A Visual Survey of Inshore Rockfish Abundance and Habitat in the Southern Strait of Georgia Using a Shallow-Water Towed Video System

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A VISUAL SURVEY OF INSHORE ROCKFISH ABUNDANCE AND HABITAT IN THE SOUTHERN STRAIT OF GEORGIA USING A SHALLOW-WATER TOWED VIDEO SYSTEM

by

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Visual surveys are useful for the assessment of rocky reef fishes and their habitat. Many visual surveys have used divers, ROVs and submersibles. Areas which are beyond the safe scuba diving limit and yet too shallow to justify the expense of manned submersibles and ROVs may be best suited to towed camera surveys. In June of 2003 we investigated the utility of a small towed video camera system to conduct an assessment of inshore rockfish abundance and habitat quality in the southern Strait of Georgia, British Columbia. Transects targeted rocky reefs between 30 and 100 meters. Video was reviewed to identify fish and classify habitat along transects and laboratory calibrations of the camera field of view enabled density estimates to be made for fish species observed over various habitat types. We find that inshore rockfish show strong associations with bedrock and boulder-dominated substrates.

RÉSUMÉ

Martin, J.C. and Yamanaka, K.L. 2004. A visual survey of inshore rockfish abundance and habitat in the southern Strait of Georgia using a shallow-water towed video system. Can. Tech. Rep. Fish. Aquat. Sci. 2566: xi + 52 p.

Les sondages visuels sont utiles pour évaluer l'état des poissons de récifs et de leur habitat. De nombreuses sortes de sondages visuels nécessitent le recours aux plongeurs, aux engins télécommandés et aux submersibles. Les zones quoi ne se prêtent pas à la plongée en scaphandre autonome pour des raisons de sécurité mais qui ne sont pas assez profonde pour justifier l'emploi de submersibles habités et d’engins télécommandés sont tout indiquées pour les observations par caméra remorquée. En juin 2003, nous avons étudié l'utilité d'un petit système de caméra vidéo remorquée pour faire une évaluation des stocks de sébaste côtier et de la qualité de leur habitat dans la partie sud du détroit de Georgia, en Colombie-Britannique. Les transects établis visaient des récifs rocailleux de 30 à 100 mètres de profondeur. Les enregistrements ont servi à identifier les poissons et à en classifier l'habitat le long des transects, et l'étalonnage en laboratoire du champ de vision de la caméra a permis de faire des estimations de la densité des espèces de poisson observées dans différents types d'habitat. Nous constatons que le sébaste côtier présente des analogies considérables avec celui des substrats où prédominent la roche mère et les blocs rocheux.

1.0 INTRODUCTION

Inshore rockfish are an assemblage of 6 *Sebastes* species; yelloweye (*S. ruberimus*), copper (*S. caurinus*), tiger (*S. nigrocinctus*), china (*S. nebulosus*), quillback (*S. maliger*) and black (*S. melanops*) rockfish. They inhabit rocky reefs in shallow water from Alaska to California (Hart 1973). These species have been the target of recreational and commercial fishing activity for well over a century and have likely always been a significant component of First Nations fisheries (Love et al 2002). Currently these stocks are at low levels of abundance within the Strait of Georgia (Yamanaka and Lacko 2001).

This report summarizes video observations of inshore rockfish from two different towed camera systems from June 4th –8th of 2003. The objectives of this study were to:

1. Develop visual assessment methods for shallow water (<70m) applications
2. Assess rockfish abundance and habitat in the southern Strait of Georgia (statistical areas 17, 18 and 19)

2.0 METHODS

2.1 Survey methods

The video survey was conducted from June 4th – 8th of 2003, in the Strait of Georgia, British Columbia, from Newcastle Island south to Darcy Island (Table 1; Figures 1 - 4) onboard the CCGS *Neocaligus*. A depth-stratified random design was employed where the survey area was divided into two depth strata of 10-50 m and 51-100 m and overlain with a 1 km^2 grid. Twenty blocks were randomly selected from each depth strata. Transects targeted areas of hard bottom and/or high slope as determined by charts and depth-sounder readings, and the transect was oriented into the prevailing current.

2.2 Towed cameras

Two different towed camera platforms were used; the ‘Toad II’ and the ‘Delta Wing’, which are hereafter referred to as ‘Toad’ and ‘Delta’ respectively (Figure 5), manufactured by A.G.O. Environmental Electronics Ltd. (10 - 626 Esquimalt Rd., Victoria, BC, V9A 3L4). The ‘Toad’ system consisted of a stainless steel frame on skids, with two ballast/floatation tubes mounted dorsally. Several fins were attached; an inverted V-shaped tailfin mounted on a steel spar and two laterally-mounted depressor vanes for increased planing in strong current conditions. The ‘Delta’ system consisted of a delta-shaped ‘wing’ of coated aluminum, canted downwards at a slight angle from the centerline. A vertical fin mounted at the rear increased stability, and several counterweights were mounted and adjusted to maintain an ideal balance.

The instrument package was central to each platform. On the ‘Toad’, this package was mounted inside the frame, above the skids and below the floatation tubes. On the ‘Delta’, it was mounted under the rear of the wing surface, protected from impacts by a steel bar.

Video imaging was provided by a high-resolution digital colour camera (A.G.O. Environmental Electronics 'Zip' model; <1 lux sensitivity, >400 lines resolution), mounted for a forward view with a pair of parallel lasers (red on 'Delta' and green on 'Toad') to provide a means of estimating distance and size on camera. Environmental data were collected using a temperature/depth (HPD) sensor (A.G.O.). Lighting modules were used on each towed body, using standard halogen bulbs with integrated parabolic reflectors (A.G.O. 'Zip' model; 15-50 watt, using MR-15 or MR-11 bulbs). Diffusers were used on the lighting modules to optimize illumination over a range of turbidity. All of these components were connected to a pressure-proof junction unit (A.G.O., rated to 500 m), which connected the entire towed body to the umbilicus.

Equipment on board the research vessel was integrated in the following manner (Figure 6): The umbilicus (A.G.O. 1000 lb breaking strength, mini coaxial plus 5, 20 gage unshielded conductors, urethane jacket) relayed 12 v power from battery packs on the surface to the towed body while relaying video signal and data from the HPD sensor. A ship-mounted GPS unit (Garmin GPS 76) provided geographic data as well as a time stamp. Both these inputs were combined with a text overlay titler (V.O.L.T. – A.G.O.) which overlaid time, position, depth and temperature data on the video. The data stream was logged on a PC running a terminal program. The video signal with the data overlay was recorded in MiniDV format on a Sony GV-D900 recording deck.

2.3 Deployment

The camera was deployed from the stern of the CCGS *Neocaligus* with a cable attached directly to the camera unit and a hydraulic winch was used to either pay out or reel in cable. The umbilicus was trailed separately and paid out with a hand-cranked winch equipped with a slip-ring assembly (A.G.O. Environmental Ltd.). The umbilicus was secured to the winch cable at 5 m intervals to minimize drag. A large monitor, placed where it was visible to the winch operator, allowed the winch operator to 'fly' the camera over the substrate by raising and lowering the cable to maintain an optimal height off the sea floor.

2.4 Data integration

Post-survey, data streams logged from the V.O.L.T. overlay unit proved difficult to delimit into tabular format and a Visual Basic script was employed to import the data for date, time, latitude, longitude, depth and temperature into a relational database (Microsoft Access). Some records did not contain valid data for temperature, depth or GPS coordinates. For gaps of short duration, values were estimated from surrounding data and for longer gaps, values were simply omitted.

2.5 Video analysis

Videos were reviewed in the laboratory using a Sony GVD-900 MiniDV deck for playback on a Sony PVM-14M2U Trinitron monitor (14"). Fish habitat was classified according to substrate type, relief, complexity, biocover type and biocover thickness (Table 2) using a coding system modified from Pacunski and Palsson (2001). The habitat descriptor "Biocover thickness" was added to the substrate types given that biocover such as sponges or sea whips can influence the presence of rockfish (Richards 1986 and Brodeur 2001). This descriptor recorded area coverage in 25% bins from 0 to 100% cover (Table 2).

Organisms were identified to the lowest possible taxonomic level and entered into the database using a standardised numeric species coding system (Gillespie 1993). All observed fish were recorded regardless of distance from the camera and for invertebrate species the larger and/or rarer species (i.e. *Cancer spp*, *Hyas spp*, *Parastichopus californicus*) were recorded on an individual basis, with size estimates being made whenever possible for both fish and invertebrates. Smaller or more common invertebrate species (i.e. *Strongylocentrotus spp*, *Pandalus spp*, *Metridium spp*, or sponges) were noted only when larger aggregations were observed. Sex and maturity were recorded for species whose differences could be determined visually.

2.6 Processing of geospatial data

After video review, GPS coordinates from transects were converted from degrees/minutes/decimal minutes to degrees/decimal degrees and plotted in ESRI ArcMap™ to give a geographical representation of the vessel track during the course of transects (Figures 7-17). These tracks were colour-coded by bottom type and symbols representing observed fish species were plotted along the length of transects to allow visualization of habitat specificity by species. Sections of differing substrate types along transects were traced in ArcMap to measure distance. These segments were then summed by substrate type and overall to yield total transect length.

2.7 Calibration to estimate area swept by the camera

Calibrations to allow quantitative estimates of area swept by the cameras were conducted in a large seawater tank. Calibrations were made using a flat-bottomed tank and a constant camera altitude from the bottom of the tank. A large rigid plastic board with an area of 5.95 m^2 was overlaid with black electrical tape in a 20 cm grid on the bottom of the tank. Both camera platforms were suspended 50 cm off the bottom and with lasers on, slowly tilted up and down so that the beams were clearly visible.

The video was then reviewed and a calibration curve was constructed. As the camera was tilted up and down, the distance between the lasers was measured on the video screen, and at each measurement, a known distance on the calibration grid at the top of the field of view was also measured on the video screen. This enabled the maximum field of view of the camera to be expressed as a function of the distance between the laser dots. This function was quadratic due to the curvature of the camera lens (Donna M. Kocak, pers. comm.) and since the lasers were mounted at different distances apart for each of the towed bodies, two different equations are used. For the "Delta", the equation used was:

$$F_v = 0.0365 (D_l^2)$$

While for the 'Toad", the equation used was:

$$F_v = 0.0350 (D_l^2)$$

Where F_v = distance measured on screen for 100 cm of the calibration grid, and D_l = measured distance on screen between the laser dots.

Measurements of distance between lasers on the recorded survey videos were performed at intervals of 30 seconds over the survey videos and average fields of view were calculated for each transect. The area by substrate type was calculated by the following equation:

$$A_x = \left(L_x \overline{F}\right)$$

Where A_x = area swept by substrate type x, L_x = total length of substrate type x (m) and $\overline{F}$ = mean field of view (m) for the transect.

Comparisons of the mean field of view were also made between the 'Toad' and 'Delta' camera sleds, and this revealed that the 'Toad' provided a much larger mean field of view. The mean width of the field of view for 'Delta' was approximately 76 cm, while that of the 'Toad' was 1125 cm.

2.8 Density estimates

Using the area swept derived above, fish density estimates were calculated. Mean density estimates were calculated for each species by substrate type and reported as number of fish km^{-2} using the formula:

$$D_{sx} = \frac{n_s}{A_x}$$

Where D_{sx} = Density per substrate type x for a given species s (fish m^{-2}), n = number of fish observed of a given species s and A_x = Area swept as calculated above by substrate x.

3.0 RESULTS

3.1 Fish counts

A total of 745 individual fish were recorded along the 42 transects of the survey (Table 3) of which 439 were rockfish of five species. Puget Sound rockfish were the most numerous with 285 individuals recorded; inshore species (quillback, copper, tiger and yelloweye) made up the remaining 154 observed rockfish.

Kelp Greenlings (*Hexagrammos decagrammus*) were the most ubiquitous fish (Table 3), recorded along 26 of the total transects, followed by quillback rockfish (16 transects) and Lingcod (*Ophiodon elongatus,*14 Transects). Overall, 204 of the total 744 individual fish were species of commercial value. These included quillback, copper, tiger and yelloweye rockfish, lingcod, spiny dogfish (*Squalus acanthias*) and rock sole (*Lepidopsetta bilineata*), English sole (*Parophrys vetulus*) and Dover sole (*Microstomus pacificus*).

Mean depths at which species were observed ranged from 23 m for kelp greenlings to 41 m for Puget sound rockfish and while there was less variability in mean temperatures, the parameter ranged from 9.6 ºC for Puget Sound rockfish to 10.9 ºC for copper rockfish. Means of depth and temperature for all species are provided in Table 3.

3.2 Physical and biological descriptions of transects

Forty-two transects were conducted over 5 days (Table 4). The first two transects (denoted Test00 and Test00b) were part of pre-survey testing to ensure all equipment was functioning properly and to refine sampling procedures. These two transects were included in the analyses. Over the course of the survey, the camera was towed over a total linear distance of 15.9 km and total measured transect lengths ranged from approximately 21 m (Transect Greig 12) to 1138 m (Transect Danger 35) with a mean length of approximately 381 m. Transect depths ranged from a minimum of approximately 10 m to a maximum of 65.2 m, with an average depth of 27.9 m. Water temperatures ranged from a minimum of approximately 8.0 ºC to 15.2 ºC, with a mean value of 10.4 ºC.

Figures 8-17 show the GPS track of the camera transects with primary substrate colour-coded to enable visualization of its change along the course of the transect. We also plot location of fish observations along transects using symbols to represent species. Transects Zero Rock 09 and Danger 34 were the only transects not represented in this fashion due to GPS and video recording problems.

3.3 Primary substrate proportion

The percent makeup of the primary substrates varied greatly between transects conducted over the course of the survey (Table 5). ‘Mixed coarse’ was the most common substrate encountered along the transects (40.9% of the total), followed by ‘boulder’ (21.9%) and ‘bedrock’ (8.9%). ‘Hardpan’ made up 7.5% of the total, ‘mud’ made up (7.4%), ‘cobble’ made up 6.3%, ‘sand’ made up 5.9%, and ‘gravel’ made up only 1.1% of the total. Some transects showed only a single substrate type (i.e. Darcy 07, Zero

Rock 09, Greig 12, Ragged 30 ('Mixed coarse'); Trincomali 27 ('Sand') and Peille 24 ('Mud')) while the maximum different types of substrate in a single transect was 6 (Darcy 2, Deer Point 29 and Danger 35). Figure 19 shows the total area of each substrate type over the survey. A summary of the primary substrate and biocover for each transect can be found in Appendix A.

3.4 Spatial distribution of species densities

Estimates of density by transect for species encountered over the course of the survey were plotted geographically. Of the rockfishes, Puget Sund, quillback, copper and tiger were plotted in Figure 20 and of the groundfish, eelpout, kelp greenling, lingcod and rock sole were plotted in Figure 21.

Puget Sound rockfish were encountered in the lower portion of the study area (Figure 20), to the southeast of Saltspring Island, towards U.S. waters. Quillback rockfish were encountered uniformly throughout the study area (Figure 20), with the highest concentrations being found off Newcastle Island in the north. Copper rockfish were distributed uniformly thoughout the northern portion of the study area, but were absent in the southeast portion of the region (Figure 20). Tiger rockfish were only present in small numbers and no geographic trends were evident (Figure 20).

Eelpout were encountered in the central portion of the study area, with the highest concentrations being found off Thetis and Saltspring Islands (Figure 21). Kelp greenling were ubiquitous over the course of the study (Figure 21). Lingcod and rock sole were also uniformly distributed, and were found throughout the study area (Figure 21).

3.5 Habitat associations and substrate-dependant estimates of density

3.5.1 Transect Plots

Transect plots (Figures 8-17) show qualitatively that fish exhibit an affinity for specific habitat types. Transect Test 00 (Figure 8) exhibited two areas of high numbers of both quillback rockfish and lingcod, with boulder as the predominant substrate. Transect Darcy 05 (Figure 9) had one area with high numbers of Puget Sound rockfish, in a localized area with boulder as primary substrate. Transect Greig 11 (Figure 10) contained an area with a elevated number of rockfish (Puget Sound rockfish, quillback rockfish, tiger rockfish and lingcod) associated with boulder bounded by areas of bedrock and mixed coarse substrates. Transect Beaver 20 (Figure 13) had elevated numbers of Puget Sound rockfish in a very small area of boulders surrounded by areas of mud. This same degree of correlation with habitat primary substrate types is shown by non-rockfish taxa. Eelpouts (family Zoarcidae) are markedly correlated with mud substrates, as illustrated by the plots for transects Annette 22 and Annette 23 (Figure 13). These transects show high numbers of eelpout throughout areas of mud bottom, with the taxon absent from areas of 'mixed coarse' and 'boulder' substrates.

3.5.2 Numbers per substrate type

Examination of numbers of rockfish per type of primary substrate type show that rockfish exhibit an affinity for 'boulder' habitats. High numbers of rockfish were also found associated with 'mixed coarse' and 'bedrock' habitats (Table 6, Figure 22).

3.5.3 Number of fish per linear meter

These counts of rockfish were standardized for linear distance of transect by substrate, expressed as fish per metre of transect. As with the counts, both individual species and rockfish as a whole (Table 7; Figure 23) were associated with boulder and bedrock substrates. Approximately twice as many copper rockfish per meter of transect are correlated with bedrock-dominated substrates than for boulder or sand (Figure 24). Approximately the same number of quillback rockfish per linear meter were found associated with boulder-dominated substrate as with bedrock-dominated substrate and these substrates had dramatically greater numbers per linear meter than other substrates (Figure 23).

In areas of boulder-dominated substrate, Puget Sound rockfish displayed almost three times the number per linear meter as over cobble, the next-most common substrate (Figure 23). Only four tiger rockfish were observed during the survey and these were associated with areas of bedrock- and boulder-dominated substrate.

The four most numerous taxa of groundfish were eelpout, kelp greenling, lingcod and flatfish (family pleuronectidae) (Figure 24). The highest numbers of eelpout per linear meter were correlated with muddy substrates. Kelp greenling showed similar correlation with bedrock-, boulder- and sand-dominated substrates, all three of which had higher numbers per linear meter than 'mixed coarse', the next-most common substrate. Numbers of lingcod per linear meter were highest for bedrock- and boulder-dominated substrates, but they were observed at low densities over all habitats except gravel. Higher numbers of flatfish per linear meter were correlated with gravel-dominated substrate than with other types of bottom.

3.5.4 Fish density (fish m^{-2})

In addition to calculating number of fish per linear meter of transect, estimates of density (fish km^{-2}) were calculated for each substrate type. Mean rockfish densities are presented in Figure 25, and mean groundfish densities in Figure 26. Estimates of overall rockfish densities (Figure 25) indicated the highest densities were found in areas of bedrock and boulder-dominated substrates. Groundfish densities (Figure 26) varied between species but sand, bedrock and boulder had higher densities than other substrates for all species except eelpout, which were correlated with mud substrate.

Densities of Puget Sound rockfish were highest in areas of boulder-dominated substrate (approximately 39,214 km^{-2}), followed by mud- (approximately 10,371 km^{-2}) and bedrock-dominated substrate (approximately 9,676 km^{-2}). Densities of quillback rockfish were highest in areas of bedrock-dominated substrate (approximately 12,283 km^{-2}), followed by boulder-dominated (approximately 7,632 km^{-2}) and sand-dominated substrates (approximately 5,507 km^{-2}). Densities of copper rockfish were highest in areas of boulder-dominated substrate (approximately 7,334 km^{-2}), followed by bedrock- (approximately 6,186 km^{-2}) (Table 8) and sand-dominated substrates (approximately 4,951 km^{-2}). Densities of tiger rockfish were highest in areas of bedrock-dominated substrates (approximately 424 km^{-2}), though this estimate was only based on 2 individuals.

Estimates of mean densities for common groundfish species (other than rockfish) were also calculated (Table 7; Figure 26). Densities of eelpout were much higher in areas of mud-dominated substrate (approximately 35,585 km^{-2}) than sand (approximately 1,515 km^{-2}) or hardpan-dominated substrates (approximately 469 km^{-2}). Densities of kelp greenling were highest in areas of boulder-dominated substrate (approximately 27,390 km^{-2}), followed by hardpan (approximately 14,034 km^{-2}) and bedrock-dominated substrates (approximately 3,636 km^{-2}). Densities of lingcod were highest in areas of bedrock-dominated substrate (approximately 5,123 km^{-2}), followed by sand (approximately 3,176 km^{-2}) and mud-dominated substrates (approximately 2,450 km^{-2}). Densities of rock sole were highest in areas of hardpan-dominated substrate, though this is likely the result of the small total area of hardpan-dominated substrate. This anomaly aside, densities are highest over sand (approximately 1,863 km^{-2}) and mud-dominated substrates (approximately 1,772 km^{-2}).

In addition to mean density values for species over the range of habitat types, coefficients of variation (CV) were calculated (Table 9). The calculated CVs were variable over combinations of species and habitat type; values ranged from 1.08 for eelpout over mud-dominated habitat to 4.89 for copper rockfish over habitats dominated by mixed coarse substrates (Table 9).

3.6 Comparison of the two camera systems

The two camera platforms used in the survey incorporate the same components but performed differently due to their unique weight, shape and lighting configurations.

The ‘Delta’ towed body is much lighter than the ‘Toad’ and tended to point directly down at the substrate, resulting in a much smaller effective field of view (Figure 18). In addition to the restricted field of view the angle of the view (perpendicular to the substrate) made it difficult to avoid oncoming obstacles. The ‘Delta’ also had a shallower maximum effective depth with a fixed length of umbilical.

The lighting of the ‘Toad’ proved to be more useful in conditions of higher turbidity, as the increased angle between camera and lights resulted in less backscatter than the camera and light mounted parallel on the ‘Delta’.

As a measure of the sampling efficiency of the ‘Toad’ and ‘Delta’ camera systems, we calculated coefficients of variation for both camera sleds, for quillback rockfish over all survey sites in the study. Quillback were chosen for the comparison because they were one of the most common species of rockfish, and were distributed throughout the range of the survey and as such were present on transects which were conducted using both camera platforms. For quillback rockfish, the ‘Toad’ exhibited an overall CV of 1.502, while the ‘Delta’ exhibited a comparable CV of 1.856. It is difficult to compare the CVs from these two vehicles directly, as there were many more transects conducted with the ‘Toad’ (n = 33) than with the ‘Delta’ (n = 9).

Overall, we found the 'Toad' system to be preferable for our purposes because of its larger field of view and deeper effective depth with a fixed length of cable. We feel that the CVs of both systems are close enough that the data can be used together in this study.

3.7 Discussion and Conclusions

Our towed video camera approach is comparatively inexpensive at under $30,000 (2003 CDN Dollars) for purchase (Price includes both towed bodies with cameras, lasers and lights, HPD, umbilicus, winch and V.O.L.T. overlay titler) when compared to submersibles and ROVs. It is readily available for use, easy to deploy from a small vessel, and provides valuable information on rockfish habitat, relative abundance and numerical density. It can be used to survey depths exceeding scuba surveys without the constraints on bottom time and available divers.

Over the course of the study, a number of fish species were enumerated, of which copper and quillback rockfish were the most abundant inshore rockfish species. These species, and inshore rockfish in general, were found in highest densities in bedrock and boulder habitats, with estimated densities of 12,283 quillback and 6,186 copper km^{-2} associated with bedrock, and 7,632 quillback km^{-2} and 7,333 copper km^{-2} associated with boulders. It should be pointed out however that these densities are per specific habitat types, and not for area of seafloor; 1 km^2 of seafloor would likely have only a fraction of its area occupied by rockfish-favourable boulder and bedrock habitat.

A large number of Puget Sound rockfish were encountered in the southern portion of the survey, resulting in very high densities. We feel that density estimates of these fish are likely larger than in reality. Large schools of Puget Sound rockfish were often observed during times when the camera crested a boulder or rise, and the field of view was difficult to estimate. These factors suggest to us that the camera is likely not ideally suited to the enumeration of schooling fish which hover over the top of rock outcroppings.

The towed camera survey provided important data on fish and their habitat and is a useful tool for providing an estimate of relative fish density in the areas surveyed.

The estimation of area swept provided by our calibrations is difficult in areas of high relief and over complex substrate, and these are the areas where rockfish are most likely to be found. However, relative visual indices are a useful non-intrusive population monitoring tool. Conducted in the same manner over time, they will provide a useful relative index in areas where fishing surveys are prohibited, such as Rockfish Conservation Areas (RCAs).

There are increasing numbers of studies which utilize visual methodologies to assess population, habitats and densities of reef fish and yet it remains acutely difficult to provide a quantitative assessment. For example, an ROV survey of nearshore rocky reef habitats conducted by Fox et al (2000) used a more complex method to estimate density. The ROV used was equipped with two pairs of lasers, which permitted area of the field of view to be estimated using a Canadian (perspective) grid methodology (Wakefield and Genin 1987). Despite the higher degree of sophistication of the laser mensuration system, Fox et al (2000) were forced to make assumptions similar to those of our study. Both assumed a flat, simple seafloor but the more stable platform provided by the ROV allowed the assumption of no pitch and roll from the ROV, and the height off the bottom to be calculated. As pitching of the towed camera was common, we assumed a fixed distance from the bottom and measured field of view as a function of pitch of the platform. Fox et al (2000) also made no consideration for the distortion created by the camera lens, a factor for which our calibration corrects. One of the more comprehensive and complex systems for the visual assessment of groundfish is being used by Kocak et al (2004). Their system uses a submersible-mounted system integrating a roll/pitch motion reference sensor, three lasers, Doppler velocity logger, ring laser gyro, ultra-short-baseline sonar tracking system, and integrated positioning system software with a video camera and software to calculate area swept by analysis of the lasers on the recorded video. Though comprehensive, this methodology still makes an assumption of flat relief for its algorithms, and thus has greater error in areas of increased relief and complexity (Donna Kocak, pers. comm.).

Visual surveys, regardless of cost or technological sophistication, seem to be affected by many of the same limitations or assumptions. Through our work, we now have preliminary habitat-dependant estimates of density for Puget Sound, quillback, copper and tiger rockfish in the Strait of Georgia. These estimates may be combined with acoustic habitat mapping data to provide regional population estimates.

It is increasingly important that rockfish surveys, while producing useful information on stocks, also do not contribute to the overall mortality of the populations. While visual surveys cannot replace those built upon fishing methodologies for the collection of demographic data such as sex and age structure, they can greatly add to the data produced by experimental fishing surveys (e.g. Lochead and Yamanaka, 2004).

Visual methodologies clearly have an important role to play in the assessment of inshore rockfish stocks in B.C. waters as a non-lethal, fisheries-independent quantitative survey tool.

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Table 1. Synopsis of video stations sampled during survey of June 4-8th, 2003.

Date	Cast Number	Station Name	Vehicle	Start Time	End Time	Total time	Latitude	Longitiude	Direction
June 4/2003	0	Test	Toad	14:55:17	3:23:37 PM	00:28:20	49.1975	-123.9137	NW/SE
June 4/2003	0b	Test	Delta	3:52:04 PM	4:02:14 PM	00:10:10	49.19825	-123.9142833	W
June 5/2003	1	Darcy	Toad	12:36:57 PM	12:49:50 PM	00:12:53	48.58045	-123.27435	NE
June 5/2003	2	Darcy	Toad	1:04:50 PM	1:19:15 PM	00:14:25	48.5796	-123.2815833	NE
June 5/2003	3	Darcy	Toad	1:49:24 PM	2:07:45 PM	00:18:21	48.57396667	-123.2574333	NW
June 5/2003	4	Darcy	Toad	2:28:02 PM	2:53:15 PM	00:25:13	48.55821667	-123.2490667	N
June 5/2003	5	Darcy	Toad	3:05:44 PM	3:31:09 PM	00:25:25	48.55943333	-123.2412167	W
June 5/2003	6	Darcy	Toad	3:48:52 PM	4:05:58 PM	00:17:06	48.56601667	-123.2456833	SE/NW
June 5/2003	7	Darcy	Toad	4:28:31 PM	4:47:15 PM	00:18:44	48.57326667	-123.2969333	SW
June 5/2003	8	Darcy	Toad	4:59:11 PM	5:16:36 PM	00:17:25	48.55591667	-123.2955833	SE
June 5/2003	9	Zero Rock	Toad	6:22:04 PM	6:25:15 PM	00:03:11	48.5297	-123.2970167	
June 6/2003	10	Greig	Toad	7:46:01 AM	8:12:49 AM	00:26:48	48.67926667	-123.3436333	NW
June 6/2003	11	Greig	Delta	9:00:07 AM	9:33:46 AM	00:33:39	48.67963333	-123.3437833	N
June 6/2003	12	Greig	Delta	9:53:01 AM	9:54:19 AM	00:01:18	48.67931667	-123.3436333	NW
June 6/2003	13	Greig	Delta	10:15:44 AM	10:30:00 AM	00:14:16	48.6789	-123.3434833	N
June 6/2003	14	Portland	Delta	11:29:49 AM	11:42:33 AM	00:12:44	48.72451667	-123.3462833	N/SW
June 6/2003	15	Portland	Delta	12:12:23 PM	12:20:51 PM	00:08:28	48.72458333	-123.3487167	S
June 6/2003	16	Bedwell	Delta	1:06:46 PM	1:17:49 PM	00:11:03	48.73746667	-123.21585	N
June 6/2003	17	Tilly	Delta	1:35:03 PM	1:47:27 PM	00:12:24	48.73093333	-123.20035	W
June 6/2003	18	Wallace	Delta	2:08:01 PM	2:25:33 PM	00:17:32	48.73448333	-123.2470833	SE
June 7/2003	19	Beaver	Toad	7:56:16 AM	8:13:57 AM	00:17:41	48.78938333	-123.3729833	NW/SE
June 7/2003	20	Beaver	Toad	8:25:57 AM	8:44:30 AM	00:18:33	48.78855	-123.37245	NW/SE

Table 1 (Continued)

Date	Cast Number	Station Name	Vehicle	Start Time	End Time	Total time	Latitude	Longitiude	Direction
June 7/2003	21	Ganges	Toad	9:15:11 AM	9:21:28 AM	00:06:17	48.8169	-123.4220667	E
June 7/2003	22	Annette	Toad	9:42:08 AM	9:54:00 AM	00:11:52	48.83186667	-123.40445	NE/SW
June 7/2003	23	Annette	Toad	10:06:53 AM	10:25:59 AM	00:19:06	48.8301	-123.4033167	NW
June 7/2003	24	Peile	Toad	10:42:23 AM	10:49:21 AM	00:06:58	48.84925	-123.39995	SE
June 7/2003	25	Wallace Island	Toad	12:01:01 PM	12:22:35 PM	00:21:34	48.93623333	-123.5523	SE
June 7/2003	26	Trincomali	Toad	12:42:47 PM	12:55:25 PM	00:12:38	48.93776667	-123.5373833	SE
June 7/2003	27	Trincomali	Toad	1:13:45 PM	1:21:45 PM	00:08:00	48.94873333	-123.5577167	SE
June 7/2003	28	Kuper	Toad	1:53:58 PM	2:22:30 PM	00:28:32	48.97108333	-123.6181	NW
June 8/2003	29	Deer Point.	Toad	8:12:31 AM	8:33:21 AM	00:20:50	49.02591667	-123.7585167	W
June 8/2003	30	Ragged	Toad	8:57:57 AM	9:07:41 AM	00:09:44	49.03226667	-123.7028	SE
June 8/2003	31	Ragged	Toad	9:18:42 AM	9:42:22 AM	00:23:40	49.03661667	-123.7040333	SE
June 8/2003	32	Unknown Reef	Toad	9:57:12 AM	10:14:04 AM	00:16:52	49.03831667	-123.6736167	SE
June 8/2003	33	Unknown Reef	Toad	10:36:58 AM	10:54:11 AM	00:17:13	49.04003333	-123.6738833	NW
June 8/2003	35	Danger	Toad	12:22:03 PM	12:49:30 PM	00:27:27	49.05756667	-123.71575	SE
June 8/2003	36	Ruxton	Toad	1:12:21 PM	1:24:38 PM	00:12:17	49.08495	-123.71925	NW
June 8/2003	37	Ruxton	Toad	1:35:27 PM	1:56:55 PM	00:21:28	49.08725	-123.7150333	NW
June 8/2003	38	Round	Toad	2:28:50 PM	2:50:51 PM	00:22:01	49.11565	-123.7868667	NW
June 8/2003	39	Dodds	Toad	3:10:03 PM	3:22:56 PM	00:12:53	49.14036667	-123.8120167	NW
June 8/2003	40	Protection	Toad	4:01:40 PM	4:12:41 PM	00:11:01	49.18651667	-123.9141	SE

Table 2. Codes and descriptions for habitat classifications.

Codes and descriptions for habitat substrate classifications	
1	Artificial (pilings, tires, ships, etc)
2	Hardpan (e.g. sandstone)
3	Bedrock
4	Boulder (rocks > 25cm)
5	Cobble (6 - 25cm)
6	Mixed Coarse (cobble/gravel/shell)
7	Gravel (small rocks and pebbles 1 - 6cm)
8	Sand (or sand/shell)
9	Mud (or mud/shell)
Codes and descriptions for habitat relief	
1	None (flat or rolling)
2	Low (vertical relief 0.5 - 2m)
3	High (vertical relief > 2m)
4	Steep slope or wall
Codes and descriptions for habitat complexity classifications	
1	Simple (flat/rolling with no crevices)
2	Low (very few crevices)
3	Medium (more than a few but not lots of crevices)
4	High (lots of crevices)
Codes and descriptions for habitat biocover classifications	
1	Bare (<10% cover)
2	Kelp
3	*Ulva spp.*
4	Other algae
5	Algal mat
6	Scallops
7	Barnacles
8	Anemones (mainly *Metridium spp.)*
9	Encrusting organism complex (Psolus spp., barnacles, hydroids, bryozoans, anemones)
10	Eelgrass
11	Opiuroids
12	Tube worms/empty tubes
13	Debris/detritus
14	Sea pens/whips
15	Sponges
99	Unidentified
Codes and descriptions for habitat biocover thickness classifications	
1	0-25% cover
2	26-50% cover
3	51-75% cover
4	76-100% cover

Table 3. Summary of all fish species enumerated along transects, including number observed, frequency of observation and mean depth (m) and temperature (°C).

Species	Total Number Observed	# transects	Mean Depth(m)	Mean Temperature(°C)
Puget Sound Rockfish	285	10	40.6	9.6
Eelpouts	88	14	30.2	10.0
Quillback Rockfish	85	16	24.2	10.9
Unidentified Fish	59	25	28.2	10.4
Kelp Greenling	52	26	23.0	10.5
Lingcod	38	15	23.2	10.4
Copper Rockfish	35	13	20.2	11.0
Unidentified Rockfish	29	14	29.3	10.3
Unidentified Flatfish	26	10	26.6	10.2
Rock Sole	13	9	24.6	10.7
Unidentified Greenlings	9	7	24.8	10.6
Poachers	6	4	32.2	10.3
Gunnels	5	2	34.3	10
Tiger Rockfish	4	3	-	-
Sculpins	4	4	-	-
Wolf Eel	2	2	-	-
Red Irish Lord	1	1	-	-
English Sole	1	1	-	-
Dover Sole	1	1	-	-
Yelloweye Rockfish	1	1	-	-
Dogfish	1	1	-	-
Total	745			

Table 4. Total measured lengths by transect conducted over the 2003 towed camera survey and total and average length for all transects combined.

Station	Length (m)
Test00	663
Test00B	193
Darcy01	552
Darcy02	378
Darcy03	553
Darcy04	625
Darcy05	571
Darcy06	467
Darcy07	421
Darcy08	251
Greig10	526
Greig11	493
Greig12	21
Greig13	188
Portland14	247
Portland15	562
Bedwell16	179
Tilly17	641
Wallace18	242
Beaver19	305
Beaver20	359
Ganges21	68
Annette 22	189
Annette 23	244
Peile24	222
Wallace25	456
Trincomali26	342
Trincomali27	360
Kuper28	459
DeerPt29	453
Ragged30	231
Ragged31	460
UnknownReef32	640
UnknownReef33	481
Danger35	1138
Ruxton36	355
Ruxton37	366
Round38	419
Dodds39	273
Protection40	319
Total for all transects	**15910**
average transect length	**398**

Table 5. Total number of rockfish by species per primary substrate type over all transects.

	Hardpan	Bedrock	Boulder	Cobble	Mixed Coarse	Gravel	Sand	Mud
Unidentified Rockfish	1	16	15	0	3	0	2	0
Copper Rockfish	1	13	14	0	8	0	6	2
Quillback Rockfish	0	30	72	1	25	0	4	0
Puget Sound Rockfish	0	9	201	12	53	0	1	9
Tiger Rockfish	0	2	3	0	0	0	0	0
Yelloweye Rockfish	2	0	0	0	0	0	0	0
Total for All Species	**4**	**70**	**305**	**13**	**89**	**0**	**13**	**11**

Table 6. Number of Rockfish by species per linear meter of transect for all primary substrate classifications

	Hardpan	Bedrock	Boulder	Cobble	Mixed Coarse	Gravel	Sand	Mud
Unidentified Rockfish	0.0010184	0.01020363	0.004192	0	0.0005986	0	0.0013267	0
Copper Rockfish	0.0010184	0.00829045	0.003913	0	0.0015964	0	0.0039802	0.000813
Quillback Rockfish	0	0.0191318	0.020123	0.00151	0.0049887	0	0.0026535	0
Puget Sound Rockfish	0	0.00573954	0.056178	0.018126	0.010576	0	0.0006634	0.003658
Tiger Rockfish	0	0.00127545	0.000838	0	0	0	0	0
Yelloweye Rockfish	0.0020368	0	0	0	0	0	0	0

Table 7. Percentage of total area surveyed (number observed km^{-2}) for each transect by primary substrate type.

Transect	% Hardpan	% Bedrock	% Boulder	% Cobble	% Mixed Coarse	% Gravel	% Sand	% Mud
Test 00	11.63	20.35	21.01	—	45.67	—	1.34	—
Test 00b	13.06	65.59	—	—	21.35	—	—	—
Darcy 01	—	—	—	—	96.97	3.03	—	—
Darcy 02	4.87	—	6.76	9.35	48.47	6.60	23.95	—
Darcy 03	—	—	30.67	28.01	22.15	15.81	3.35	—
Darcy 04	33.21	—	0.00	4.72	62.08	—	—	—
Darcy 05	—	27.41	17.88	—	54.71	—	—	—
Darcy 06	—	—	6.49	—	93.51	—	—	—
Darcy 07	—	—	—	—	100.00	—	—	—
Darcy 08	18.45	—	37.77	—	43.78	—	—	—
Zero Rock 09								
Greig 10	—	0.30	35.70	54.65	9.36	—	—	—
Greig 11	—	12.50	37.53	0.56	49.41	—	—	—
Greig 12	—	—	—	—	100.00	—	—	—
Greig 13	—	—	24.81	—	75.19	—	—	—
Portland 14	—	—	59.01	4.47	36.52	—	—	—
Portland 15	—	16.91	11.96	18.04	50.98	2.11	—	—
Bedwell 16	—	50.21	—	—	49.79	—	—	—
Tilly 17	—	—	98.20	—	1.80	—	—	—
Wallace 18	—	—	18.03	—	81.97	—	—	—
Beaver 19	—	—	36.41	—	39.15	—	—	24.43
Beaver 20	—	—	22.62	—	53.33	—	—	24.05
Ganges 21	—	—	32.60	—	—	—	—	67.40
Annette 22	—	—	8.93	—	5.40	—	—	85.67
Annette 23	—	—	23.33	—	—	—	—	76.67
Peile 24	—	—	—	—	—	—	—	100.00
Wallace 25	—	—	14.47	—	—	—	68.97	16.56
Trincomali 26	—	—	26.81	—	—	—	73.19	—
Trincomali 27	—	—	—	—	—	—	100.00	—
Kuper 28	3.24	24.35	—	—	—	—	0.58	71.83
Deer Point 29	25.69	29.67	10.05	—	5.63	—	27.08	1.88
Ragged 30								
Ragged 31	23.81	—	44.47	—	—	—	—	31.72
Unknown Reef 32	50.32	—	14.70	1.99	1.18	—	—	31.80
Unknown Reef 33	—	7.45	3.26	—	21.49	—	—	67.80
Danger 35	—	11.03	56.21	2.34	10.55	—	6.87	12.99
Ruxton 36	—	59.67	6.42	—	—	—	18.44	15.46
Ruxton 37	—	55.16	14.93	—	2.53	—	—	27.38
Round 38	—	3.96	44.13	—	2.12	—	46.81	2.97
Dodds 39	16.35	—	—	—	73.59	—	—	10.05
Protection 40	—	20.08	1.09	—	—	—	—	78.83

Table 8. Mean densities (Number km^{-2}) of most numerous species of Rockfish and Groundfish observed over the course of the survey, by primary substrate type. No fish were observed over gravel substrates, therefore it is not included in the results. Descriptive statistics for each substrate type are provided.

Hardpan	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	312.42	0.00	0.00	156.21	0.00	468.62	14033.68	1624.34	13494.77
Standard Error	312.42	0.00	0.00	156.21	0.00	468.62	13445.56	1624.34	13494.77
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	987.94	0.00	0.00	493.97	0.00	1481.92	42518.60	5136.60	42674.21
Sample Variance	976034.15	0.00	0.00	244008.54	0.00	2196076.84	1807831311.08	26384649.59	1821088034.17
Range	3124.15	0.00	0.00	1562.08	0.00	4686.23	134947.69	16243.35	134947.69
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	3124.15	0.00	0.00	1562.08	0.00	4686.23	134947.69	16243.35	134947.69
Confidence Level (95%)	706.73	0.00	0.00	353.37	0.00	1060.10	30416.00	3674.50	1060.10

Bedrock	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	33701.82	9676.31	12283.06	6186.16	424.17	0.00	3636.21	5123.13	0.00
Standard Error	14298.07	8731.15	6239.08	2831.80	424.17	0.00	1891.52	2871.57	0.00
Median	4666.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	55376.20	33815.61	24163.85	10967.51	1642.82	0.00	7325.82	11121.56	0.00
Sample Variance	3066523692.52	1143495278.62	583891867.39	120286307.10	2698859.06	0.00	53667595.05	123689029.37	0.00
Range	152702.79	131552.51	69988.78	33513.53	6362.62	0.00	21863.09	33513.53	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	152702.79	131552.51	69988.78	33513.53	6362.62	0.00	21863.09	33513.53	0.00
Confidence Level (95%)	30666.35	18726.48	13381.51	6073.61	909.76	0.00	4056.91	6158.92	0.00

Table 8 (Continued).

Boulder	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	64599.29	39214.45	7632.21	7333.57	365.60	0.00	27389.67	1374.91	0.00
Standard Error	18242.44	14914.98	2610.81	5657.70	254.49	0.00	21267.68	589.93	0.00
Median	7927.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	98238.53	80319.62	14059.65	30467.64	1370.46	0.00	114529.97	3176.86	0.00
Sample Variance	9650808950.66	6451241630.85	197673847.06	928276951.13	1878153.76	0.00	13117114848.92	10092435.34	0.00
Range	389384.37	304735.59	50789.27	163187.71	5660.27	0.00	619903.38	13559.24	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	389384.37	304735.59	50789.27	163187.71	5660.27	0.00	619903.38	13559.24	0.00
Confidence Level (95%)	37367.98	30551.98	5348.01	11589.28	521.29	0.00	43564.92	1208.41	0.00

Cobble	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	3286.27	3033.48	252.79	0.00	0.00	0.00	0.00	252.79	0.00
Standard Error	3286.27	3033.48	252.79	0.00	0.00	0.00	0.00	252.79	0.00
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	9858.82	9100.45	758.37	0.00	0.00	0.00	0.00	758.37	0.00
Sample Variance	97196390.63	82818226.34	575126.57	0.00	0.00	0.00	0.00	575126.57	0.00
Range	29576.47	27301.36	2275.11	0.00	0.00	0.00	0.00	2275.11	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	29576.47	27301.36	2275.11	0.00	0.00	0.00	0.00	2275.11	0.00
Confidence Level (95%)	7578.17	6995.23	582.94	0.00	0.00	0.00	0.00	582.94	0.00

Table 8 (Continued).

Mixed Coarse	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	12415.47	5630.47	405.05	984.80	0.00	131.61	2340.36	397.04	260.89
Standard Error	8673.36	3461.59	110.46	894.09	0.00	91.60	958.59	250.84	173.67
Median	0.00	0.00	146.03	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	46707.49	18641.24	594.82	4814.84	0.00	493.26	5162.17	1350.80	935.26
Sample Variance	2181589537.31	347495787.21	353815.11	23182638.83	0.00	243309.23	26648025.39	1824660.21	874705.55
Range	245918.64	77658.52	2370.73	25886.17	0.00	2034.55	21114.40	6847.72	4640.30
Minimum	0.00	0.00	3.16	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	245918.64	77658.52	2373.89	25886.17	0.00	2034.55	21114.40	6847.72	4640.30
Confidence Level (95%)	17766.60	7090.76	226.26	1831.47	0.00	187.63	1963.59	513.82	187.63

Sand	All Rockfish	Puget Sound Rockfish	Quillback Rockfish	Copper Rockfish	Tiger Rockfish	Eelpout	Kelp Greenling	Lingcod	Rock Sole
Mean	13357.39	0.00	5506.94	4951.28	0.00	1515.41	2916.80	3177.00	1862.69
Standard Error	10855.19	0.00	5506.94	3355.93	0.00	1183.87	1811.15	2743.67	1296.86
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	36002.59	0.00	18264.45	10067.78	0.00	3926.45	6006.92	9099.73	4301.20
Sample Variance	1296186760.46	0.00	333590243.53	101360095.20	0.00	15417027.15	36083075.88	82805110.95	18500314.22
Range	121152.68	0.00	60576.34	30288.17	0.00	12834.47	18635.12	30288.17	12819.42
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	121152.68	0.00	60576.34	30288.17	0.00	12834.47	18635.12	30288.17	12819.42
Confidence Level (95%)	24186.88	0.00	12270.23	7738.78	0.00	2637.83	4035.50	6113.28	2637.83

Table 8 (Continued).

Mud	**All Rockfish**	**Puget Sound Rockfish**	**Quillback Rockfish**	**Copper Rockfish**	**Tiger Rockfish**	**Eelpout**	**Kelp Greenling**	**Lingcod**	**Rock Sole**
Mean	11314.38	10371.51	0.00	942.87	0.00	35584.62	1162.26	2450.49	1772.26
Standard Error	10336.16	10371.51	0.00	646.85	0.00	9079.04	872.01	1417.62	943.43
Median	0.00	0.00	0.00	0.00	0.00	25805.05	0.00	0.00	0.00
Standard Deviation	43852.60	44002.58	0.00	2744.34	0.00	38519.12	3699.62	6014.46	4002.63
Sample Variance	1923050390.17	1936227486.33	0.00	7531412.95	0.00	1483722964.38	13687196.05	36173779.74	16021070.34
Range	186687.16	186687.16	0.00	8576.92	0.00	103568.61	14828.41	20743.02	14828.41
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	186687.16	186687.16	0.00	8576.92	0.00	103568.61	14828.41	20743.02	14828.41
Confidence Level (95%)	21807.41	21882.00	0.00	1364.73	0.00	19155.14	1839.78	2990.93	19155.14

Table 9. Summary of mean densities and coefficients of variability over primary substrate types for the most common species of rockfish and Groundfish

	Hardpan		Bedrock		Boulder		Cobble		Mixed Coarse		Sand		Mud	
	Mean (km^{-2})	**CV**	**Mean (km^{-2})**	**CV**	**Mean (km^{-2})**	**CV**	**Mean (km^{-2})**	**CV**	**Mean (km^{-2})**	**CV**	**Mean (km^{-2})**	**CV**	**Mean (km^{-2})**	**CV**
Puget Sound Rockfish	—	—	9676.31	3.49	39214.45	2.05	3033.48	3.00	5630.467	3.31	—	—	10371.51	4.24
Quillback Rockfish	—	—	12283.06	1.97	7632.21	1.84	252.79	3.00	405.05	1.47	5506.94	3.32	—	—
Copper Rockfish	156.21	3.16	6186.16	1.77	7333.57	4.15	—	—	984.80	4.89	4951.28	2.03	942.87	2.91
Tiger Rockfish	—	—	424.17	3.87	365.60	3.75	—	—	—		—	—	0.00	—
Eelpout	468.62	3.16	—	—	—	—	—	—	131.61	3.75	1515.41	2.59	35584.62	1.08
Kelp Greenling	14033.68	3.03	3636.21	2.01	27389.67	4.18	—	—	2340.36	2.21	2916.80	2.06	1162.26	3.18
Lingcod	1624.34	3.16	5123.13	2.17	1374.91	2.31	252.79	3.00	397.04	3.40	3177.00	2.86	2450.49	2.45
Rock Sole	13494.77	3.16	—	—	—	—	—	—	260.89	3.58	1862.69	2.31	1772.26	2.26

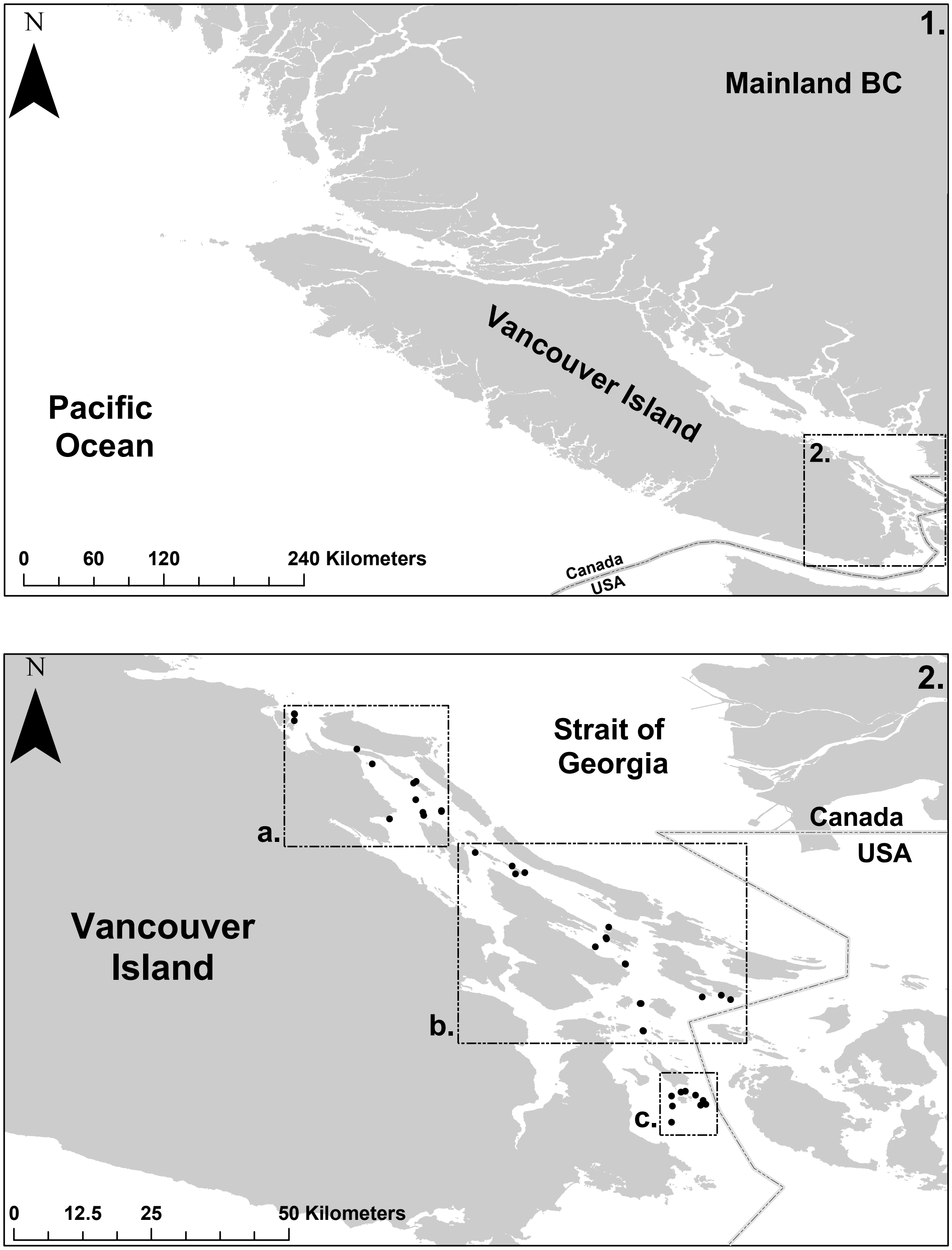


Figure 1. Study area. Chart 1 indicates location of study area in relation to Vancouver Island. Chart 2 shows detail of the study area with insets A, B and C showing the location of individual stations in greater detail.

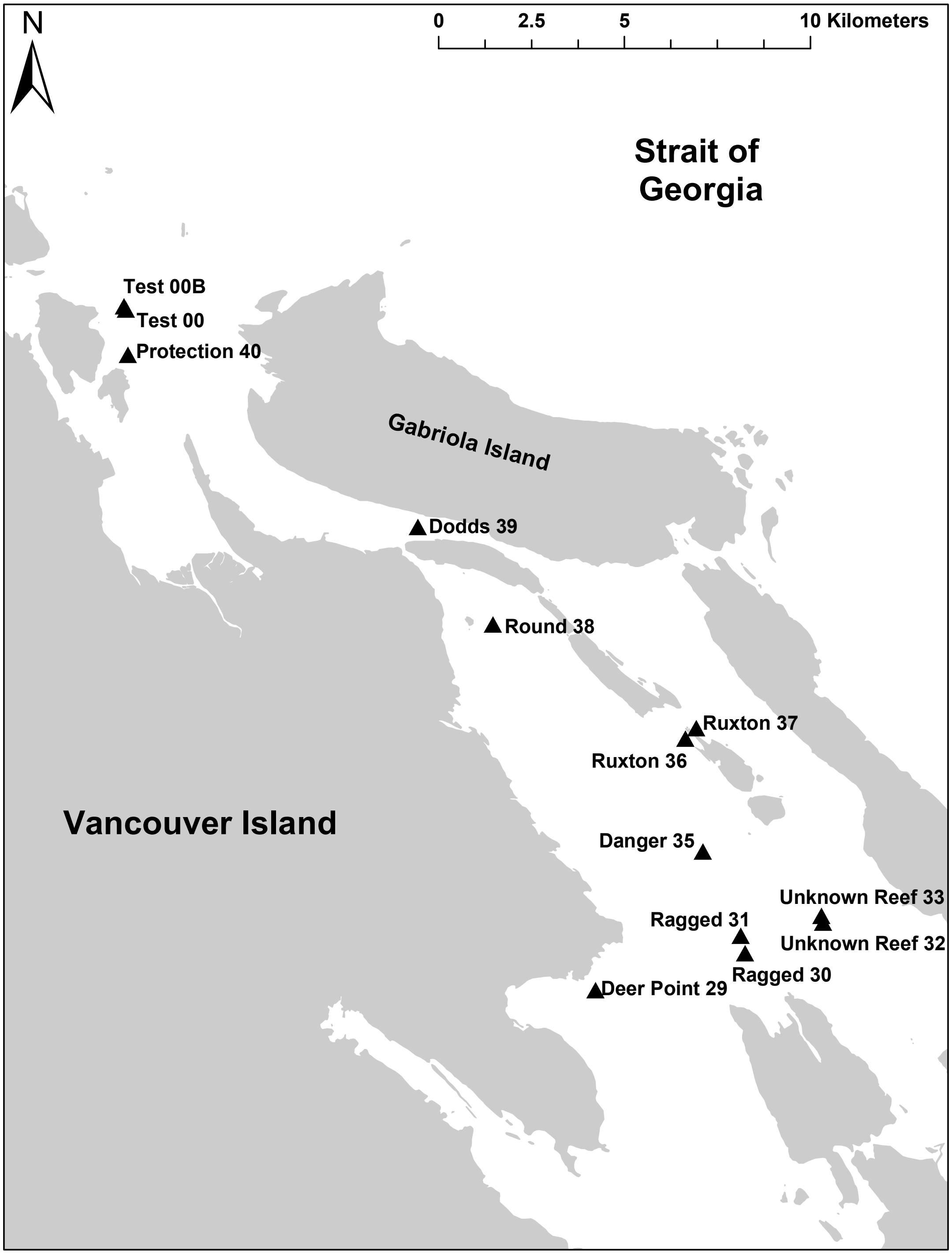


Figure 2. Detail of inset A from Figure 1, showing locations of stations in relation to Vancouver Island, the Gulf Islands and the Strait of Georgia.

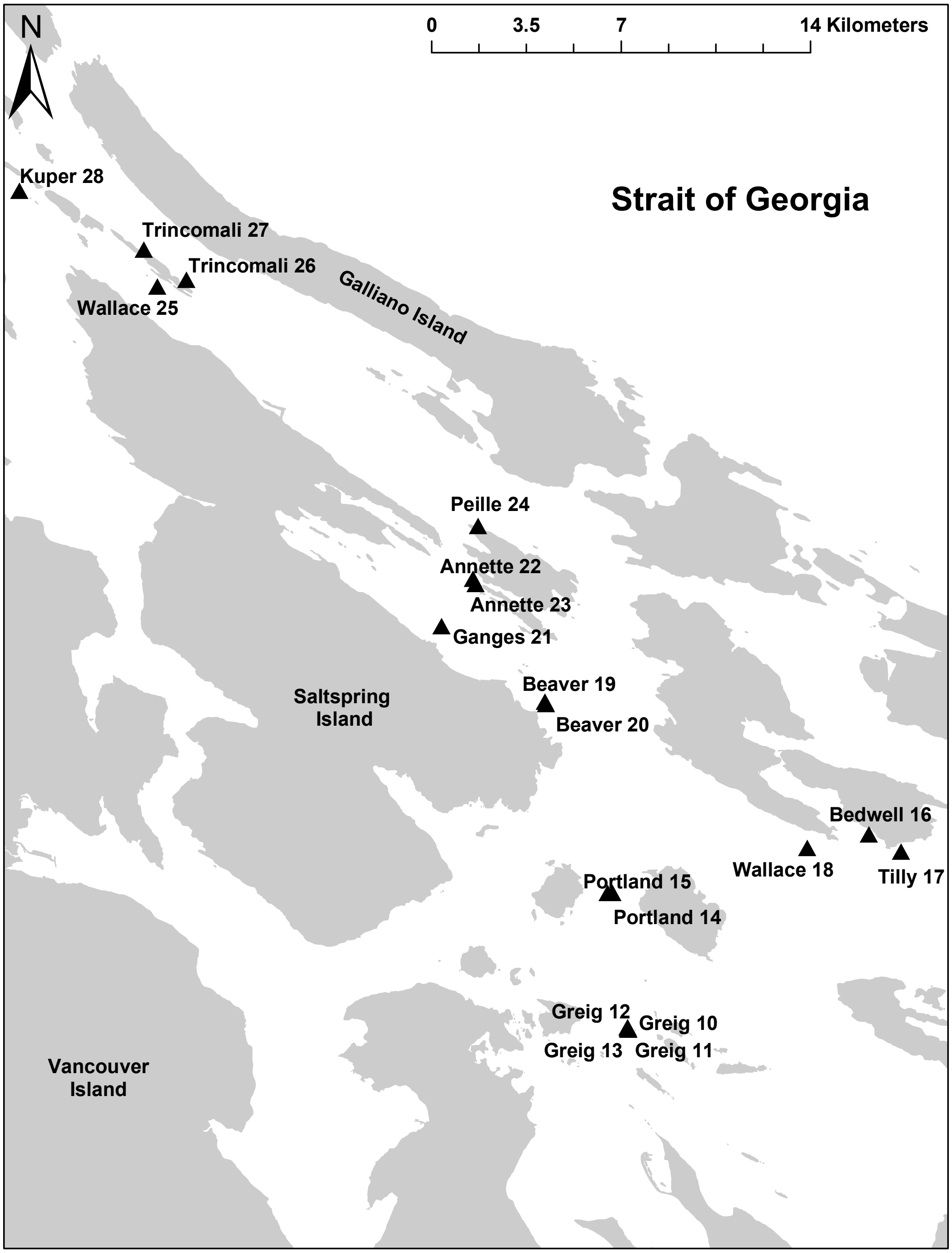


Figure 3. Detail of inset B from Figure 1, showing locations of stations in relation to Vancouver Island, the Gulf Islands in the Strait of Georgia.

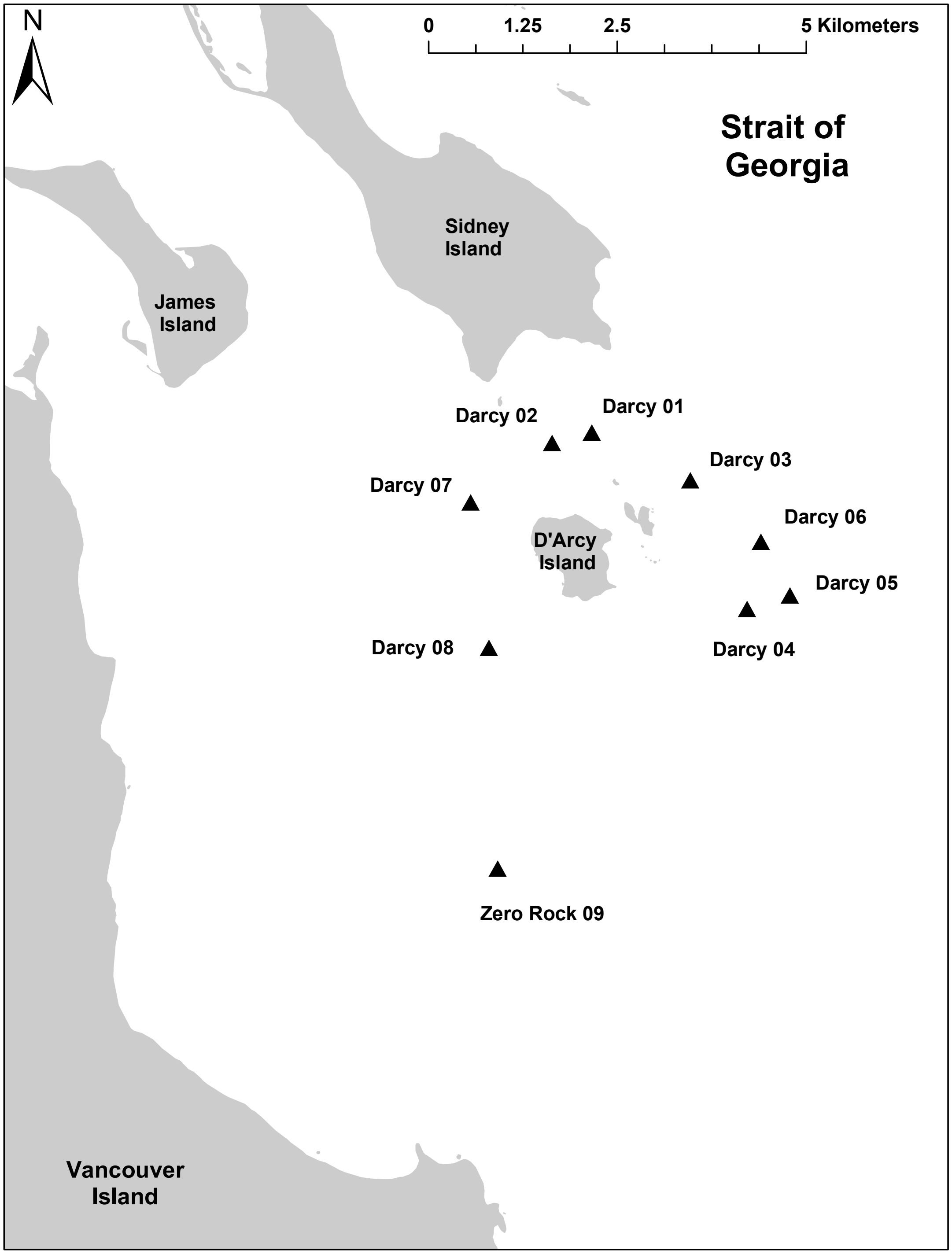


Figure 4. Detail of inset C from Figure 1, showing locations of stations in relation to Vancouver Island, the Gulf Islands and the Strait of Georgia.

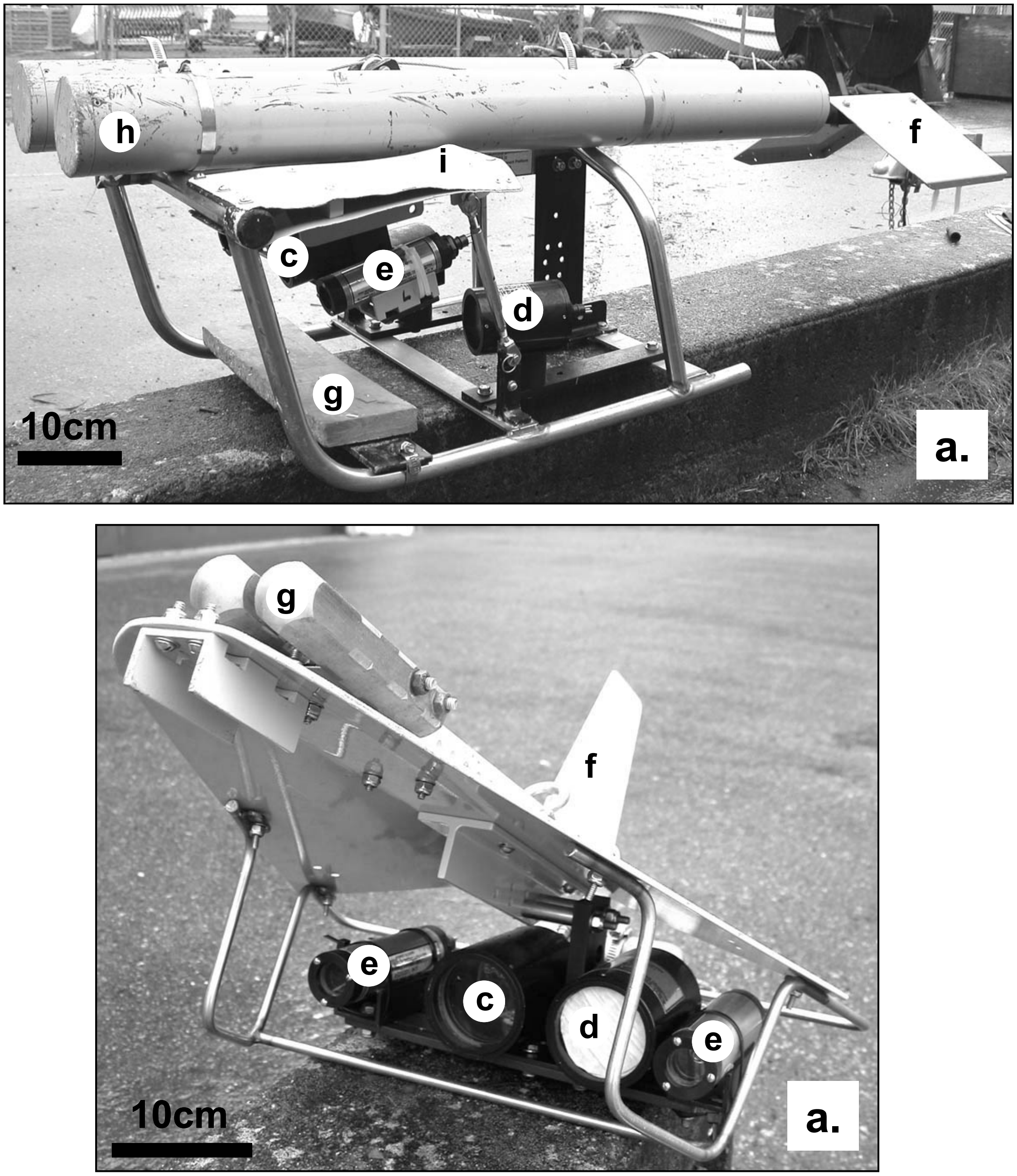


Figure 5. Photographs showing the ‘Toad’ (a.) and ‘Delta’ (b.) towed bodies used in the survey. Components indicated include camera modules (c), Halogen light modules (d – port and starboard on ‘Toad’), laser modules (e – port and starboard), stabilising fin (f), balance/ballast weights (g), floatation tubes (h – ‘Toad’ only) and depressor vanes (i - ‘Toad’ only). HPD sensor and cabling have been omitted for photo clarity.

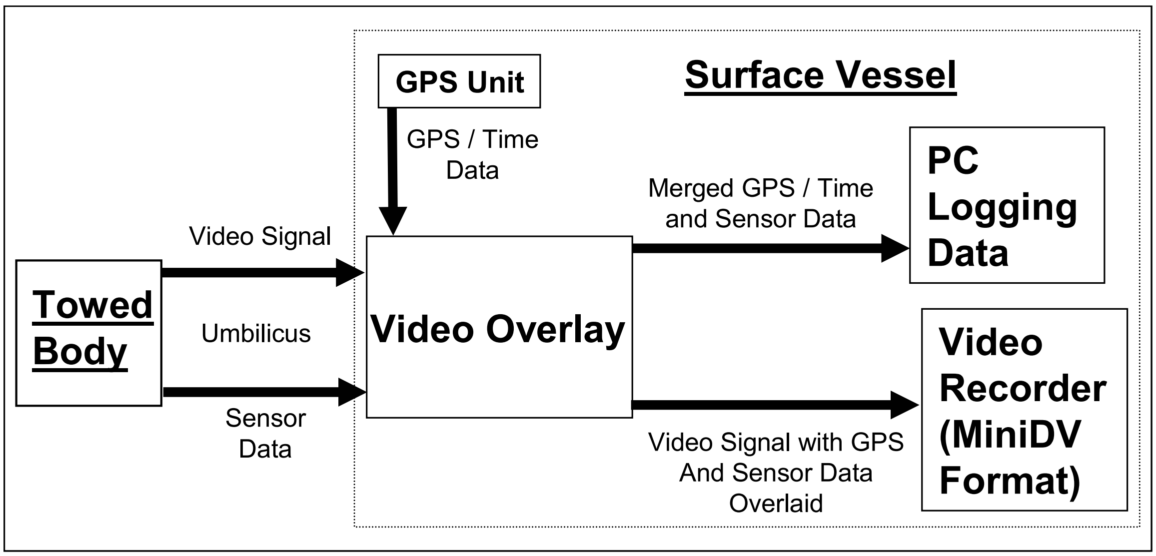


Figure 6. Diagram showing the connections between the electronic components of the sampling suite

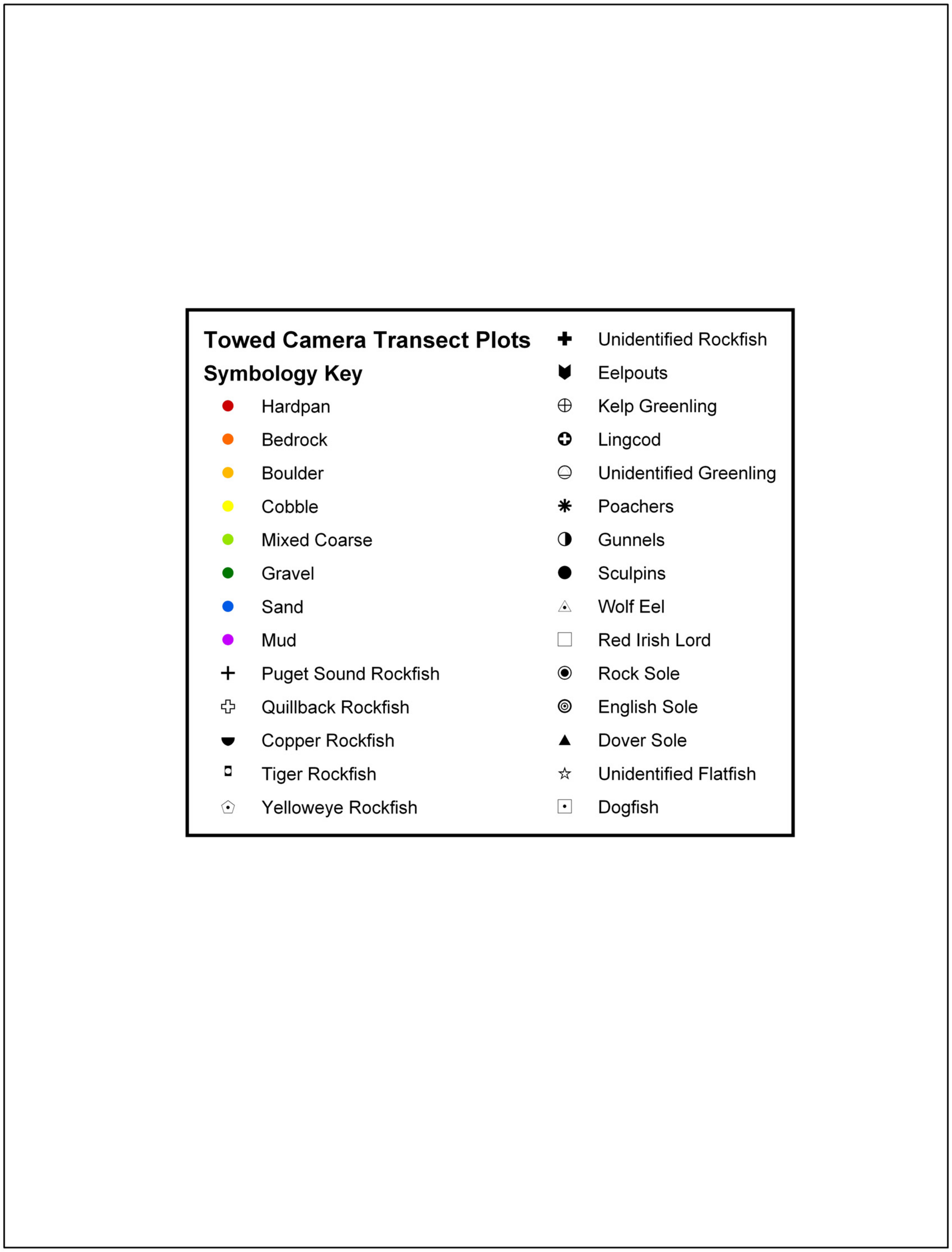


Figure 7. Key to substrate and fish species symbology used in figures 8-17.

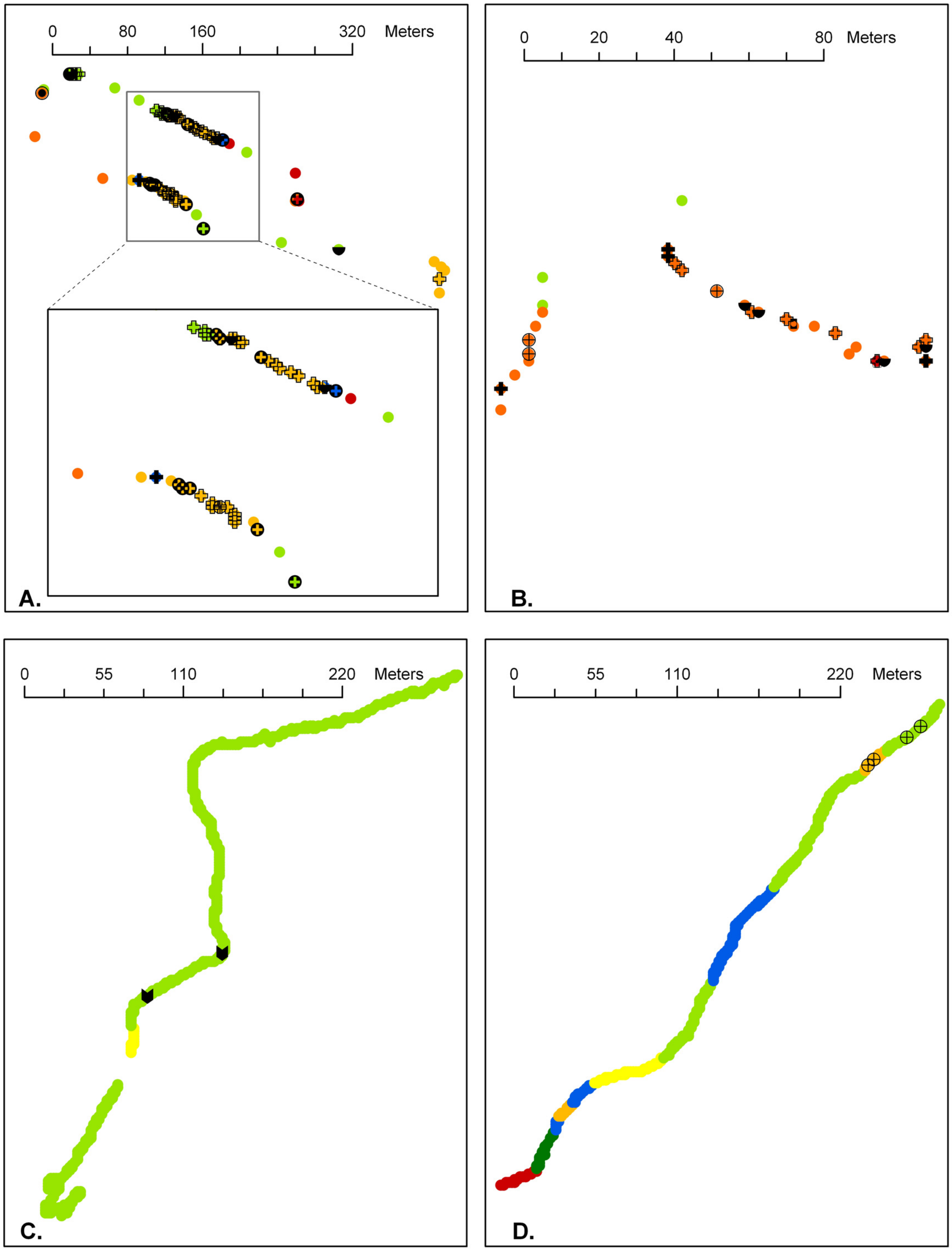


Figure 8. Plot of primary substrate type and fish locations along transects Test 00 (A., with exploded inset for clarity), Test 00b (B.), Darcy 01 (C.) and Darcy 02 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

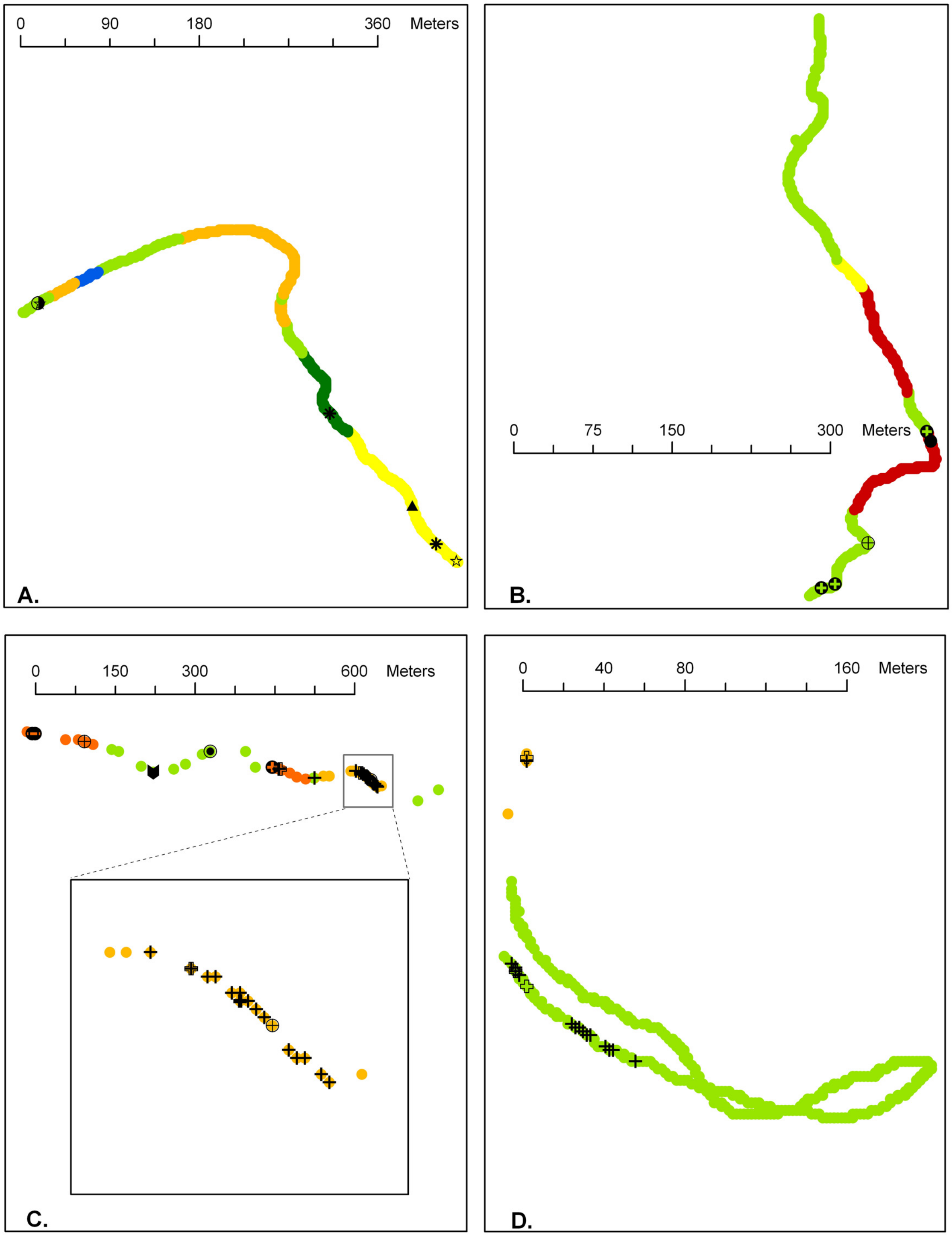


Figure 9. Plot of primary substrate type and fish locations along transects Darcy 03 (A.), Darcy 04 (B.), Darcy 05 (C., with exploded inset for clarity) and Darcy 06 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

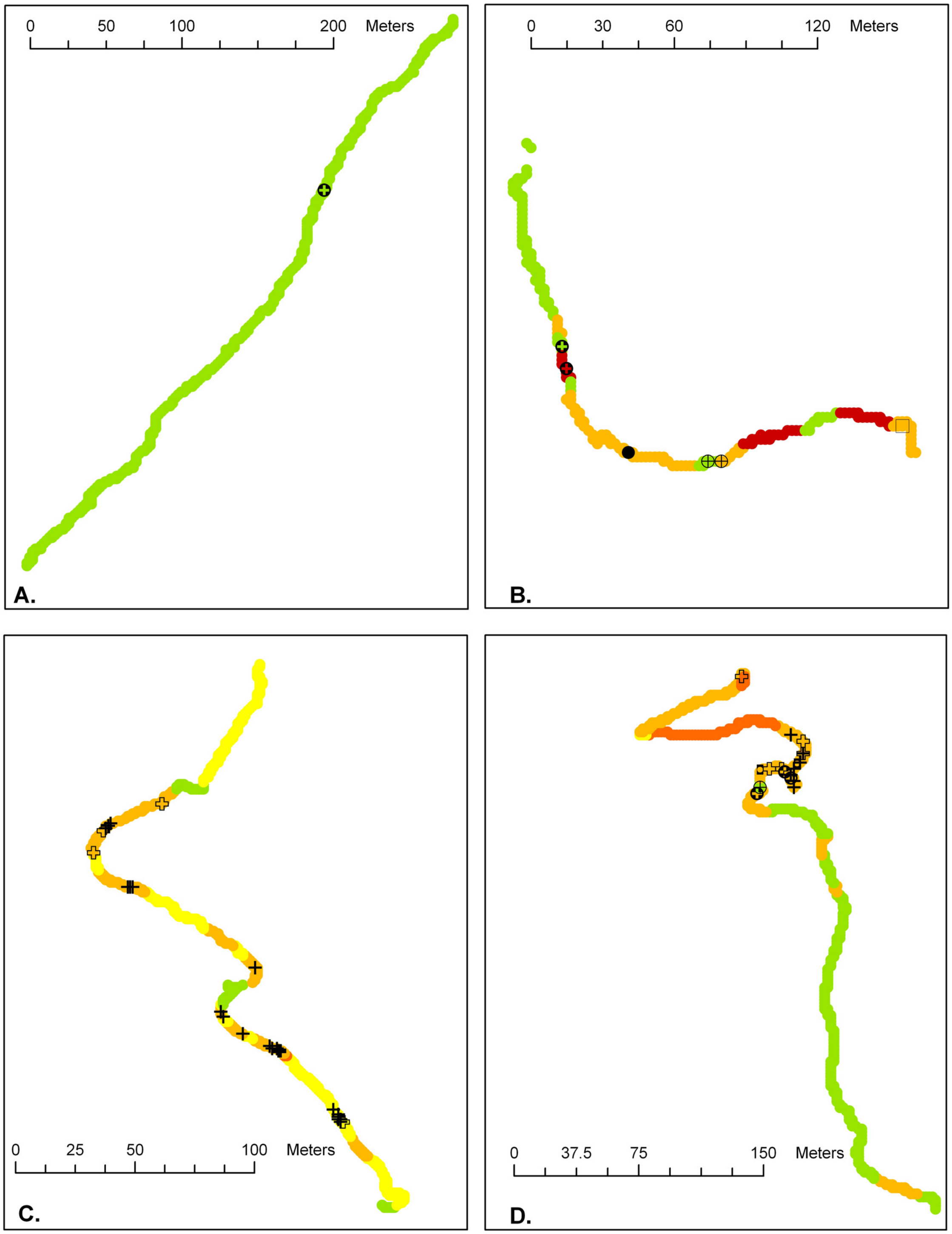


Figure 10. Plot of primary substrate type and fish locations along transects Darcy 07 (A.), Darcy 08 (B.), Greig 10 (C.) and Greig 11 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

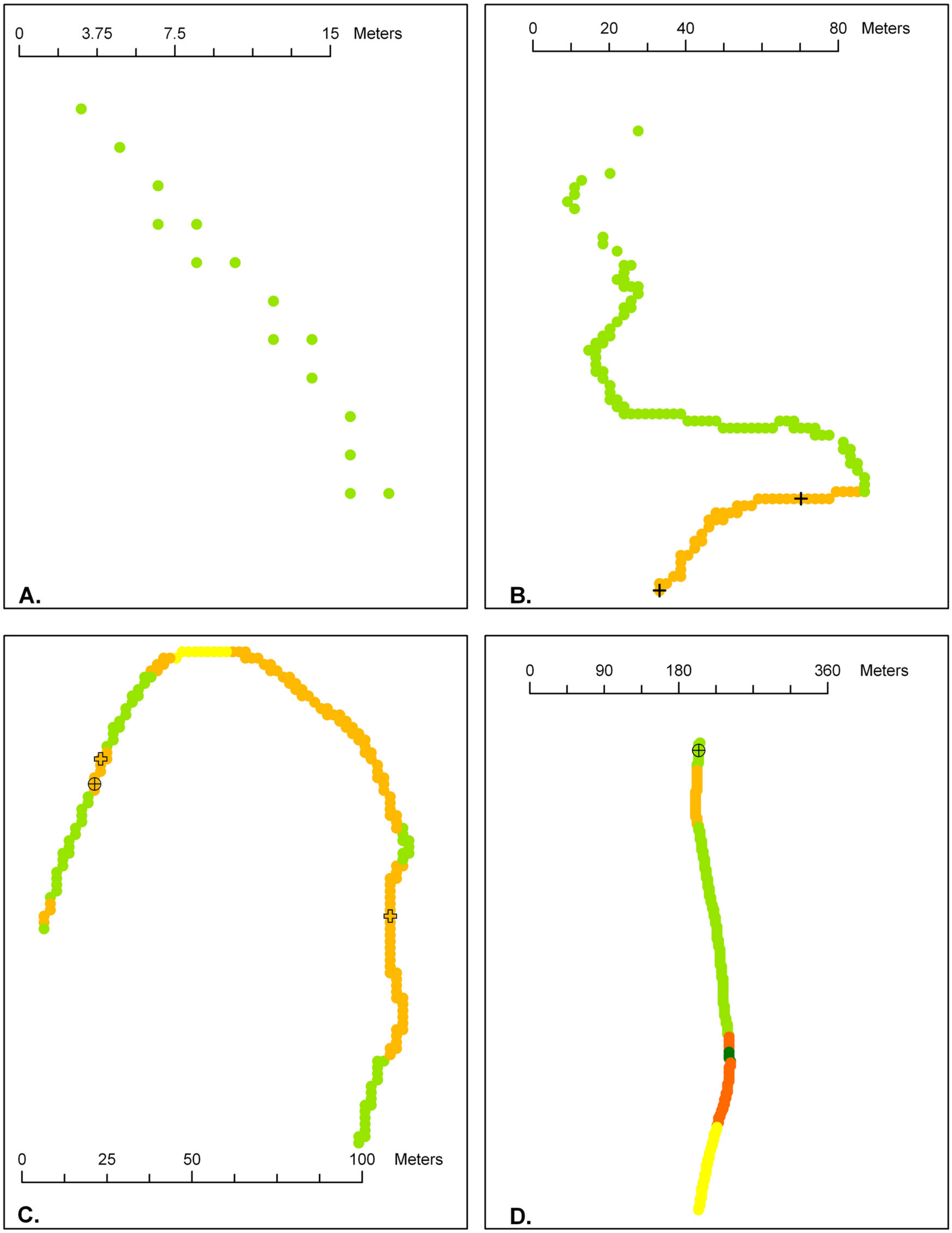


Figure 11. Plot of primary substrate type and fish locations along transects Greig 12 (A.), Greig 13 (B.), Portland 14 (C.) and Portland 15 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

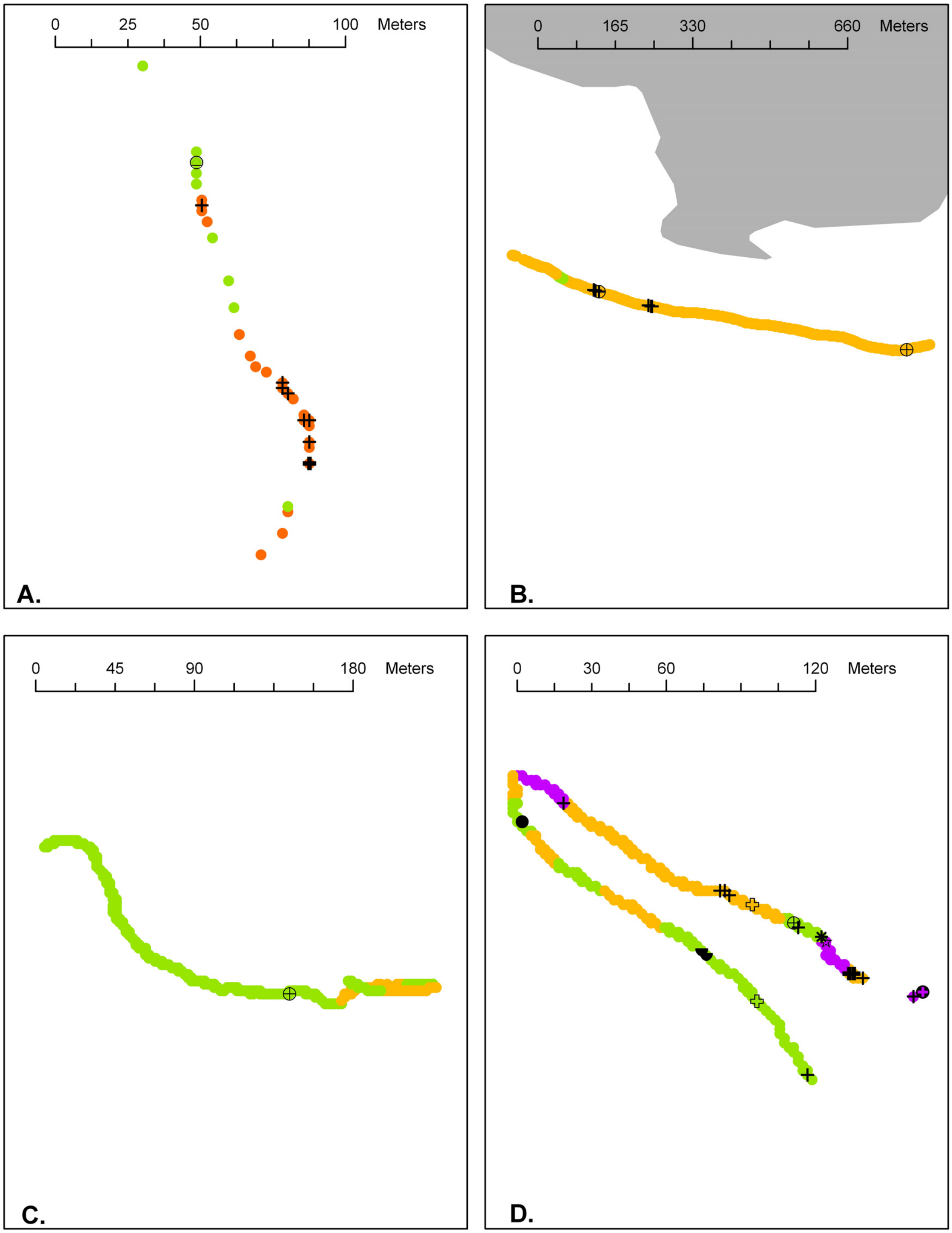


Figure 12. Plot of primary substrate type and fish locations along transects Bedwell 16 (A.), Tilly 17 (B.), Wallace 18 (C.) and Beaver 19 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

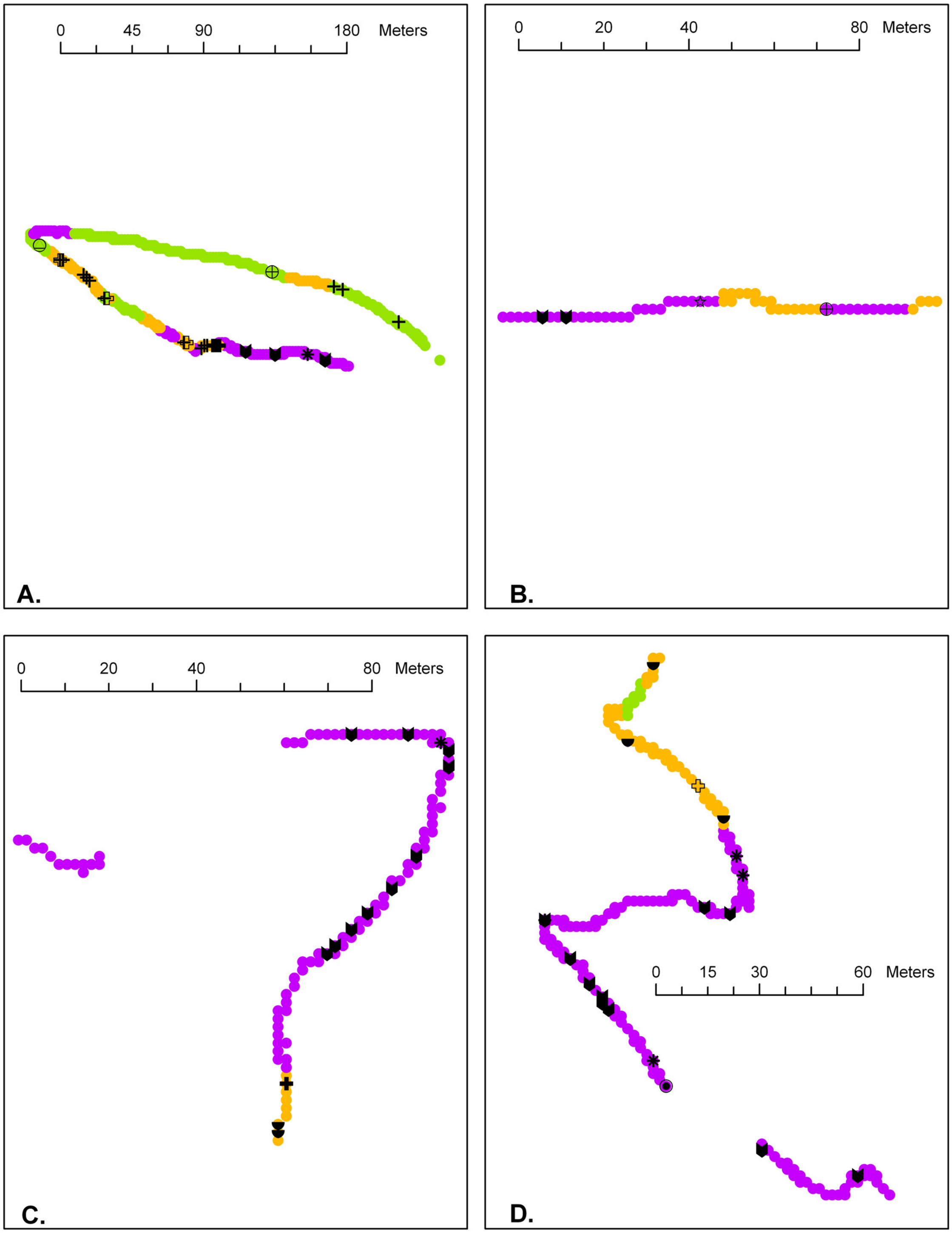


Figure 13. Plot of primary substrate type and fish locations along transects Beaver 20 (A.), Ganges 21 (B.), Annette 22 (C.) and Annette 23 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

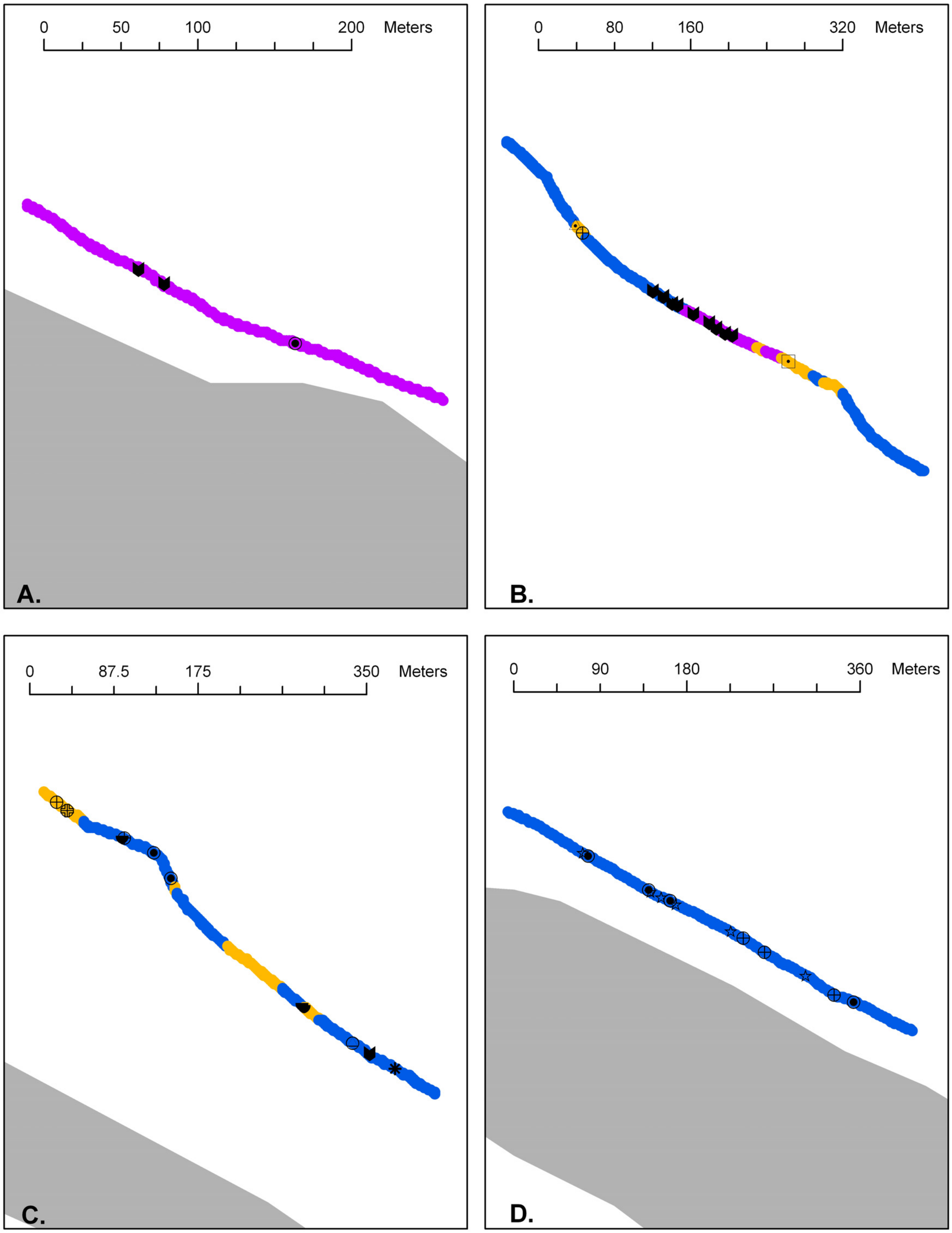


Figure 14. Plot of primary substrate type and fish locations along transects Peille 24 (A.), Wallace 25 (B.), Trincomali 26 (C.) and Trincomali 27 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

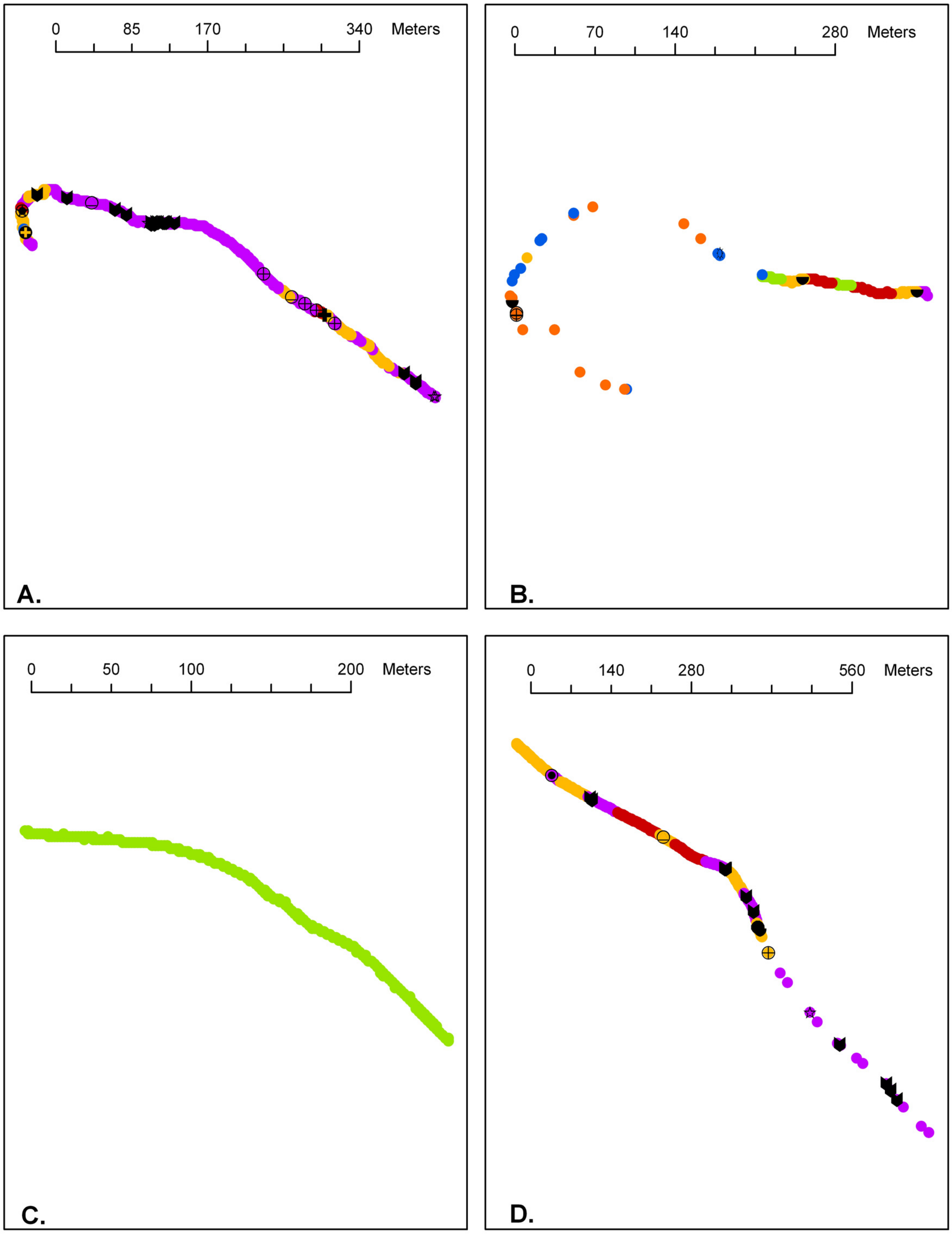


Figure 15. Plot of primary substrate type and fish locations along transects Kuper 28(A.), Deer Point 29 (B.), Ragged 30 (C.) and Ragged 31 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

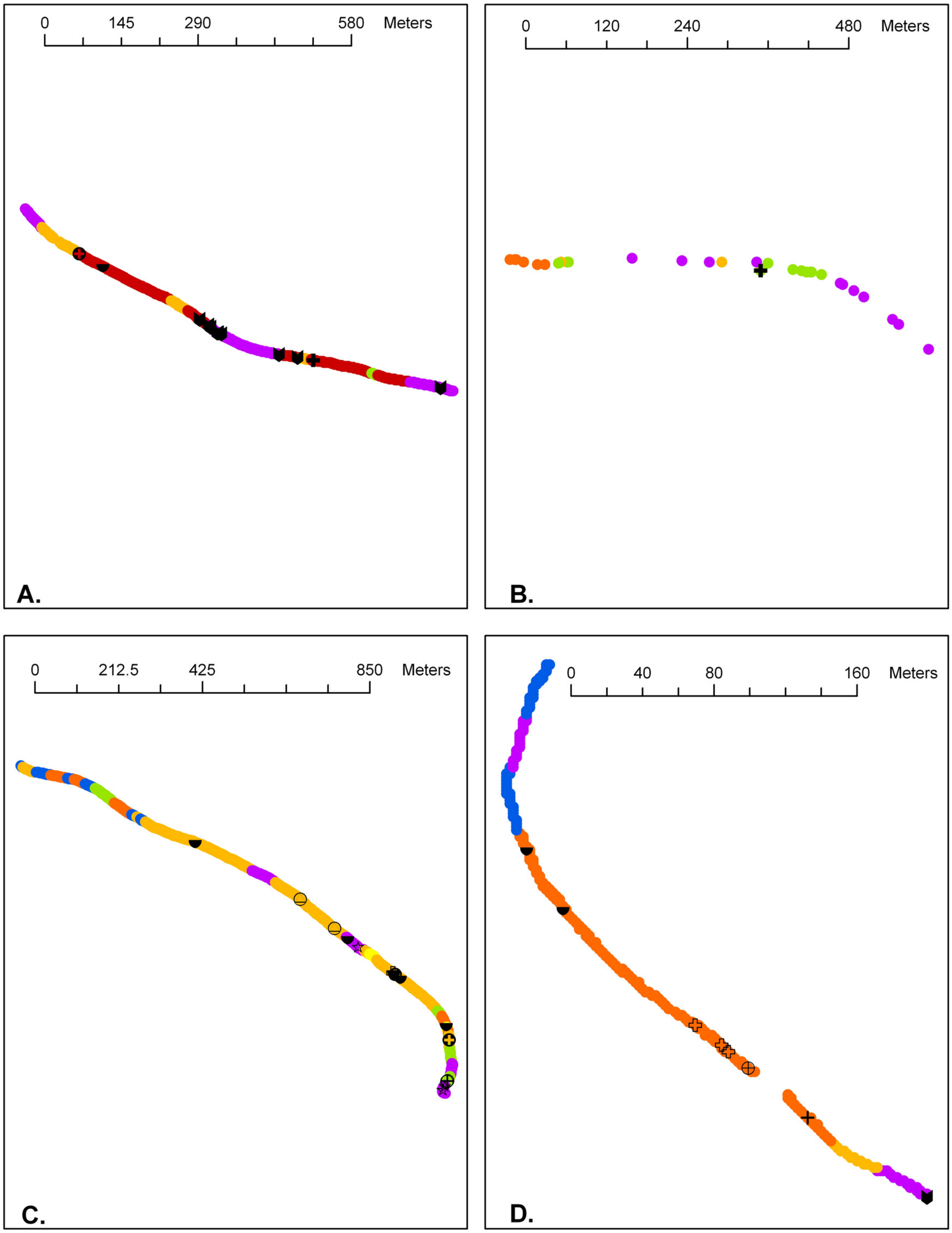


Figure 16. Plot of primary substrate type and fish locations along transects Unknown Reef 32 (A.), Unknown Reef 33 (B.), Danger 35 (C.) and Ruxton 36 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

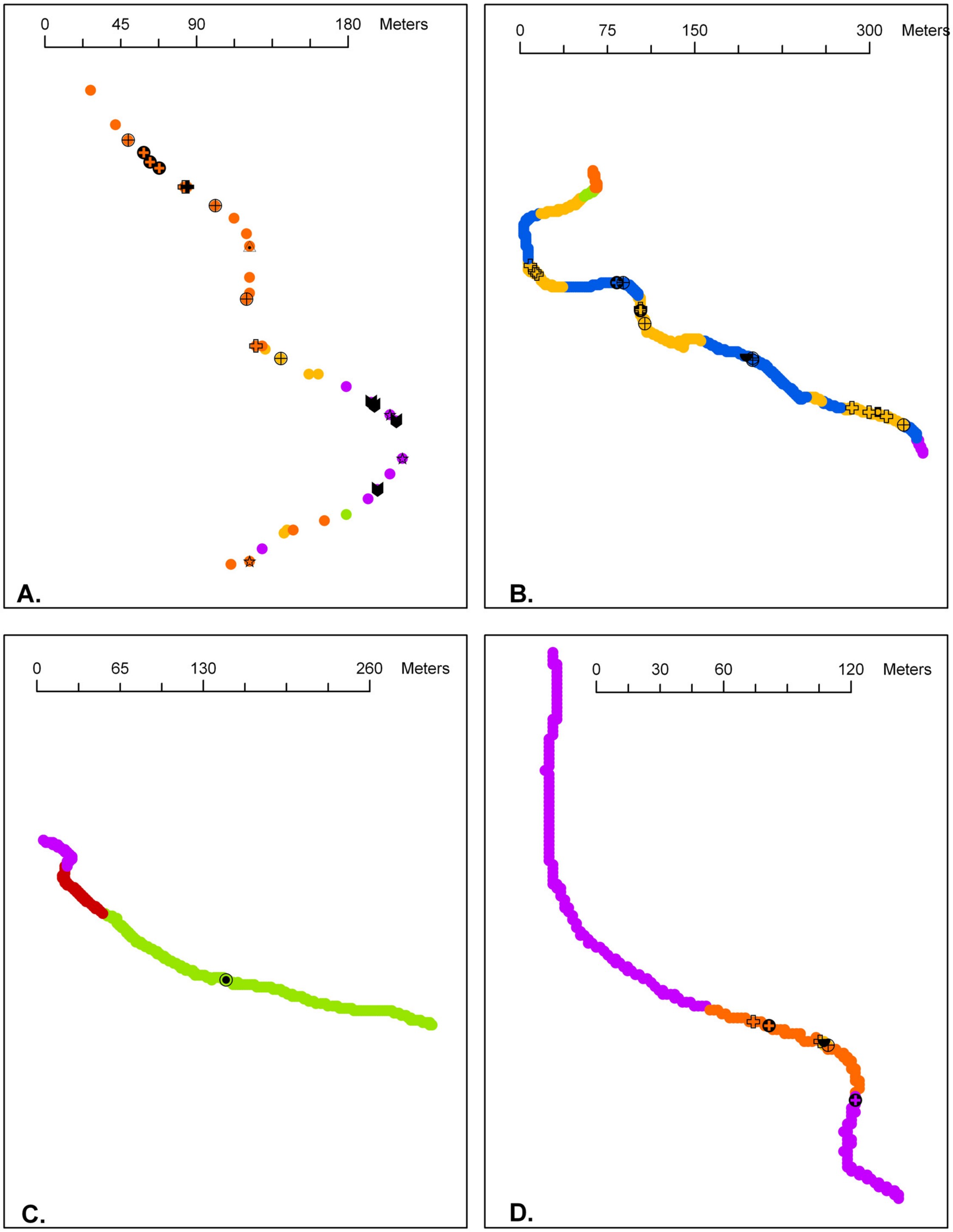


Figure 17. Plot of primary substrate type and fish locations along transects Ruxton 37 (A.), Round 38 (B.), Dodds 39 (C.) and Protection 40 (D.). Key to substrate colour coding and species symbols is provided in Figure 7.

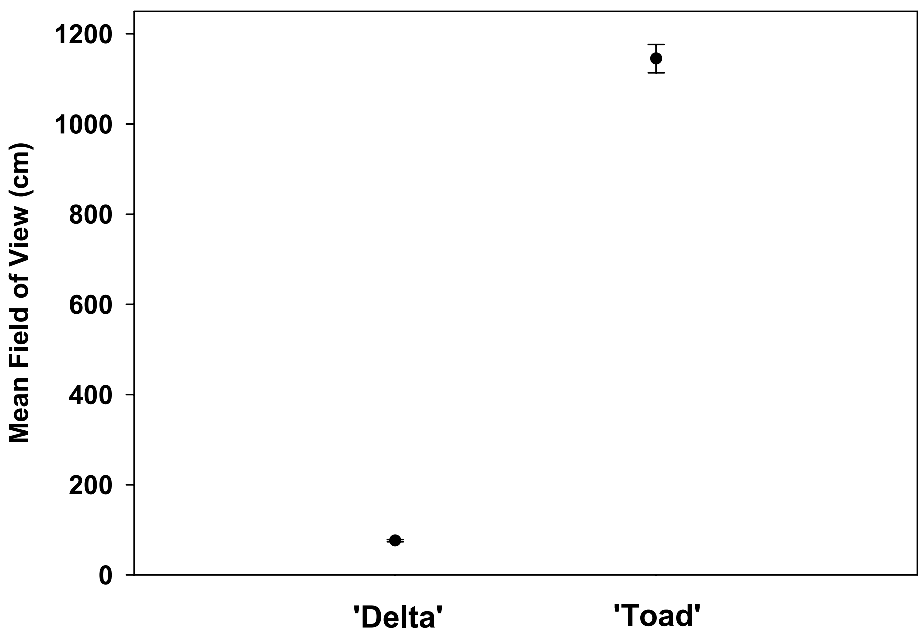


Figure 18. Comparison of the mean field of view by both towed camera platforms used over the course of the study. Error bars are one standard error.

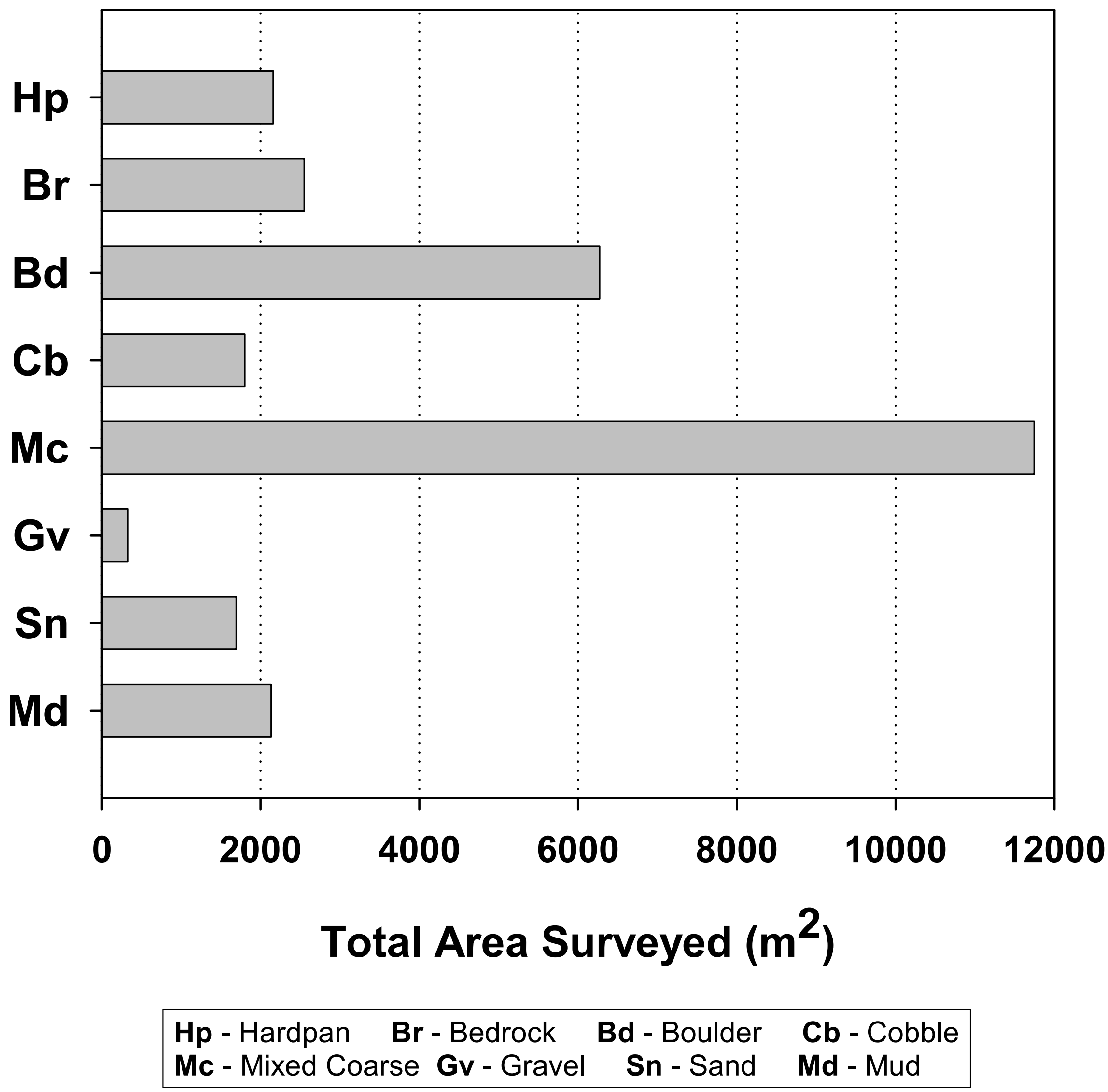
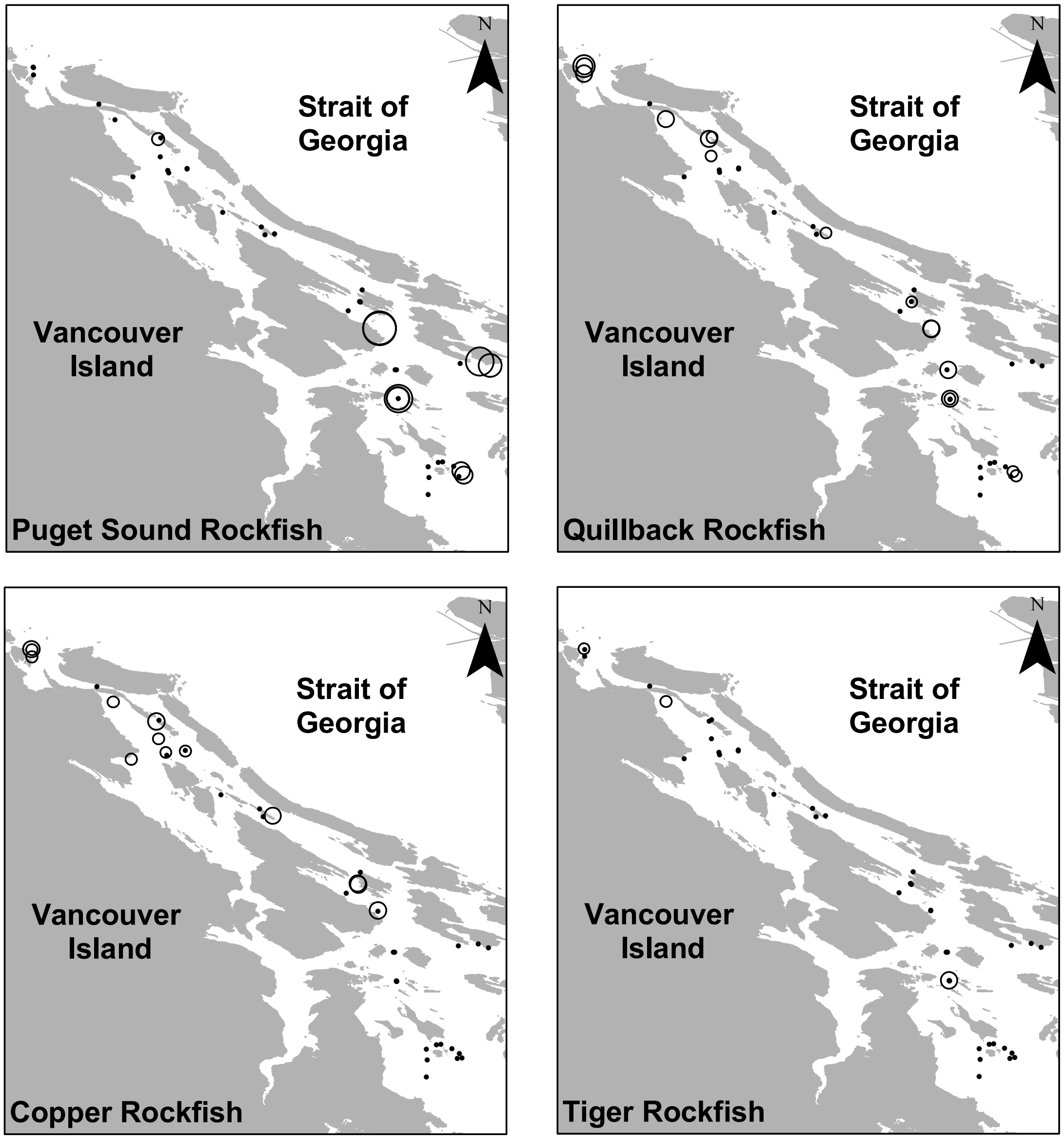


Figure 19. Total area (m²) of primary substrate types recorded.



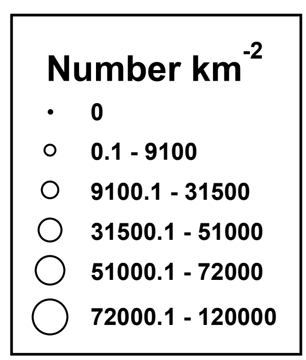


Figure 20. Plot showing distribution and relative density (km^{-2}) of Puget Sound Rockfish, Quillback Rockfish, Copper Rockfish and Tiger Rockfish.

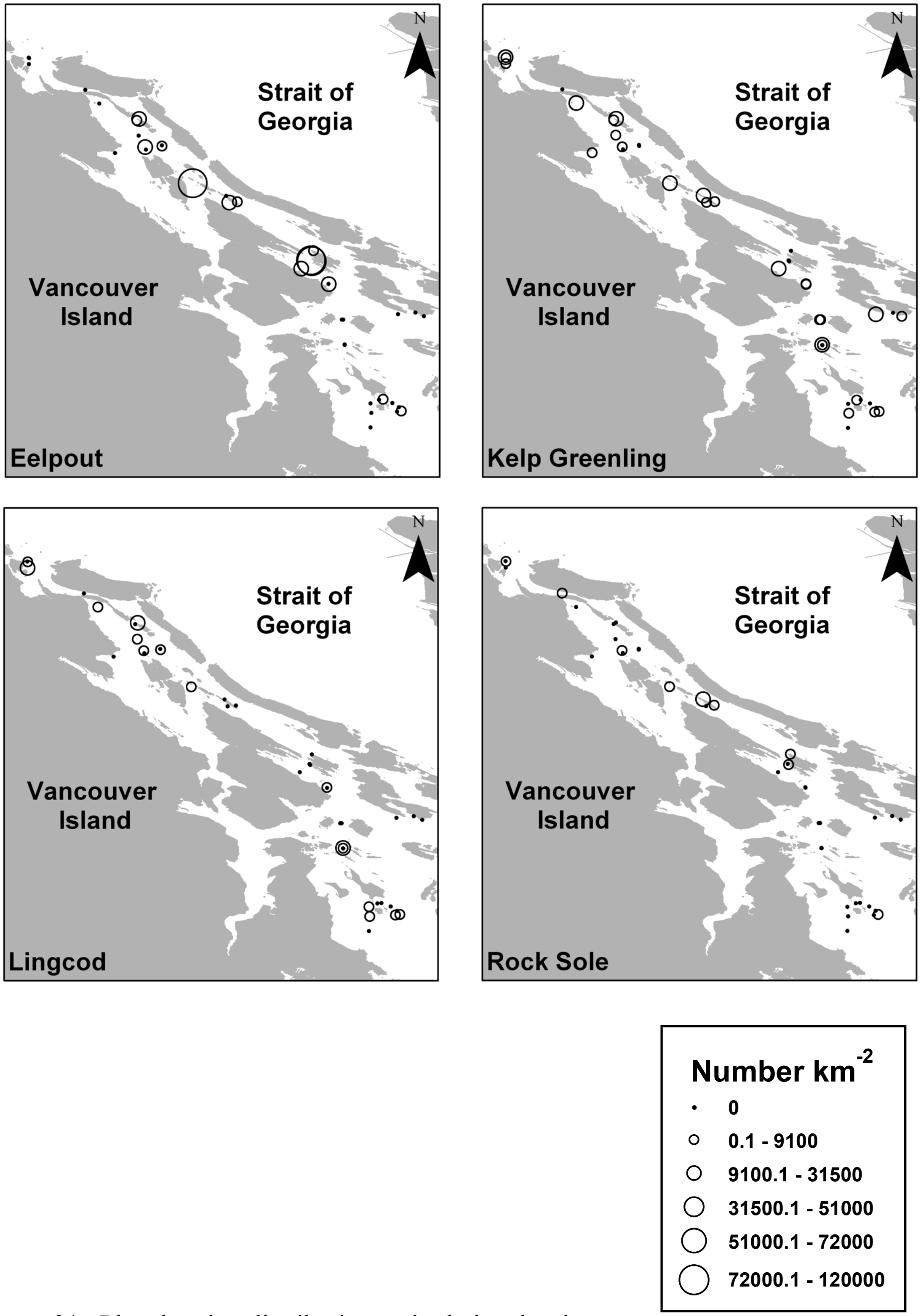


Figure 21. Plot showing distribution and relative density (km^{-2}) of Eelpout, Kelp Greenling, Lingcod and Rock Sole.

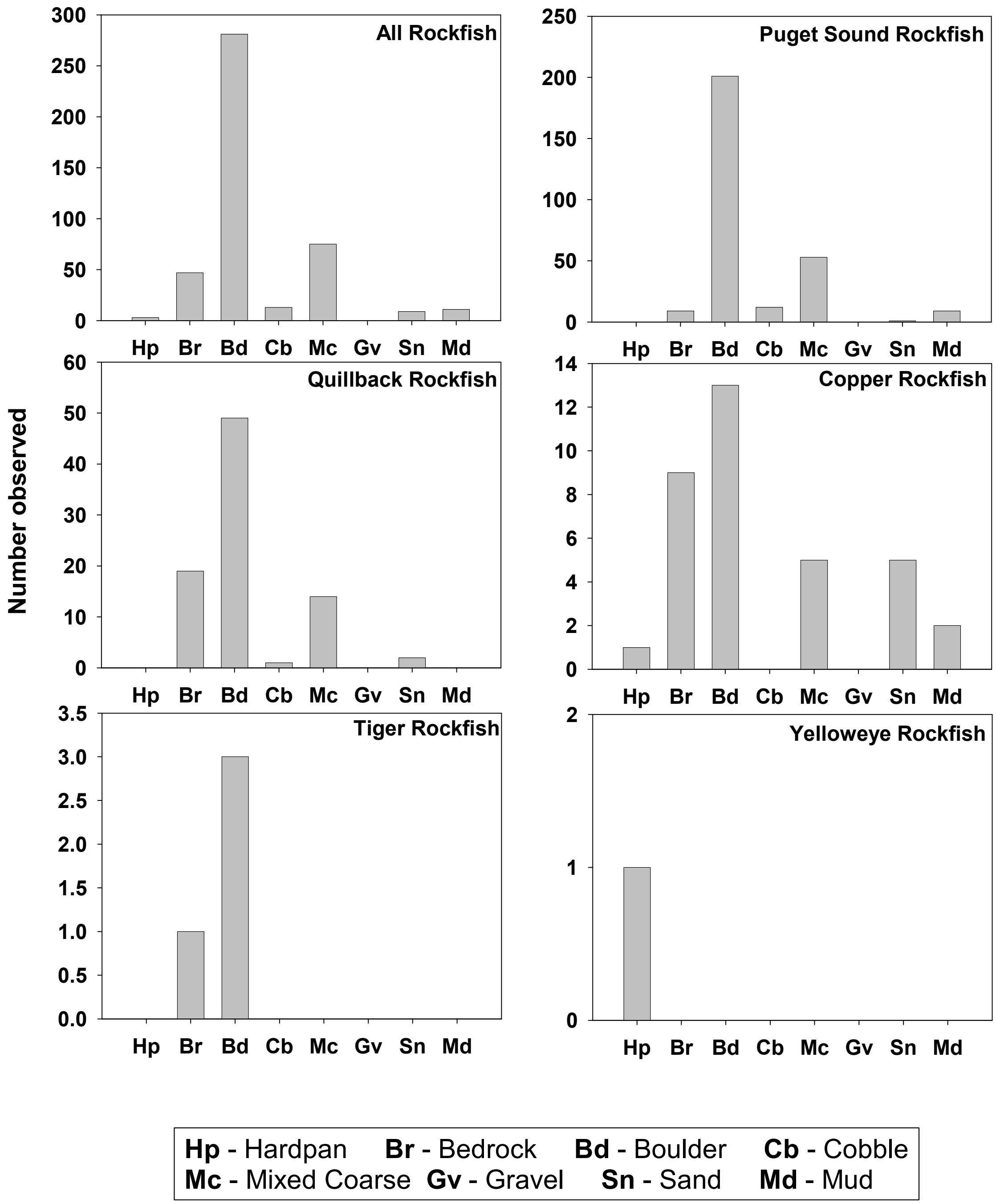


Figure 22. Number per primary substrate type for rockfish species over all transects.

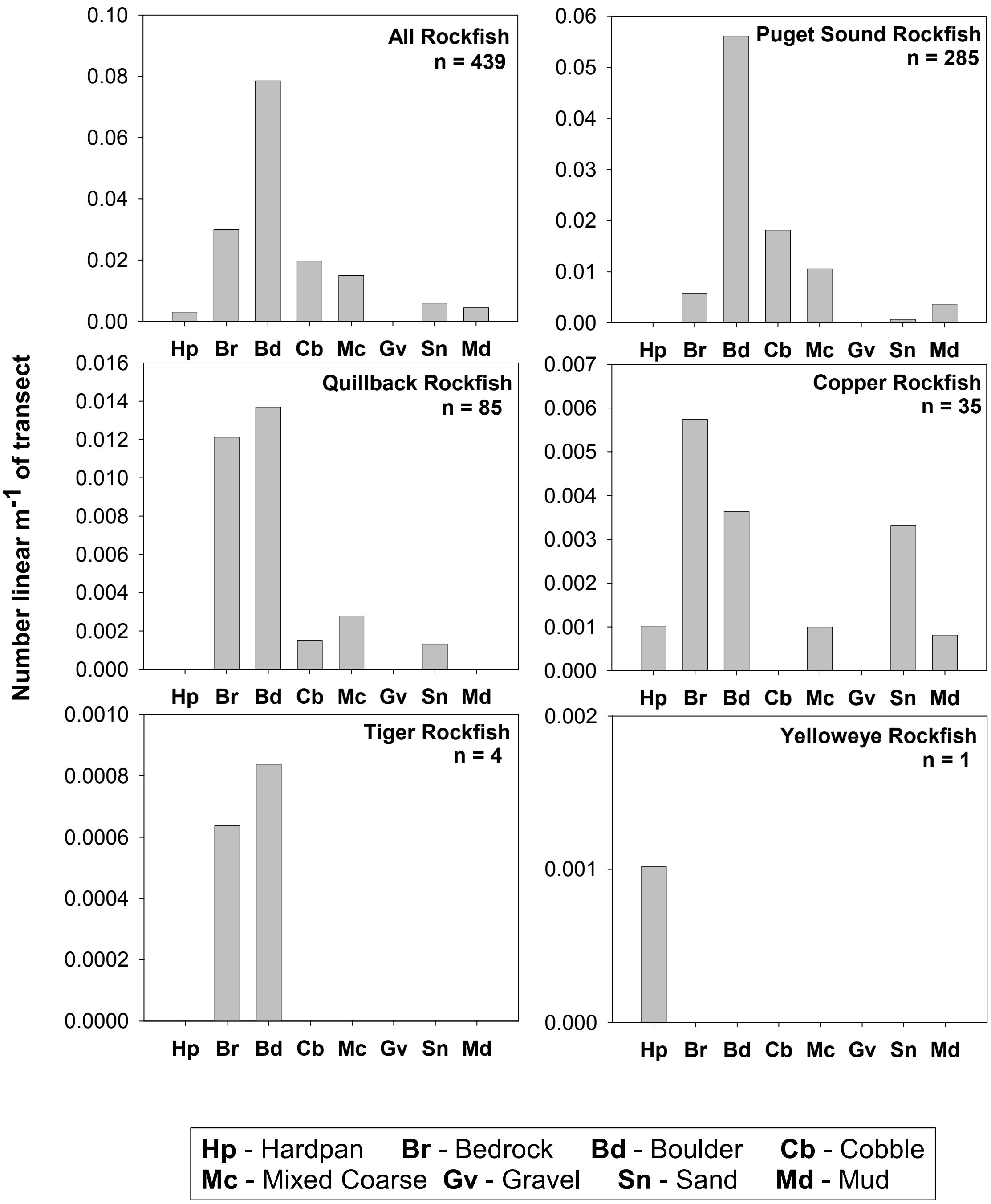


Figure 23. Number per linear transect distance for 6 species of Rockfish over all transects.

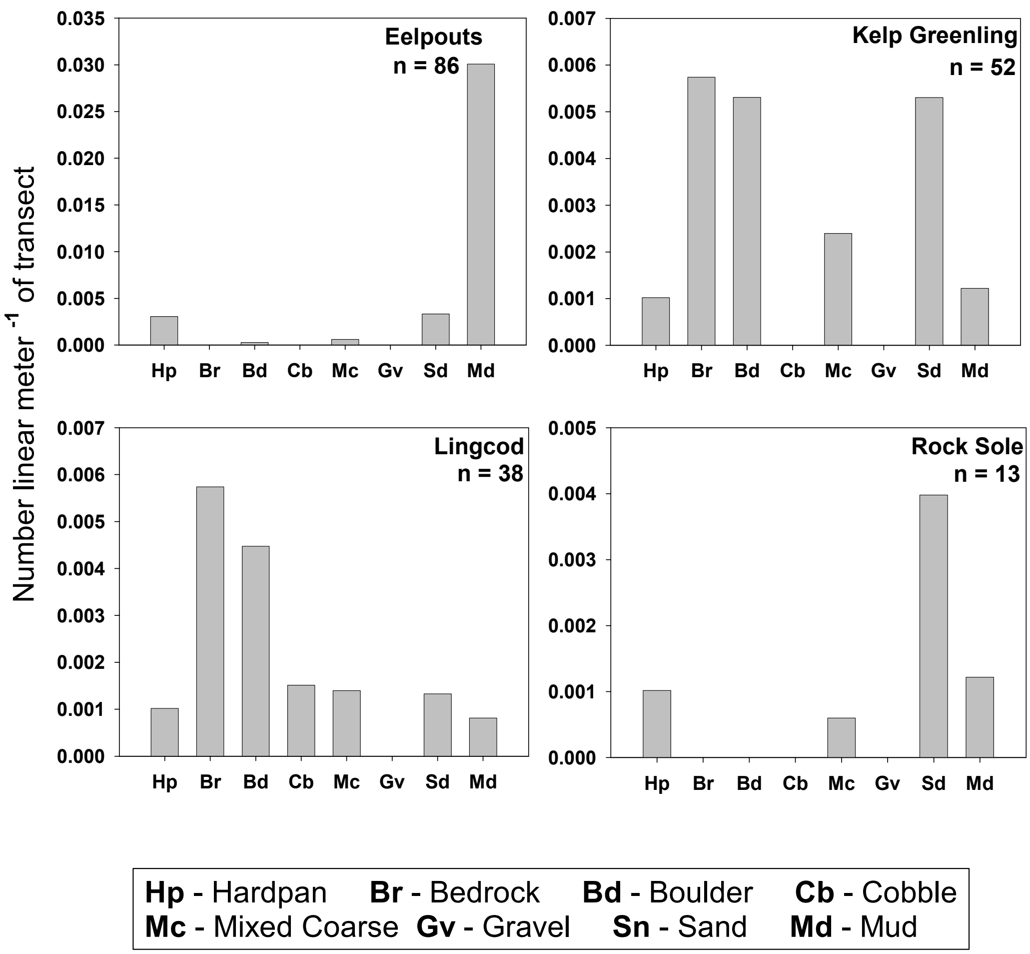


Figure 24. Number per linear transect distance for the four most common non-rockfish species over all transects

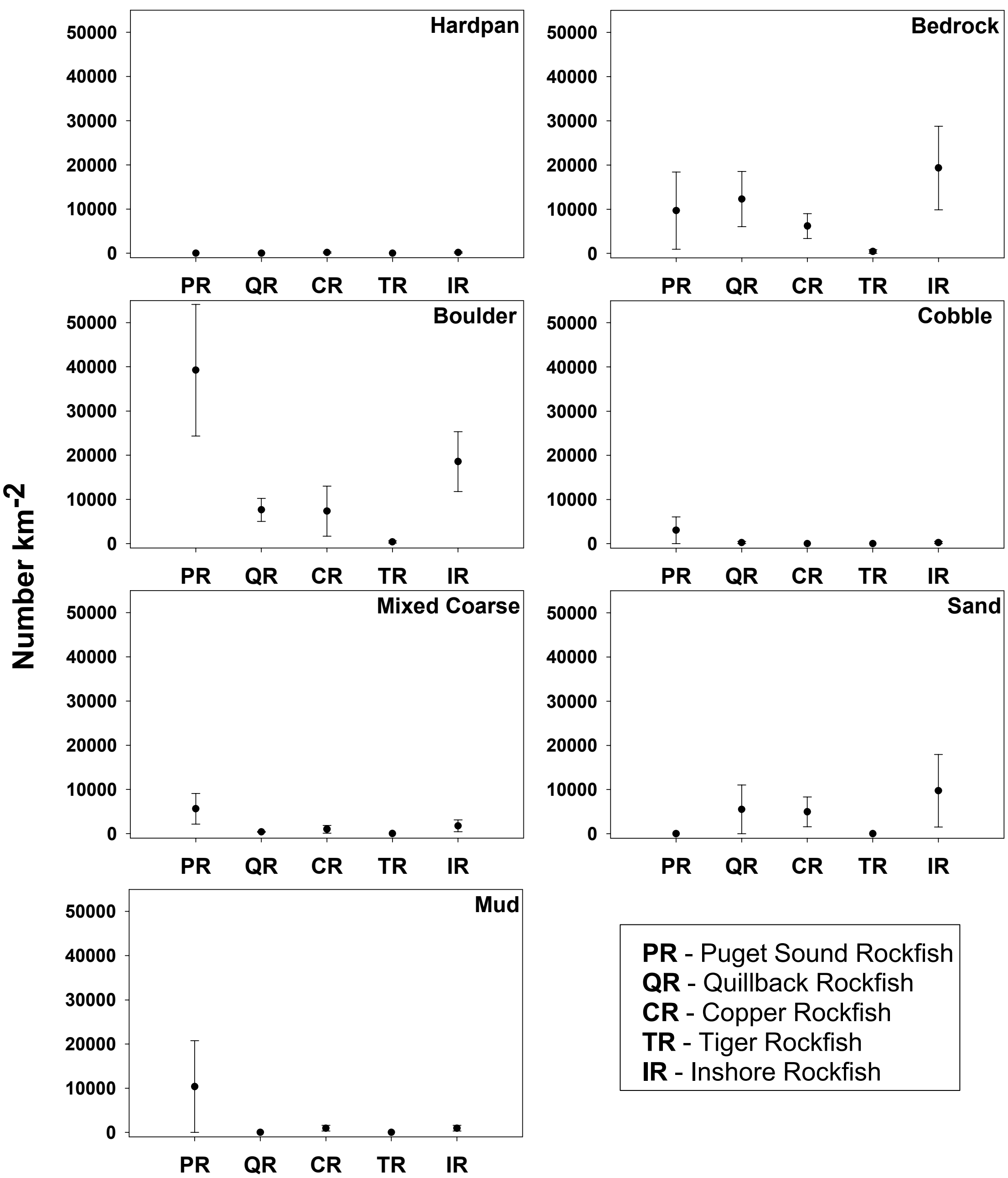


Figure 25. Mean densities by primary substrate type for the five most common rockfish taxa encountered. Gravel is not included as no fish were observed over that substrate. Yelloweye rockfish were not included, as only one individual was observed in all transects. Error bars are 1 standard error.

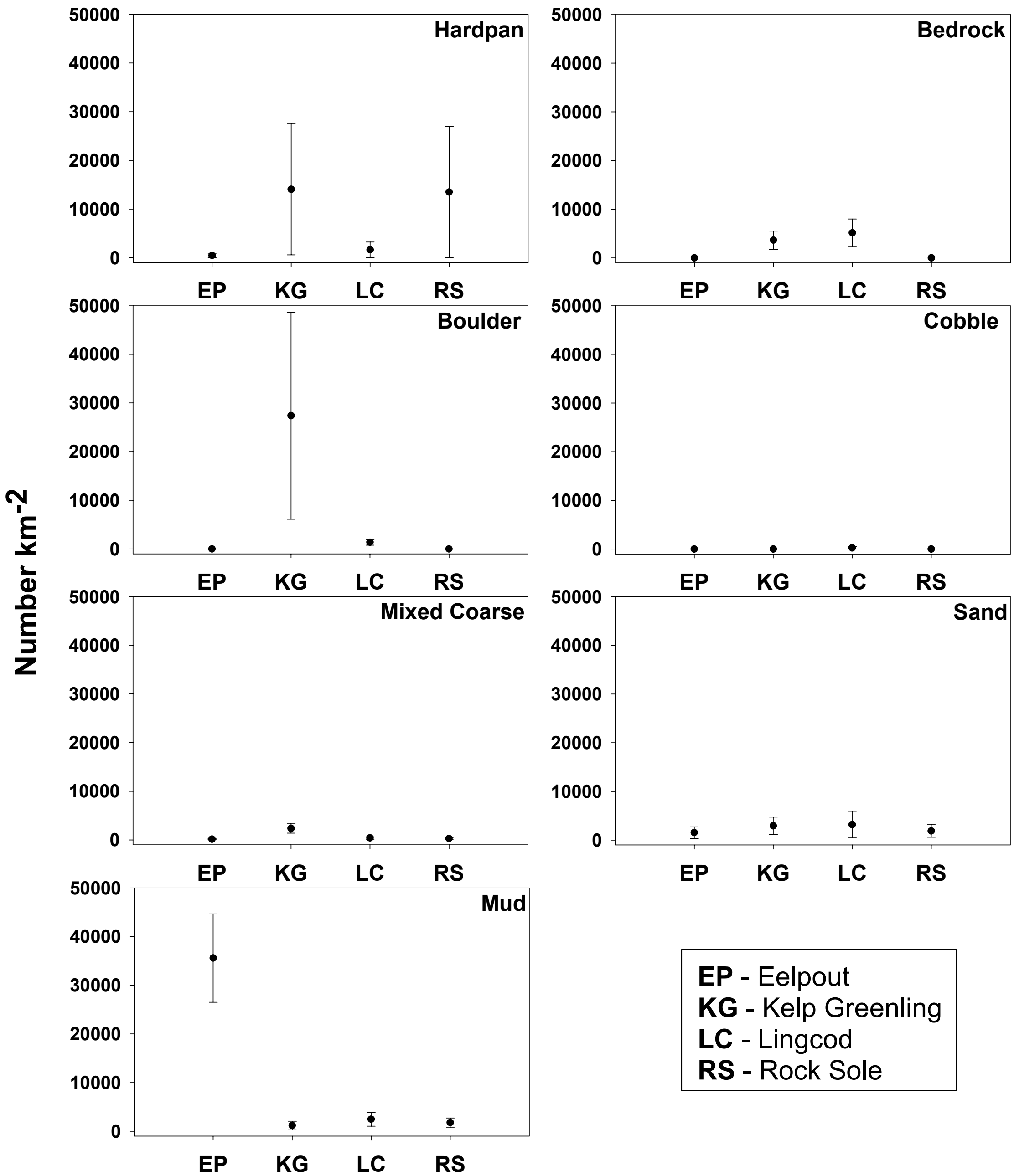


Figure 26. Mean densities by primary substrate type for the four most common non-rockfish taxa encountered. Gravel is not included as no fish were observed over that substrate. Error bars are one standard error.

Appendix. Summary of substrate cover over the course of the 2003 towed camera survey

Station Name	Habitat Synopsis
Test 00	Mostly cobble pavement, with areas of rocky reef with kelp. Occasional boulder fields. All varying
Test 00B	Mostly a cobble/gravel/sand pavement, with alternating areas of bedrock and cobble
Darcy 01	Gravel and shell debris with muddy bryozoan cover.
Darcy 02	Rocky reefs with varying relie; dense patches of purple urchins. Also areas of flat gravel/sand/shell. All with dense bryozoans or algae.
Darcy 03	Sand and mixed coarse substrate covered in muddy bryozoans. Rocky reef with dense biocover in shallows.
Darcy 04	Rocky reefs encrusted with barnacles. Feathery bryozoans/corallines throughout. Low areas with sand, and other areas with thick shell debris.
Darcy 05	Areas of high relief rocky reef, heavily encrusted with barnacles and bryozoans, interspersed with flat areas of gravel/cobble/sand/shell. Areas of dense purple urchins and sea cucumbers
Darcy 06	Several high-relief areas of rocky barnacle reef, interspersed with mixed coarse/shell debris and some low-lying barnacle reefs.
Darcy 07	Low relief areas of cobble or bedrock, covered in thick barnacles and bryozoans/corralines
Darcy 08	Areas of sand/shell between ridges of bedrock reef covered in banracles and bryozoans/algae. Some areas with high relief. Some areas of dense green algal cover.
Zero Rock 09	Flat bottom of gravel and shell debris with bryozoan cover
Greig 10	Occasional steep/sheer rocky reefs with some rolling reef, interspersed with mixed coarse/mud areas, with sea cucumbers.
Greig 11	Areas of high relief bedrock and boulder reef interspersed with gravel/shell and boulder pavement. Barnacles and bryozoans encrusting reef areas.
Greig 12	Flat bottom of gravel, cobble and shell. Dense covering of muddy bryozoans.
Greig 13	Mixed coarse substrate and cobble with occasional boulders. Dense bryozoan covering.
Portland 14	Areas of sand, or combined gravel/sand/shell with occasional areas of barnacle-encrusted rocky reef and low-lying rocky-ridges.
Portland 15	Flat sand and sand/cobble pavement with occasional protruding bedrock. Other areas of high-relief rock walls.
Bedwell 16	Mostly shell and gravel with occasional low walls of rock covered in barnacles
Tilly 17	Bedrock slope with increased encrustation and crevices towards shallows
Wallace 18	Mostly flat shell and gravel with occasional clumps of barnacles and boulders

Appendix (Continued).

Station Name	Habitat Synopsis
Beaver 19	Flat areas of mud with shell debris; rises of boulders and bedrock, encrusted with barnacles and bryozoans
Beaver 20	Flat areas of mud with shell debris; occasional raised areas of complex barnacle reef and rock
Ganges 21	Soft silt early on along transect, giving way to rising high reef of bedrock with sea cucumbers and *Metridium sp.*
Annette 22	Fine silt with some barnacle debris and sea pens. One high rocky reef area.
Annette 23	Fine mud bottom with sea pens intersperced with areas of rising rocky reefs
Peille 24	Fine mud with occasional cobbles; large pieces of kelp detritus
Wallace Island 25	Areas of bedrock and boulders intersperced with sand/shell/mud/gravel
Trincomali 26	Boulders and protruding bedrock surrounded by sand. Crinoids and urchins
Trincomali 27	Sand/mud with occasional protruding bedrock, some kelp. Bivalve siphons in soft bottom areas.
Kuper 28	Mud with Cerianthids and crinoids; occasional outcrops of bedrock ridges and boulders
Deer Point 29	Sand/shell bottom with occasional protruding flat bedrock/hardpan and boulders
Ragged 30	Mixed sand/shell/cobble bottom with occasional boulders - very turbid
Ragged 31	Interspersed hilly areas of mud and bedrock; crinoids and *Metridium sp.*
Unknown Reef 32	Mud bottom with occasional outcrops of bedrock. Dense crinoids and cerianthids
Unknown Reef 33	Fine mud bottom with occasional groups of boulders and rock. Dense crinoids and burrowing sea cucumbers.
Danger 35	Muddy bedrock and boulders with dense crinoids over exposed rock.
Ruxton 36	Areas of mud and mud/shell with occasional steep rocky reefs
Ruxton 37	Rolling bedrock and boulders with crinoids, interspersed with areas of fine mud/silt
Round 38	Boulder fields with crinoids and areas of fine mud/silt
Dodds 39	Mixed coarse substrate and shell debris with occasional protruding bedrock and boulder
Protection 40	Boulder fields separated by flat muddy bottom, occasional wood debris and kelp detritus