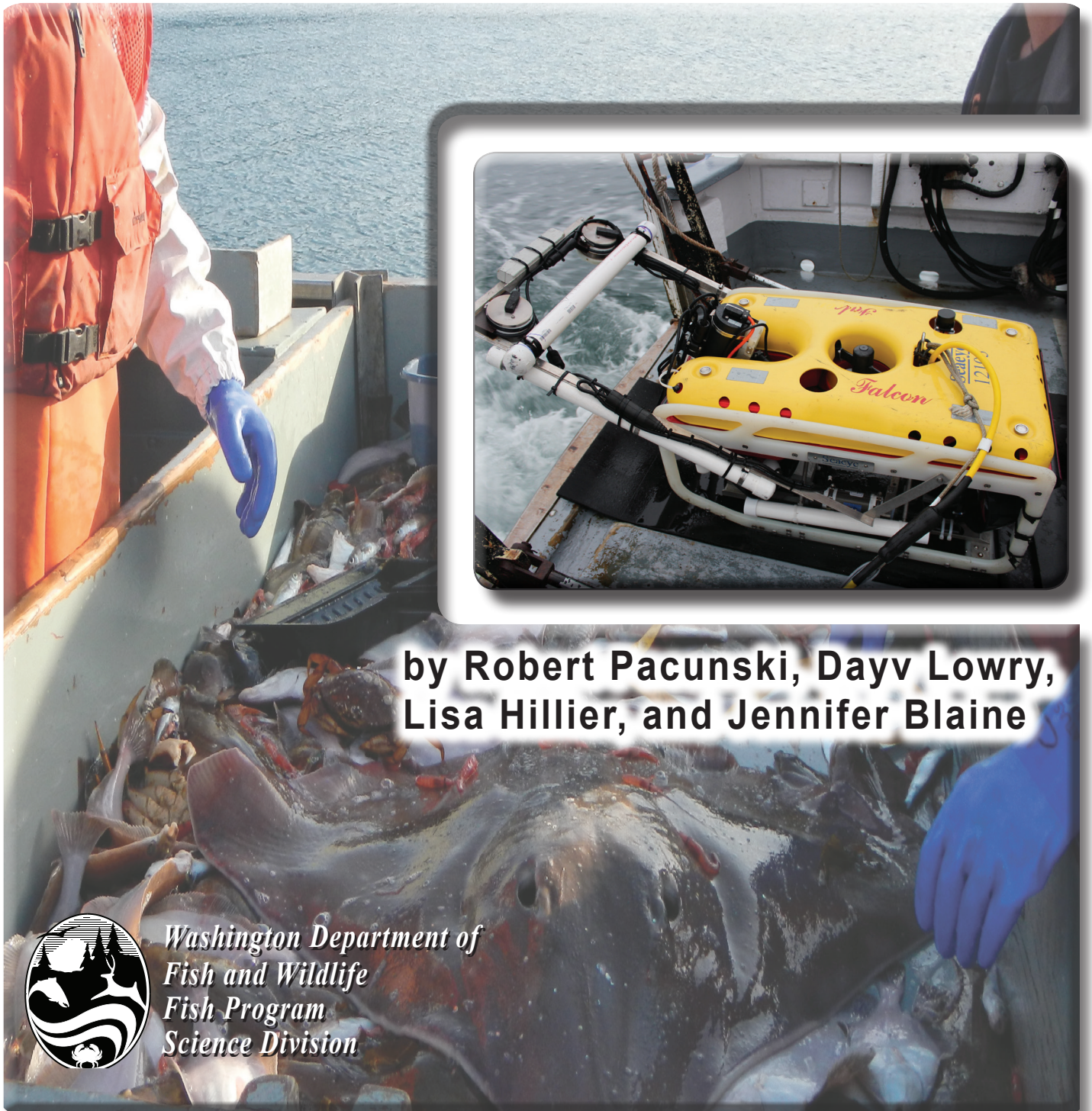# A Comparison of Groundfish Species Composition, Abundance, and Density Estimates Derived from a Scientific Bottom-Trawl and a Small Remotely-Operated Vehicle for Trawlable Habitats



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# A Comparison of Groundfish Species Composition, Abundance, and Density Estimates Derived from a Scientific Bottom-Trawl and a Small Remotely-Operated Vehicle for Trawlable Habitats

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# Abstract

Despite a long history of being used to assess the abundance and distribution of benthic marine fishes, otter trawls are acknowledged to have several shortcomings. One major problem is the systematic exclusion of species and/or specific life history stages. Over the past five decades, a diversity of visually based survey tools, such as manned submersibles, video landers, and remotely-operated vehicles (ROVs), have been developed that allow assessment of benthic fish in complex habitats where trawling is not practicable. Few studies have been conducted, however, that directly compare the species composition observed by concurrent trawl and visual surveys on trawlable habitat, let alone the density estimates derived from such sampling. The increasing use of visual survey methods presents the opportunity for supplementing, or perhaps replacing, trawl surveys, but before this can occur comparisons of sampling bias and catchability/detection will be crucial if contemporary abundance estimates based on visual surveys and historic trawl-based estimates are to be merged into a seamless index for resource management purposes. Here, we report the results of paired benthic marine fish surveys using an observation-class ROV and an Eastern otter trawl. We conclusively demonstrate that on trawlable habitats in northern Puget Sound, WA, catch composition and density estimates differ substantially between these two survey methods for several key fish taxa and one targeted invertebrate. We conclude that sampling trawlable habitats with an ROV provides information for several small-bodied fish species that are otherwise undersampled by a benthic trawl, but provides an insufficient assessment of harvestable species due to the narrow field of view, limited capacity to sample individuals occurring >2m off the bottom, and propensity for buried flatfishes to go undetected. Our results suggest that ROV-collected data from trawlable seafloor habitats can provide complementary information to the trawl survey that could be used to develop a more complete model of Puget Sound ecosystem structure. Further, we recommend that any groundfish survey of an area consisting of heterogeneous habitats be conducted using a combination of trawl and ROV rather than by eliminating benthic trawling. Statistical methods must be developed to combine data for species that occur on both trawlable and untrawlable habitats that adequately account for methodological variation in detection rate and other sampling biases.

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# Introduction

In the northeastern Pacific, swept-area trawls are a primary method for obtaining fishery-independent estimates of marine bottomfish distribution and abundance (Gunderson and Sample, 1980; Krieger, 1993; Adams *et al*., 1995; Jagielo *et al*., 2003), and are commonly used to survey exploitable groundfish resources (Wilderbuer *et al*., 1998). Since 1987, the Washington Department of Fish and Wildlife (WDFW) has been conducting semi-regular otter trawl surveys within the interior marine waters of Washington State (hereafter referred to as Puget Sound) to detect trends in population abundance and calculate the biomass of key groundfish species including flatfishes, codfishes, North Pacific Spiny Dogfish *Squalus suckleyi*, and Spotted Ratfish *Hydrolagus colliei,* and to quantify the impact of fisheries on these populations (Quinnell and Schmitt, 1991; Palsson *et al*., 2002, 2003). While these surveys provide a long-term dataset for Puget Sound groundfish and allow for the collection of biological samples, they are temporally limited (surveys only conducted in May and June), expensive, habitat-disruptive, and subject to the availability of chartered fishing vessels. Additionally, the use of an otter trawl precludes the sampling of high-relief, rocky habitats due to concerns about gear damage and/or loss, and habitat alteration as a consequence of bottom contact (Dieter *et al*., 2003; Shephard *et al*., 2010; Jones *et al*., 2012).

In 2003, the WDFW began using a small, observation class remotely-operated vehicle (ROV) to survey high-relief and high-complexity seafloor habitats with the goal of producing estimates of abundance for species of high recreational and commercial fishery interest that were seldom encountered during WDFW trawl surveys, primarily rockfishes (*Sebastes* spp.), Lingcod (*Ophiodon elongatus)* and other greenlings (Hexagrammidae), and Cabezon (*Scorpaenichthys marmoratus).* Although most WDFW ROV surveys were designed to sample untrawlable seafloor habitats, some have included large areas of the seafloor that could be trawled. The WDFW owns the ROV and support vessel, which are available year-round. Consequently, WDFW scientists and managers wanted to explore the potential for using the ROV to conduct surveys that could complement or replace the trawl survey. However, before this possibility can be considered, it is important to understand how the species-specific quality and quantity of the two methods compare when sampling occurs concurrently at a given site.

Ideally, non-selective fishing gears would be used to obtain unbiased, representative estimates of stock distribution and abundance, but in reality, all gears are selective (Hovgård and Riget, 1992). In the case of trawl nets, fish may be herded by the net, bridles, and doors (otter boards) (Krieger, 1993). Fish and other organisms may also escape the net due to their size and shape (Adams *et al*., 1995), or swim completely out of the path of the net prior to being encountered. Visual methods, such as an ROV, may exhibit selectivity patterns by altering the behavior of

animals as a result of stimuli produced by platform speed, noise (from motors, sonars), and artificial lighting (including lasers). Studies of marine fish with visual methods show a range of responses to these factors that vary both by fish size and species (Adams *et al.*, 1995; Norcross and Mueter, 1999; Laidig *et al.*, 2013; Rooper *et al.*, 2015).

Few studies comparing species composition, density, and abundance data between trawls and visual survey methods have been conducted. Uzmann *et al.* (1977) used a submersible, camera sled, and shrimp-rigged trawl to study lobster and crab on Georges Bank, and observed significantly higher abundances of flatfishes and hakes with the visual tools than with the trawl. Krieger (1993) found the percent composition of flatfish observed from a manned submersible and captured with a trawl to be highly correlated, but that flatfish were underestimated by the submersible. In a study of Pacific coast groundfishes by Adams *et al.* (1995), the mean abundance from the ROV was greater than trawl abundance in 37 of 46 species/depth strata comparisons. While these studies provide some insight into differences and similarities between trawls and visual sampling methods, differences in the types of gear used, target species, and study areas do not allow for a direct comparison to Puget Sound species and WDFW methods. Thus, the need to understand how WDFW trawl and ROV methods compare for assessing the complex of species inhabiting Puget Sound forms the basis for the current study.

The study objective was to compare the selectivity and performance of the trawl and ROV on trawlable habitats by analyzing the concordance between species compositions and density estimates collected from paired trawls and ROV strip transects for species strongly associated with the bottom (e.g., flatfishes, sculpins, eelpouts, California sea cucumber). If species-specific ROV-trawl relationships are found to exist, ROV abundance estimates could be used to develop or improve trawl catchability coefficients, augment estimates derived from the trawl survey, detect trends in population abundance with greater power, or facilitate the replacement of annual benthic trawl surveys in preference for the use of a single survey method for all Puget Sound habitats.

# Methods

## Study location and transect selection

The study area was the northern San Juan archipelago (SJA) in Washington State (Fig. 1). The study was conducted concurrently with an ongoing WDFW ROV survey of the SJA and several weeks prior to a planned WDFW trawl survey. Sampling locations were selected as a subset of stations in the ROV survey on an *ad hoc* basis around available slack-tide windows to maximize logistical efficiency. These locations were subsequently post-stratified based on depth (see Results for detail).

## ROV operations

ROV operations were conducted from the 11-m WDFW vessel *R/V Molluscan* using the WDFW Seaeye Falcon™ ROV *Yelloweye*. The vehicle was equipped with a Seaeye CAM04P high-resolution camera (540 lines, 0.35 lux) and primary lighting was provided by three, 180 lumen LED lights mounted to a custom-built frame extending 40 cm forward of the camera, with the lights projected downward to minimize backscatter from suspended sediments and biological particulates. When needed, additional illumination was supplied by three, forward-facing, variable-intensity 75 W incandescent lights supplied as standard equipment on the ROV. The camera was maintained at a 30-35° downward angle relative to the horizon to maximize illumination of the visual field. A pair of 5 mW green lasers mounted in parallel 10 cm apart were affixed to the top of the camera and projected into the center of view to provide a scalar reference for determining transect width and estimating fish size. Per the methods of the ongoing ROV survey, a single 30-minute transect was conducted at each site, driven at an average speed over the bottom of 1 km/hr (0.5 knots). Deployment and retrieval protocols for the ROV are described in detail in Pacunski *et al*. (2008).

ROV tracking and navigation were accomplished with a LinkQuest® 1500CH ultra-short baseline (USBL) acoustic tracking system linked to a KVH Fluxgate® compass and GPS. Tracking data were collected at 1- to 2-second intervals and the georeferenced positions of the ROV were calculated with Hypack 2011® navigation software. The raw tracking data were clipped to match the video transect start and end times and post-processed with Hypack 2011® and ArcGIS 10.1® to remove outlying position fixes. The remaining points were considered to be the best approximation of the ROV path and smoothed at the lowest reasonable tolerance level using the Polynomial Approximation with Exponential Kernel (PEAK) algorithm in ArcGIS 10.1®.

We conducted strip transects and used the fixed lasers to estimate ROV transect width ($W_t$) with the relationship:

$$W_t = W_m * 0.10/W_l$$

where $W_m$ is the width of the video monitor (m), $W_l$ is the width between the lasers measured on the video monitor (m), and 0.10 is the fixed laser separation distance (m). Laser measurements were recorded at 30-second intervals along each transect during video post-processing and averaged to obtain the mean transect width. The ROV was typically driven between 10 and 50 cm above the bottom, resulting in an average strip width of ~1.5 m. When the ROV was too high above the bottom to see the laser spots on the substrate, those video segments and the associated tracking data were clipped from the transect. The area swept along each ROV transect was calculated as the length of the edited smoothed line multiplied by the mean transect width.

## ROV Video review

The ROV video data were processed post-survey by experienced WDFW staff using established protocols (Pacunski *et al.*, 2008). All fish were enumerated and identified to the lowest definitive taxonomic level, and only fish occurring below the plane of the lasers were counted to ensure that they fell within the effective strip width viewed by the ROV. For future analysis, substrate composition was recorded at the same 30-second interval as the laser measurements, and all data were entered into an MS Access database.

## Trawl operations

Trawling was conducted from the 17-m chartered fishing vessel *F/V Chasina*. The sampling net was a 400 mesh Eastern otter trawl with a 1.25" codend rigged for bottom-trawling with 4" cookie-gear on the footrope. The net tows a path ranging from 9 m to 14 m wide, depending upon bottom depth, wire (warp) out, and vessel speed, and the effective net width for each trawl was determined from the results of a net mensuration study conducted by the WDFW in 1994. Trawl path length was calculated in ArcGIS 10.1® as the linear distance between the start point (net begins fishing) and end point (net stops fishing) of each trawl. The swept area of each trawl was calculated as the product of the trawl path length multiplied by the effective net width.

Trawls were conducted along each ROV transect within a two-hour period following each ROV transect, with the exception of one trawl that was conducted the day after the ROV transect. The trawl gear was deployed as close as possible to the start of each ROV transect and towed as close as practicable along the ROV path, except where physical obstacles or safety concerns prevented this from occurring. Upon reaching the plotted ROV transect end, the trawl gear was retrieved

and the entire catch was processed on deck. The numbers and weights of all species were recorded and length measurements were collected from a subsample of selected key species (Table 1). For subsampled species, the average weight per fish from the subsample weight and numbers were used to extrapolate to the total number in the catch.

## Density estimates from ROV and trawling

Taxon density for each ROV transect and trawl was calculated as the taxon count (C) divided by the area swept (A):

$$D = \sum_{i=1}^{N} \frac{C_i}{L_i \overline{W_i}} * 10{,}000 = \sum_{i=1}^{N} \frac{C_i}{\overline{A_i}} * 10{,}000$$

where $D$ is the sum of density (individuals/ha), $L_i$ is the length (m) of the $i$th ROV transect or trawl, and $W_i$ is the mean width (m) of the $i$th ROV transect or trawl.

Paired $t$-tests were used to test for differences in the log transformed (log x + 1) density of a species or taxonomic group between gear types ($H_O$:$\mu_d = 0$, $\alpha = 0.05$). To account for the much smaller area swept by the ROV, stations were excluded from the analysis when a species or taxon was not observed with the ROV and the corresponding trawl estimate was less than the density estimate produced by the occurrence of a single individual in the paired ROV transect (i.e., the minimum detectable density)(Table 1).

# Results

Fourteen paired ROV-trawl transects were accomplished in the SJA from 11 April to 15 April, 2011 (Fig. 1). Swept area estimates for the ROV transects ranged from 184 to 914 m$^2$ ($\overline{x}$ = 550.3 m, *s.d.* = 161.5 m) and from 3,834 to 8,009 m$^2$ ($\overline{x}$ = 5,373.6 m, *s.d.* = 1,411.1 m) for trawls. Comparatively, the paired ROV transect areas were 7 to 21 times smaller, ranging from 4.4% to 14.3% of the paired-trawl area. The ROV transects clustered into two distinct depth groupings: 7 stations with mean transect depths between 23 m and 66 m, and 7 stations with mean transect depths between 101 m and 169 m. Modal trawl depths were consistent with the ROV groupings; 7 trawls ranged from 18 m to 75 m, and 7 trawls ranged from 93 m to 162 m. Because the distribution of groundfish in Puget Sound is known to vary with depth (Palsson *et al*., 2002, 2003), the program Primer-E© was used to examine the composition of major fish taxa within the two depth groupings using non-metric multidimensional scaling (MDS) and an ANOSIM test (H$_o$: no difference in taxa composition between depth groupings). The MDS showed good separation with minimal overlap between depth groupings when the two sampling methods were combined (3-D stress = 0.09) (Fig. 2), and the distribution of R values from the ANOSIM test (999 permutations) was significantly different from the observed R (*p* <0.01), thus supporting a *post-hoc* stratification of the data into Shallow and Deep groups for analysis by gear type.

Twenty-four fish taxa, including 15 species, were identified from the ROV video, whereas 53 species of fish were identified from the trawl. Reliably and accurately identifying fish to the species level from the ROV videos was difficult for several reasons, including poor visibility, fish covered with sediment, fish rapidly escaping the ROV field of view, fish too small to see identifying characteristics, and limitations in the recorded video quality. As a result, 53% of all fish observed with the ROV could not be assigned to a taxonomic group below the Family level, and many of the fishes identified to the species level represented only one or a few observations. Therefore, to provide for the most meaningful possible comparisons between methods, it was necessary to pool most fishes by major taxonomic group as follows: Cottidae (sculpins), Gadiformes (codfish and hake), Pleuronectiformes (flatfish), Stichaeidae (pricklebacks), Zoarcidae (eelpouts), and *Hydrolagus colliei* (Spotted Ratfish). Several species of forage fish were recorded in the trawls and ROV transects but were excluded from all analyses because neither method is configured to adequately sample these primarily mid-water species. The California sea cucumber (*Parastichopus californicus*) is an important, commercially harvested species in Puget Sound and, due to high prevalence and the ease of definitive identification via both survey methods, was the only invertebrate considered in this study.

Total groundfish density estimates from both gear types were higher in the Shallow group than in the Deep group (Fig. 3). In the Shallow group, ROV density was 39% greater than the trawl, but

this relationship was reversed in the Deep group where the trawl density was 28% greater than the ROV estimate; however, the differences between log-transformed average densities were not significant (*t*-tests, Shallow *p*=0.919, Deep *p*=0.089). No obvious patterns were seen in the variability between methods in either depth group (Figs. 4a and 4b). Among Shallow stations, ROV groundfish densities were greater at 4 stations, most notably at E019 and W081, which were dominated by unidentified fish. Trawl groundfish densities were greater at all Deep stations except W024.

The mean densities of Cottidae, Gadiformes, Pleuronectiformes, and 'other groundfish' from the trawls were 3- 4 times greater than ROV densities at Shallow stations and 1.3- 1.7 times greater at Deep stations (Figs. 5a & 5b). Conversely, the mean density of Zoarcidae in the Shallow group from the ROV was 8 times greater than from the trawl, and at Deep stations Zoarcidae was seen only with the ROV. ROV densities of *P. californicus* were 22 and 81 times greater than trawl densities in the Shallow and Deep groups, respectively. Stichaeidae, present only at Shallow stations, was recorded by the ROV at a mean density 91 times greater than captured by the trawl. *Hydrolagus colliei* was only recorded at Deep stations, with the mean trawl density being almost 3 times greater than the ROV density (Fig 5b). Among all taxa comparisons within depth groups, differences in the log-transformed mean densities between the ROV and trawl were only significant for Gadiformes and Stichaeidae in the Shallow group (*t*-tests, *p*=0.028 and *p*<0.001, respectively), and *H. colliei* and *P. californicus* in the Deep group (*t*-test, *p*=0.033 and *p*=0.001, respectively) (Table 2).

High densities of unidentified fish were recorded with the ROV in the Shallow group and were the dominant taxa at two stations, accounting for 67% and 82% of the total groundfish densities (Fig 5a). Based on the high densities of Stichaeidae (primarily Snake Prickleback *Lumpenus saggita*) observed at these stations and the video reviewers' observations of fish behavior, it is presumed that most of these unidentified fish at Shallow stations are juvenile Snake Prickleback, although some of these fish could also be small flatfish. Occurrences of unidentified fish at Deep stations were much lower than Shallow stations (Fig. 5b) and never composed more than 20% of the total groundfish density at an individual station.

Coefficients of variation (CVs) for the density of dominant fish taxa (Shallow: Cottidae, Gadiformes, Pleuronectiformes, Zoarcidae; Deep: Cottidae, Gadiformes, Pleuronectiformes, *H. colliei*) ranged from 36% to 247% (Figs. 6a and b). The ROV and trawl CVs for Cottidae at Shallow stations were nearly identical, but at Deep stations the ROV CV was much lower than the trawl CV. For Gadiformes, the trawl CV was lower than the ROV CV in the Shallow group, but the CVs were similar at Deep stations. ROV and trawl CVs for Pleuronectiformes in both the Shallow and Deep groups were remarkably similar. The ROV CV for Zoarcidae at Shallow stations was lower than the trawl CV, and the trawl CV for *H. colliei* (only seen at Deep stations)

was lower than the ROV CV. For *P. californicus*, the trawl CV was 2.4 times greater than the ROV CV in the Shallow group, while CVs for both gear types were they highest of any taxa in the Deep group.

# Discussion

Differences were observed between the ROV- and trawl-derived densities for the major groundfish taxa and one invertebrate considered in this study, but only four of these differences were statistically significant (Shallow: Gadiformes, Stichaeidae; Deep: *H. colliei*, *P. californicus*). The non-significant findings of other comparisons can be attributed to the small sample sizes and high between-station variability of taxa within depth groups. Despite the lack of statistical power it was clear that the two methods have different sampling capabilities. Stichaeids, Zoarcids, and *P. californicus* have a body shape and size that allows for high escapement through the trawl mesh or under the footrope, as evidenced by the higher ROV density estimates. Adams *et al*. (1995) reported a similar result for red octopus, an animal that easily passes through the trawl mesh, with ROV abundance estimates always being higher and CVs lower than trawl estimates.

Pleuronectiformes are the dominant catch component of WDFW trawl surveys and the mean trawl densities for this taxon were higher than those from the ROV in both depth groups, with the difference between survey methods being more pronounced in the Shallow group. In contrast to our findings, Uzmann *et al*. (1977) and Adams *et al*. (1995) estimated higher abundances of flatfish from visual methods than from a trawl, which may be due to differences in gear configuration and size distribution of encountered taxa between studies. Uzmann *et al*. (1977) used a shrimp trawl that does not capture fish effectively, and the more powerful ROV lighting used by Adams *et al*. (1995) may have increased the detection rate of flatfish. Also, both of these earlier studies were conducted at greater depths (80-600 m) than the current study (23-169 m) and may have encountered fish of larger average size that could be more easily detected by the visual sampling devices they used, although fish size was not specifically addressed in either study.

Gadiformes and *H. colliei* tend to exhibit more off-bottom behaviors and their higher abundance in the trawl likely represents the greater sample volume of water that includes the 2-3 m height of the headrope, which is presumed to be capturing individuals occurring above the viewing window of the ROV. This conjecture is supported by the ROV video, which often showed *H. colliei* approaching the ROV from above but not entering the counting field of view of the camera. Also, during descent, the ROV would occasionally pass through aggregations of Gadiformes occurring up to several meters above the bottom. Higher ROV density CVs for Gadiformes in the Shallow group may be a function of fish size. Trawl-caught Gadiformes (mostly Walleye Pollock, *Gadus chalcogrammus*) in the Shallow group ranged from 11 to 20 cm, whereas Walleye Pollock in the Deep group ranged from 12 to 50 cm. Because larger fish are easier to detect on the video, a lower rate of missed detections in the Deep group could be

expected to produce a lower CV. Variable results have been reported for other off-bottom species in similar studies. Catsharks (family Scyliorhinidae) had higher trawl densities and lower CVs compared to an ROV as reported by Adams *et al*. (1995), who suggested that neither method probably does an adequate job of sampling patchy distributions of off-bottom species. In contrast to our results, Uzmann *et al*. (1977) found the reverse to be true for hakes (a gadiform), with densities estimated by a submersible and a camera sled being significantly higher than trawl densities, although this is most likely due to the use of a shrimp-trawl rig that targeted deep-water crustaceans versus the trawl rigged to capture fish in the present study. In another ROV-trawl study of deep-water (>1100 m) fish, Trenkel *et al*. (2004a) determined that relative trawl availability (i.e., the ratio of the trawl population density estimate to the ROV population density estimate) increased as fish distance from the seafloor increased, which the researchers linked to differences in the vertical sampling ranges of the trawl and ROV. Higher trawl estimates of Gadiformes in the present study could also be the result of herding by the trawl doors, as suggested by Krieger (1993), who reported that trawl estimates for Pacific Ocean perch (a species of rockfish) were nearly double those obtained from a paired submersible survey. Estimates of small rockfish from that same study showed a much lower catch-to-observed ratio, which Krieger (1993) suggested may have been partly the result of higher escapement through the net mesh by smaller fish.

*Parastichopus californicus* was the only invertebrate considered in the study and is important because the species supports a valuable commercial fishery in Puget Sound. Population estimates and harvest guidelines for *P. californicus* have traditionally been derived from scuba surveys, which are limited to a practical working depth of ~25 m, thereby excluding that portion of the population residing in deeper water. Tribal co-managers and some harvesters and researchers have asserted that cucumbers in deep water may act as a recruitment reservoir (Blaine, 2011; H. Carson, pers. comm.), although a recent study suggests otherwise (Carson *et al*., in review). There is also some anecdotal evidence suggesting that some *P. californicus* migrate seasonally between depth zones (DFO, 1999; Carson *et al*., in review), although observations by Britton-Simmons *et al*. (2012) in the San Juan Islands suggest the opposite. Regardless, assessing the population status of deep-water cucumbers is critical for understanding the biology and potential reproductive capacity of this species, and may have implications for future management decisions. In the past, WDFW shellfish managers have used WDFW trawl survey data to estimate the abundance of *P. californicus* beyond scuba depths (WDFW unpublished data), although the results of this study clearly suggest that those estimates are unreliable and significantly underestimate the true population abundance, leading to the conclusion that the ROV is a better tool for assessing this species.

With the exception of Plueronectiformes, which had similar ROV and trawl CVs in both depth groups, no patterns were observed when CVs were compared between gear types; ROV and trawl CVs differed for some taxa in one depth group but were similar for both gears in another. This result was not surprising given the small number of stations sampled within each depth group, and differences in fish size, spatial distribution, and area sampled that may be contributing factors to our results. The narrow viewing frame of the ROV is highly sensitive to patchy distributions (both horizontal and vertical) occurring at very small spatial scales and would be expected to produce higher CVs for some animals relative to the trawl (e.g., Gadiformes, *H. colliei, P. californicus*), which tends to average these distributions over the larger area swept. While every attempt was made to trawl along the transect path traversed by the ROV, this was not always possible. At Shallow stations the ROV and trawl paths were strongly coincident and covered the same mesohabitats (Fig. 7), theoretically minimizing the effect of habitat on gear performance. In contrast, the ROV and trawl sampled different proportions of the same mesohabitats or completely different habitats entirely at several stations in the Deep group (Fig. 8), and the assumed variability in biotic assemblages across habitat types complicates our ability to discern possible trends by gear type.

One obvious shortcoming of the visual survey methodology employed in the current study was the small area sampled by the ROV, such that the detection, or non-detection, of a single organism could dramatically affect the resulting density estimate (see Table 1). This can be especially problematic for populations with patchy distributions and could result in ROV population estimates that are strongly biased (either low or high). This bias could be minimized by increasing the number of sampling sites or the length of transects (or both), but could greatly add to the cost and/or logistical complexity of any survey focused on achieving a representative sample of a diverse suite of species across several habitat types.

While visual methods are generally non-lethal and have minimal or no impact on seafloor habitats, they are not immune from bias. Platform speed, noise, lighting, and electromagnetic fields can all produce stimuli that may affect fish response (see review in Stoner *et al*., 2008), and these responses are often species- or size-specific (Trenkel *et al*., 2004b; Laidig, 2013; Rooper *et al*., 2015). The impacts of ROV noise, lighting, lasers, and speed on fish behavior were not considered in this study, but because the ROV was driven at a constant speed with the lasers and primary lights always on, it is assumed that any biases induced by these factors were consistent across transects. Nonetheless, understanding species-specific responses to platform-produced stimuli is an important consideration in the configuration and mode of operation of any survey tool. In Puget Sound and elsewhere, additional studies are required to optimize methodologies that minimize, or allow for calibration of, platform impacts on fish behavior before estimates from such tools can be used to supplement or replace existing survey methods.

Perhaps the most critical limitation on the ROV as configured in this study was the inability to capture imagery that would allow for the identification of most fish below the level of Order or Family. Other visual-based studies have reported difficulties identifying fish to the species level from video (Norcross and Mueter, 1999; Trenkel *et al*., 2004a), or report their findings at higher taxonomic levels, presumably for the same reason (Adams *et al*., 1995). It may be possible to improve fish identification and detection using a combination of high-definition (HD) cameras, improved lighting, and tickler chains (or fingers) and, if successful, this could improve the quantitative efficacy of the ROV. Another limitation of the ROV is the inability to accurately determine fish length from the video, a requirement of age-structured fishery models. Although the use of HD stereo cameras and image analysis software for sizing fish *in situ* is becoming more common (Williams *et al*., 2010; Rooper *et al*., 2010; Rooper *et al*., 2015), additional studies are needed to understand the biases associated with these tools before they can be used to augment or replace measurements obtained from trawls.

Despite the acknowledged limitations of the ROV, the ability to collect direct observations of organisms and the seafloor provides valuable information that can be used to define taxa-specific habitat relationships at more spatially discrete scales than possible from the trawl data. Improved understanding of these relationships will eventually allow for habitat-based stratification of future trawl surveys to produce more precise population estimates, and could also provide greater insight into historical trawl catches and population trends.

Historically, biomass and abundance estimates from the trawl survey have been used for setting harvest guidelines for Pacific cod in the Strait of Juan de Fuca and Strait of Georgia (W. Palsson, pers. Comm.). Population trends derived from trawl survey estimates, in combination with other indicators, have also been used to restrict Pacific Cod and Walleye Pollock fisheries, close rockfish fisheries in Puget Sound, and to assess the relative exploitation rates of selected flatfish species (Palsson, 1990; Palsson *et al*., 1997, 2009). Currently, no commercial fisheries for bottomfish exist in Puget Sound, thus the trawl estimates are of greater value for evaluating trends in taxa biomass for monitoring ecological changes and ecosystem dynamics within Puget Sound. In the current study, the ROV data provided a broader perspective on the Puget Sound ecosystem that until now has gone undocumented; specifically, Sticheaidae, Zooarcidae, and *P. californicus* were found to occur at much higher densities than expected based on the trawl survey. From these results it seems obvious that using only the trawl data to assess ecosystem trajectories could lead to fallacious conclusions by ignoring organisms that may play critical roles in ecosystem function. Therefore, by complementing the trawl survey with ROV surveys designed to assess organisms not captured by the trawl, a more accurate characterization of the benthic marine community within Puget Sound becomes possible, facilitating the development of more robust ecosystem models.

Whether using the ROV to complement the trawl survey or as a replacement for trawling should the aforementioned technological challenges of the vehicle be overcome, survey cost and efficiency will be important factors to consider in any ROV survey design. Not only is the ROV expensive to operate and maintain (or potentially replace should it be lost), the operating window of the ROV is generally constrained to periods of minimal tidal flows (<1 knot), which can severely negatively impact survey efficiency, especially in areas where stations are spatially distant. A better option for collecting video on trawlable bottoms would be to use a camera sled to obtain the same or directly comparable data with far less effort and expense, and this tool can be operated in almost any tidal state, thereby maximizing survey efficiency.

Given the current limitations of the ROV, we conclude that trawling remains the most reliable method for obtaining positive species identifications and accurate measurements of fish length, and for providing biological samples at a scale needed for fishery management.  However, complementing the trawl survey with ROV-collected data could provide valuable information on groundfish species that are undersampled by trawling or that occupy heterogeneous habitats at the edge of trawlable areas (e.g., ecotones) and sensitive habitats where trawling is not a practicable option.  Further, the year-round availability of the ROV provides the ability to collect data outside the temporal window of the trawl survey, allowing for the examination of seasonal trends in some species, as well as a rapid response to ecological crises if needed (e.g., fish kills, oil-spills, low dissolved oxygen events, etc.).

# Acknowledgments

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# Figures
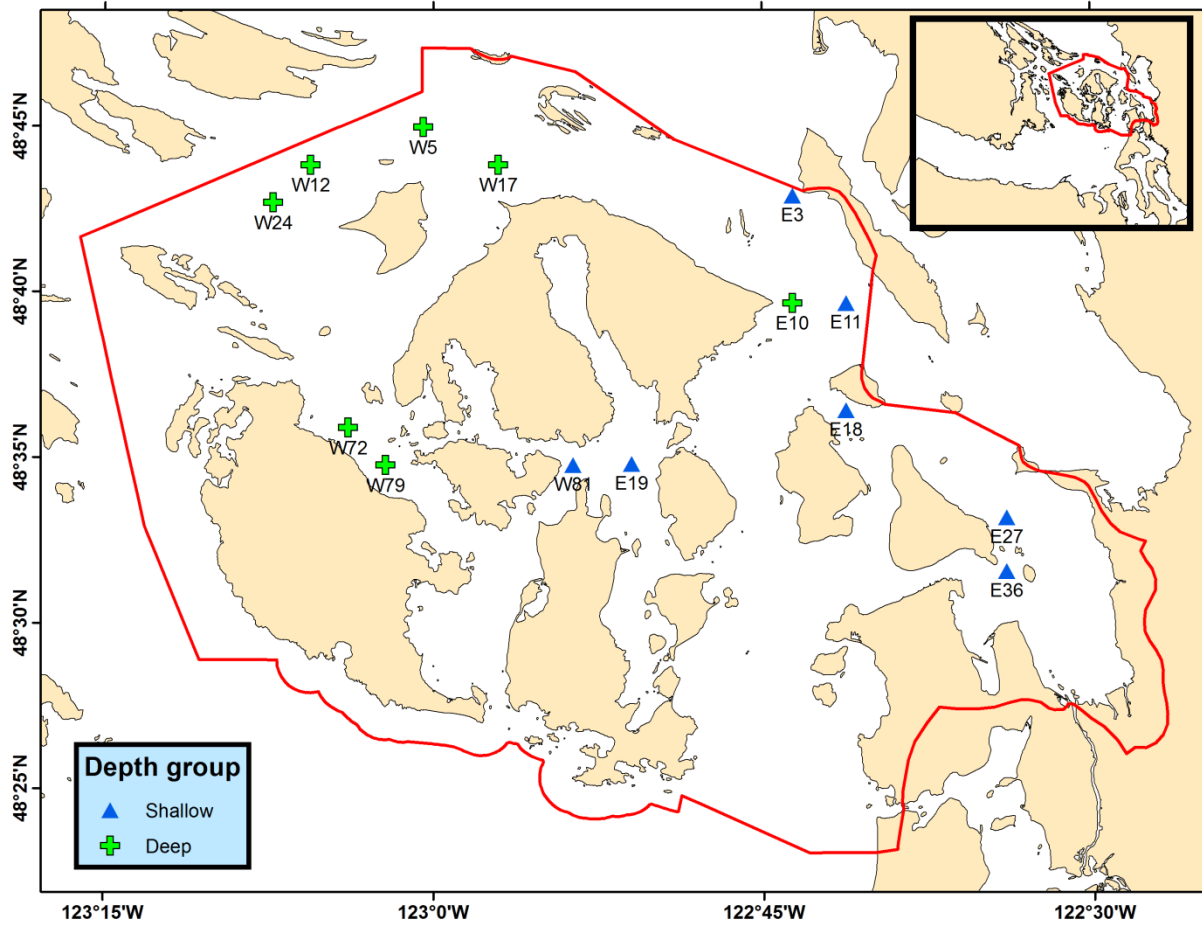


**Figure 1. Locations of paired ROV-trawl stations in the San Juan archipelago, by depth group. Inset map shows the location of the SJA in northern Puget Sound, Washington.**
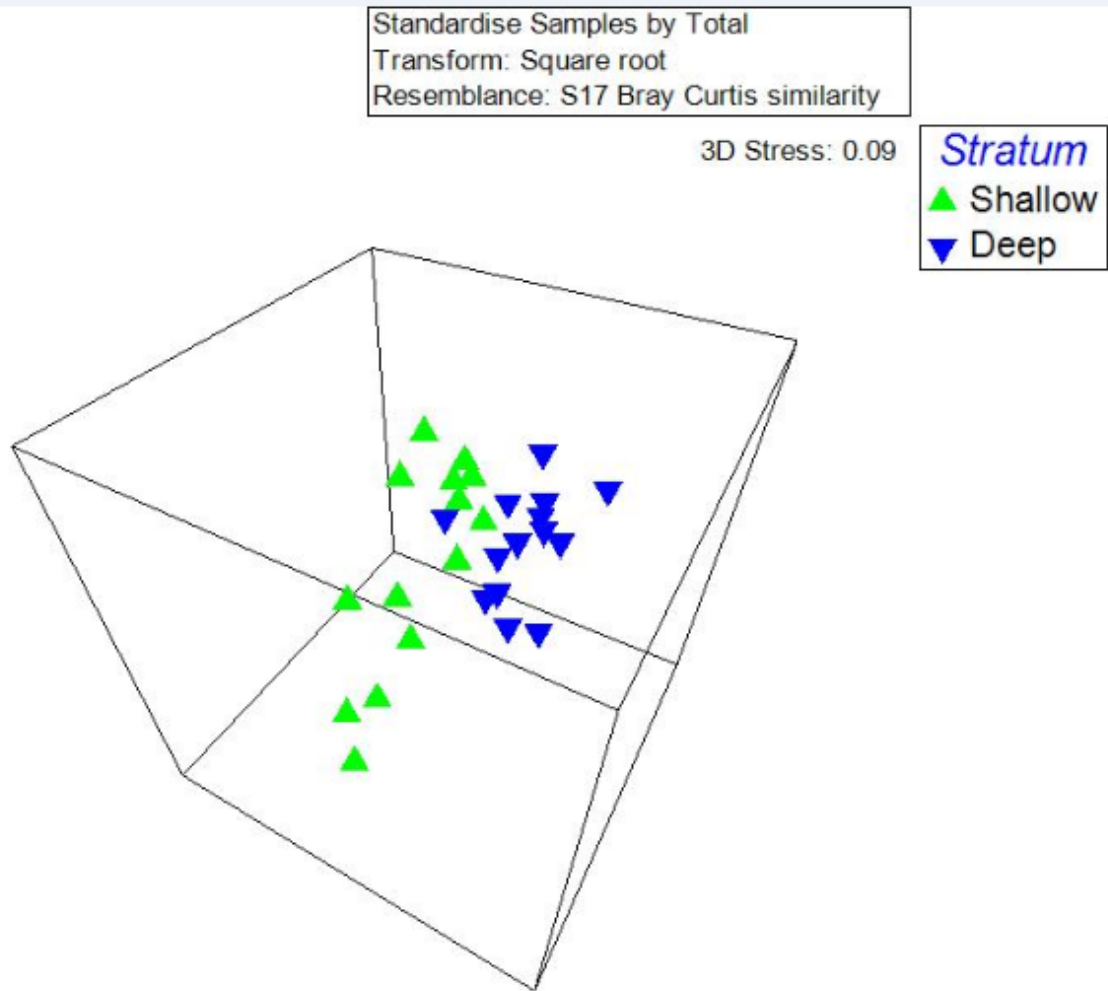
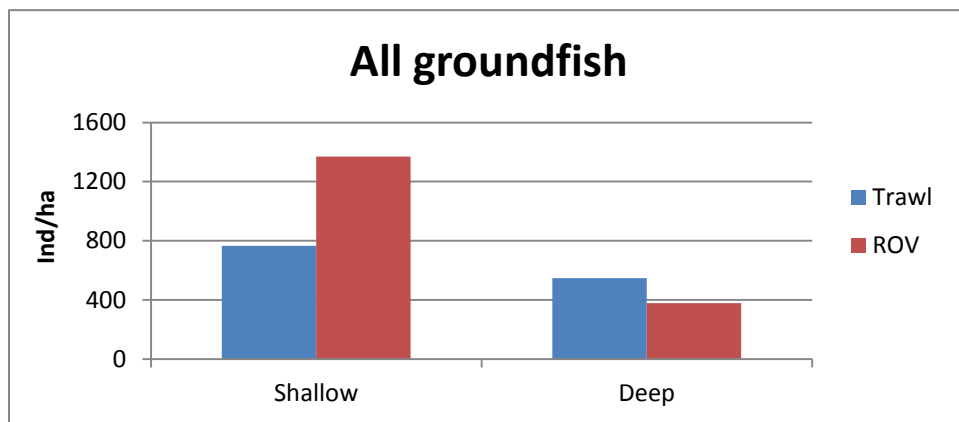**Figure 2.  MDS plot of ROV and trawl stations based on dominant groundfish taxa.**



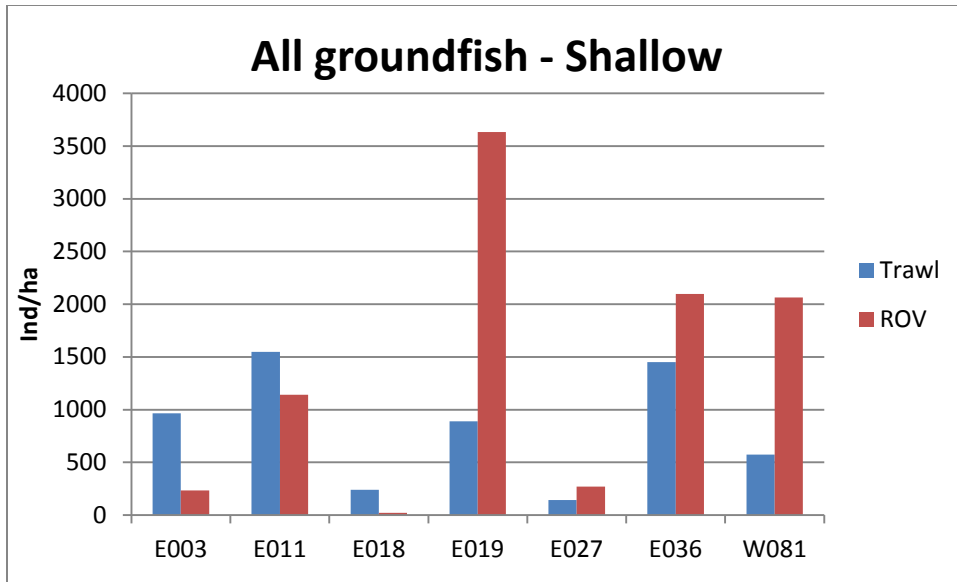**Figure 3.  Densities of all groundfish combined, by depth group.**

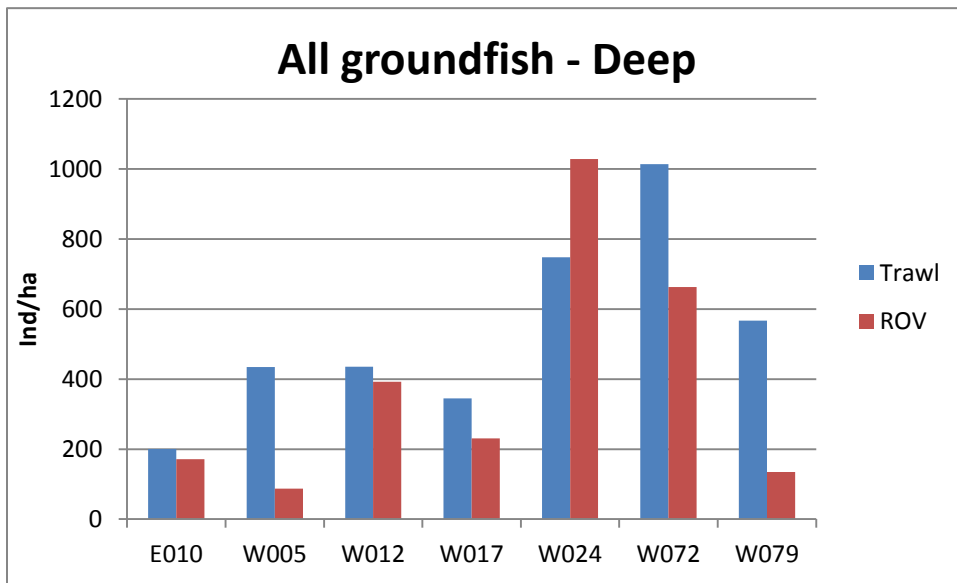**Figure 4a. Total groundfish densities by station and gear type in the Shallow group.**



**Figure 4b. Total groundfish densities by station and gear type in the Deep group.**
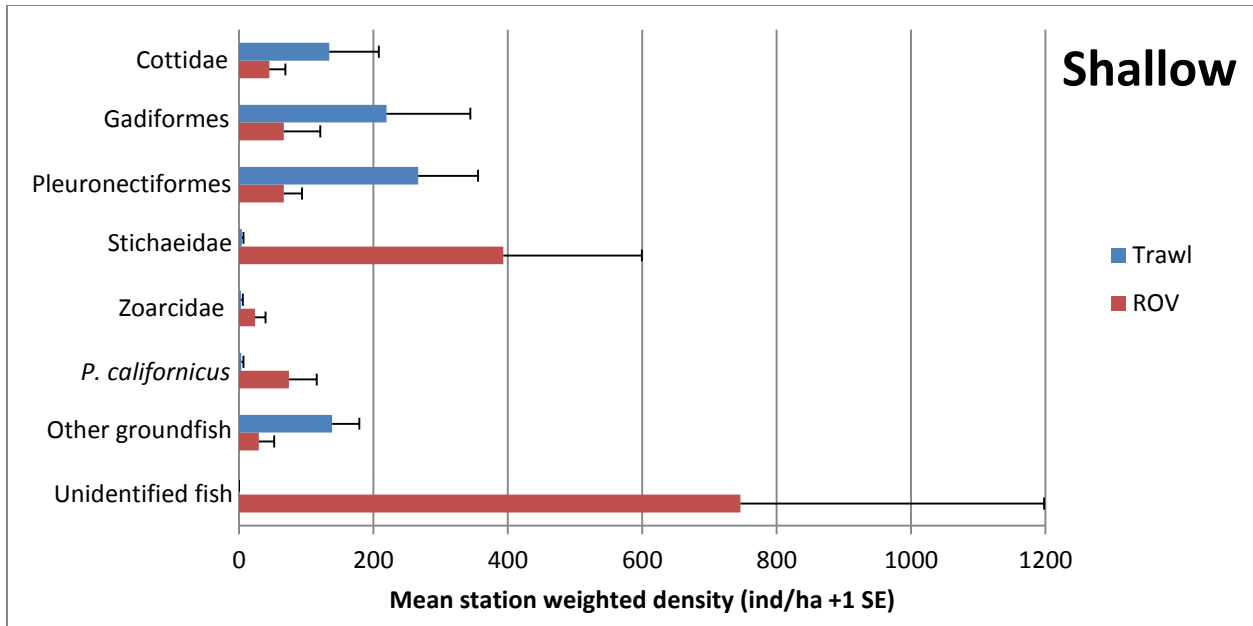
**Figure 5a. Mean densities (+1 SE) of major taxa by gear type in the Shallow group.**
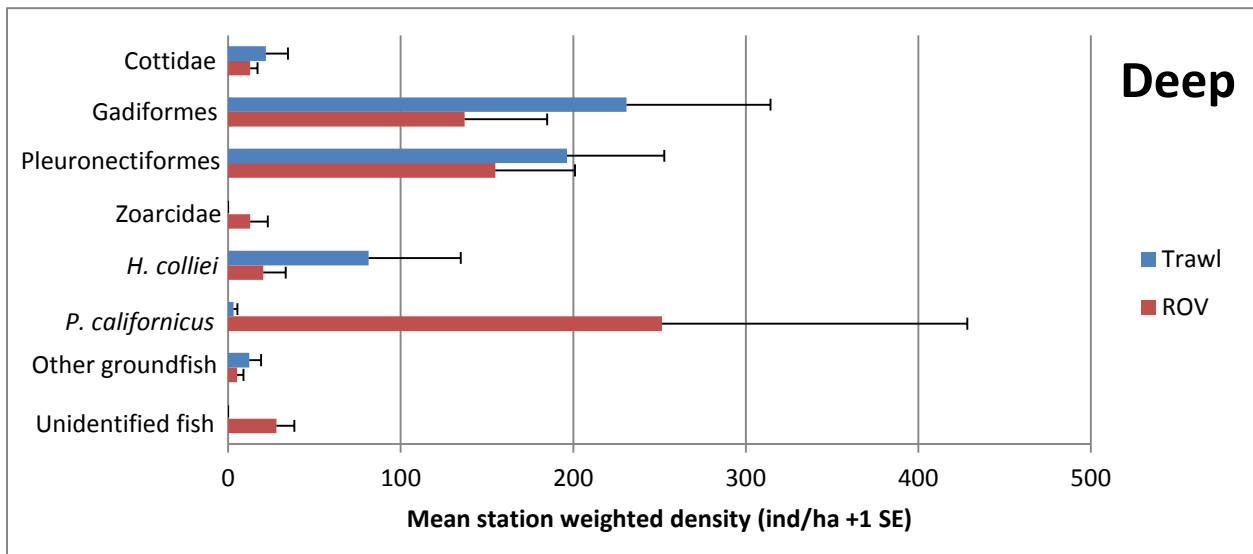


**Figure 5b. Mean densities (+ 1 SE) of major taxa by gear type in the Deep group.**
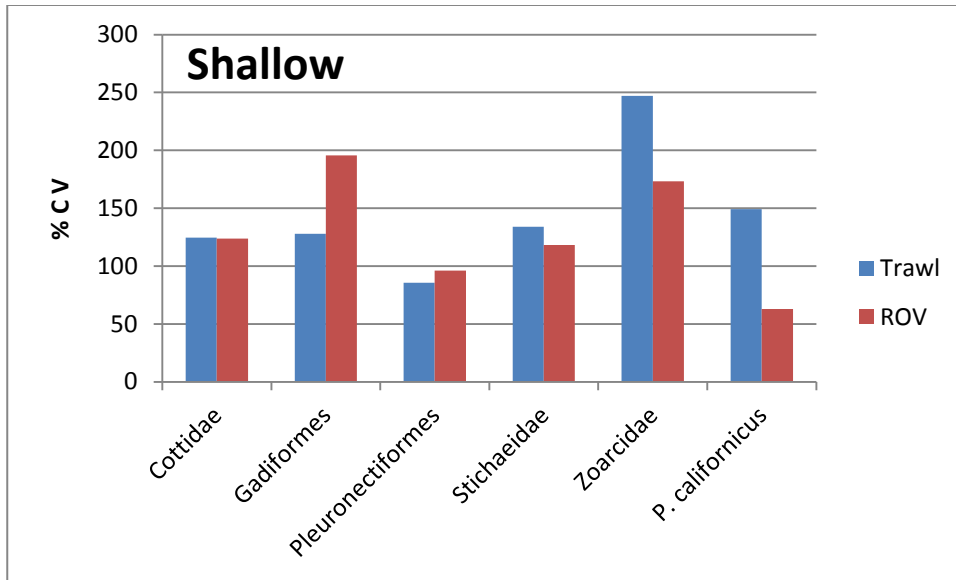
**Figure 6a. Coefficients for variation for densities of major fish taxa and CA cucumbers in the Shallow group.**
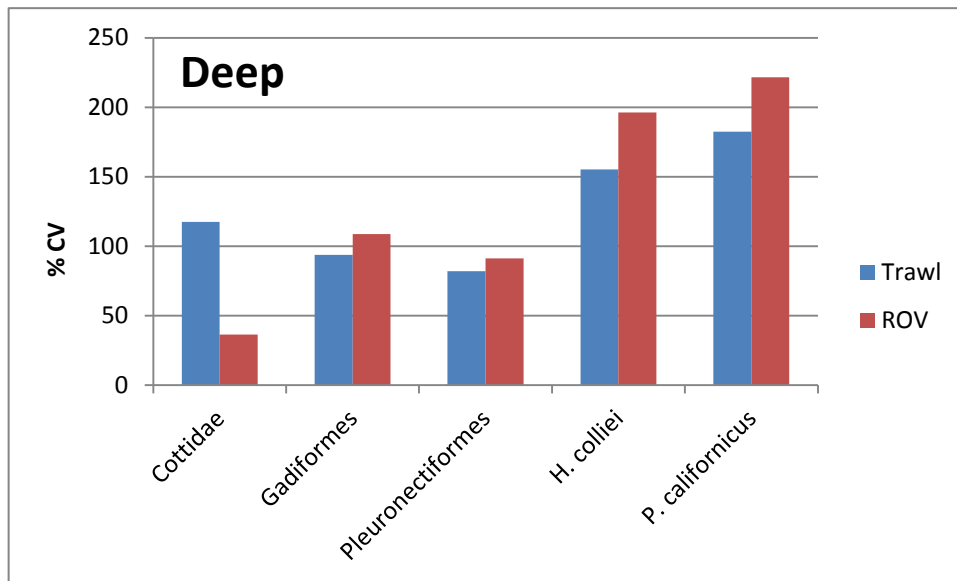


**Figure 6b. Coefficients of variation for densities of major fish taxa and CA cucumbers in the Deep group.**
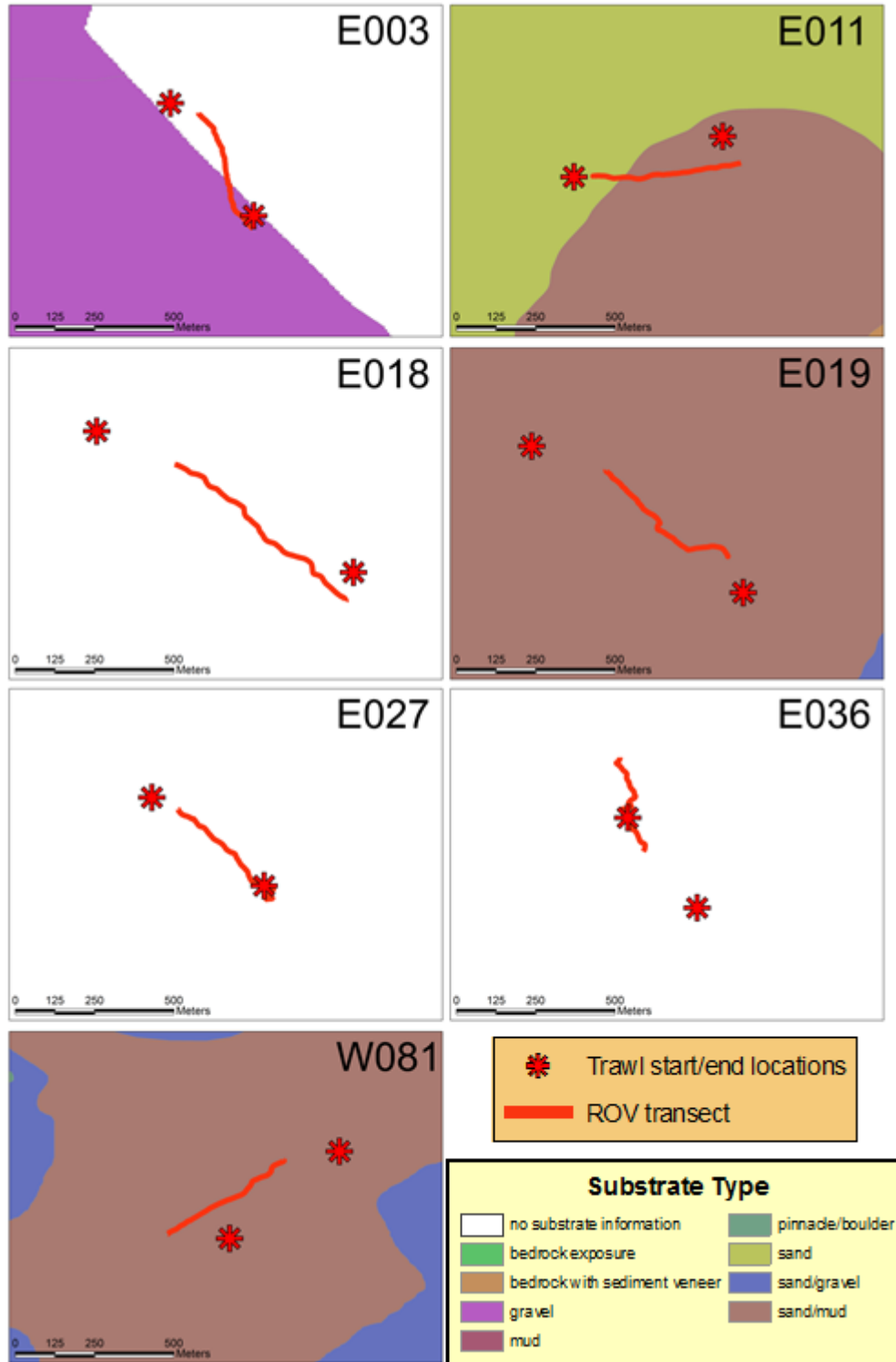
**Figure 7. ROV tracklines and trawl start-end points in the Shallow group overlaid on available benthic habitat data.**
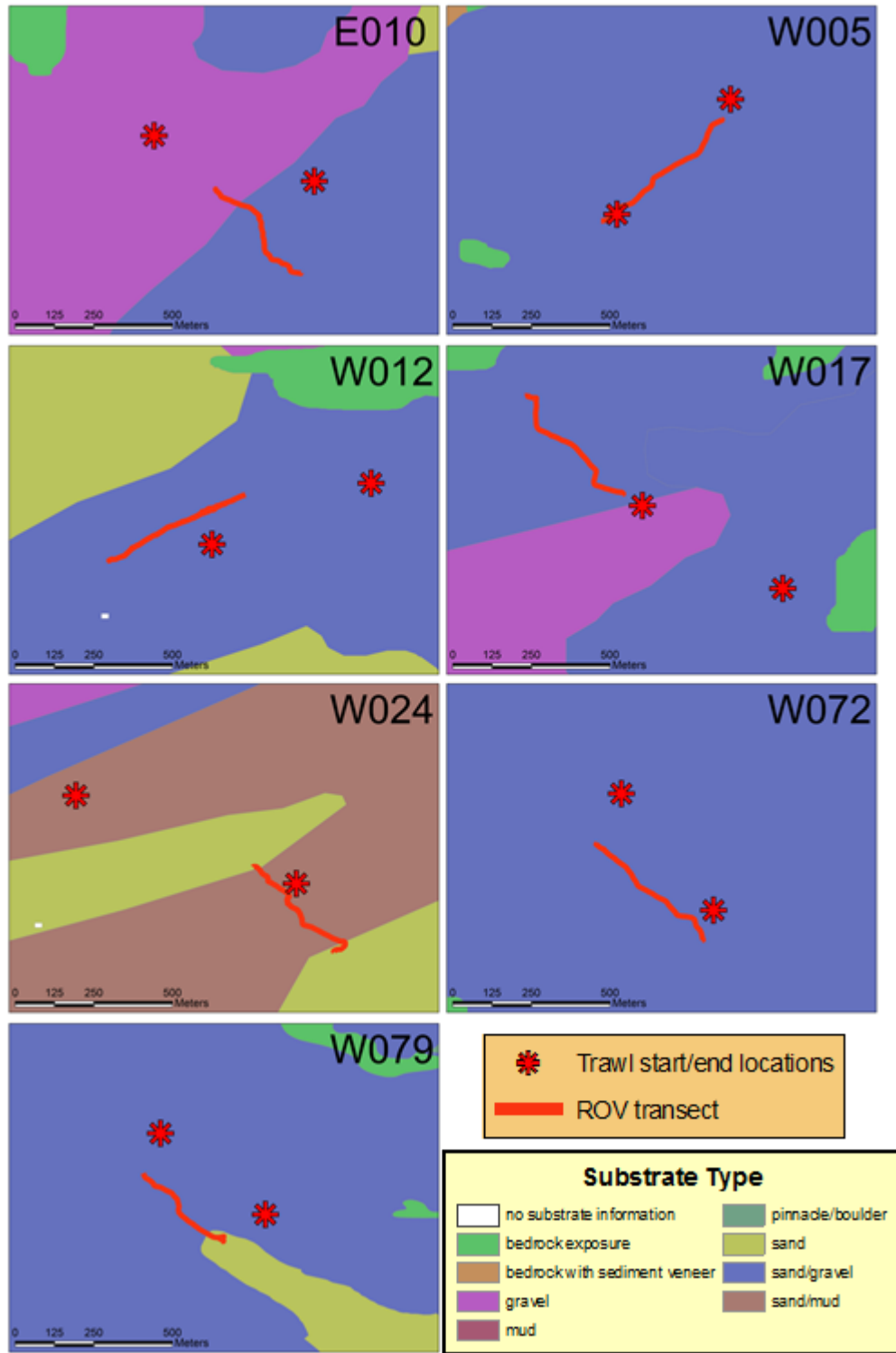
**Figure 8. ROV tracklines and trawl start-end points in the Deep group overlaid on available benthic habitat data.**

# Tables

**Table 1. Key taxonomic groups and species from the trawl survey.**

| Key taxonomic group | *Species name* | Common name |
|---|---|---|
| Chimaeridae | *Hydrolagus colliei* | Spotted Ratfish |
| | | |
| Cottidae | *Enophrys bison* | Buffalo Sculpin |
| | *Hemilepidotus hemilepidotus* | Red Irish Lord |
| | *Leptocottus armatus* | Pacific Staghorn Sculpin |
| | *Myoxocephalus polyacanthocephalus* | Great Sculpin |
| | | |
| Gadiformes | *Gadus chalcogrammus* | Walleye Pollock |
| | *Gadus microcephalus* | Pacific Cod |
| | *Merluccius productus* | Pacific Whiting (hake) |
| | | |
| Pleuronectiformes | *Citharichthys sordidus* | Pacific Sanddab |
| | *Eopsetta jordani* | Petrale Sole |
| | *Hippoglossoides elassodon* | Flathead Sole |
| | *Lepidopsetta polyxystra* | Northern Rock Sole |
| | *Lepidopsetta bilineata* | Southern Rock Sole |
| | *Microstomus pacificus* | Dover Sole |
| | *Parophrys vetulus* | English Sole |
| | *Platichthys stellatus* | Starry Flounder |
| | | |
| Squalidae | *Squalus suckleyi* | Pacific Spiny Dogfish |

**Table 2. Density estimates produced by the occurrence of a single individual on an ROV transect (i.e., minimum detectable density).**

| Depth group | Station | Density (ind/ha) |
|---|---|---|
| Shallow | E003 | 17.9 |
| Shallow | E011 | 22.4 |
| Shallow | E018 | 10.9 |
| Shallow | E019 | 15.6 |
| Shallow | E027 | 54.2 |
| Shallow | E036 | 20.8 |
| Shallow | W081 | 18.6 |
| Deep | E010 | 19.0 |
| Deep | W005 | 14.5 |
| Deep | W012 | 18.7 |
| Deep | W017 | 16.4 |
| Deep | W024 | 20.6 |
| Deep | W072 | 15.4 |
| Deep | W079 | 22.5 |

*A Comparison of Groundfish Species Composition, Abundance, and Density Estimates*
*Derived from a Scientific Bottom-Trawl and a Small Remotely-Operated Vehicle for Trawlable Habitats*
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**Table 3. Results of paired *t*-tests on log-transformed mean densities of major taxa between ROV transects and trawls (significant results in bold).**

|  | Shallow | Deep |
|---|---|---|
| **Cottidae** | 0.056 | 0.944 |
| **Gadiformes** | **0.028** | 0.178 |
| **Pleuronectiformes** | 0.070 | 0.760 |
| **Stichaeidae** | **<0.001** | no test |
| **Zoarcidae** | 0.093 | no test |
| *H. colliei* | no test | **0.033** |
| *P. californicus* | 0.094 | **0.001** |