A comparison of underwater photo, video and visual diver survey methods to assess nearshore algae and invertebrate communities

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ABSTRACT

Charles, K.E., Packham, J. Bureau, D., Lessard, J. 2022. A comparison of underwater photo, video and visual survey methods to assess nearshore algae and invertebrate communities. Can. Tech. Rep. Fish. Aquat. Sci. 3446: ix + 37 p.

This report reviews the application of three survey methods used in nearshore subtidal SCUBA surveys. Observations of habitat characteristics and the presence of algae and invertebrate species or species groups were collected with direct diver observation, video, and photographic methods along transects of varying lengths, depths and substrates. Transect sites were randomly selected along the north coast of British Columbia in two areas. Each transect was completed twice by divers, first to record video and still images, and then a second time with data sheets to record observations of habitat, algae and invertebrates. For the direct diver observation and video surveys methods, data were recorded from 1m x 5m quadrats along the transect. Photo surveys used a 0.5m x 0.5m quadrat placed every 5m along the transect. Significant differences were observed between all survey methods in the numbers of invertebrate species observed and between photo and other survey methods in the number of algal species observed. Species counts were greatest with direct observation, followed by video and then photos. We recommend direct diver observation methods be used in favour of video and photo data collection for future DFO SCUBA surveys as they returned a higher mean number of species encounters and required less time and expense to complete.

RESUME

Charles, K.E., Packham, J. Bureau, D., Lessard, J. 2022. A comparison of underwater photo, video and visual survey methods to assess nearshore algae and invertebrate communities. Can. Tech. Rep. Fish. Aquat. Sci. 3446: ix + 37 p.

Ce rapport décrit les résultats et la comparaison de l'application de trois méthodes de d’échantillonnage utilisées dans les milieux sublittoraux. Des observations des caractéristiques de l'habitat et la présence d'espèces ou de groupes d'espèces d'algues et d'invertébrés ont été recueillies à l'aide d'observations directes de plongeurs, de vidéos et de photos le long de transects de longueurs, de profondeurs et de substrats variables. Les sites ont été choisis au hasard le long de la côte nord de la Colombie-Britannique dans deux régions. Chaque transect a été complété deux fois par des plongeurs, d'abord pour prendre des vidéos et des photos, puis une deuxième fois avec des fiches de données pour les observations de l'habitat, des algues et des invertébrés. Pour les méthodes d'observation directe des plongeurs et de relevés vidéo, les données ont été enregistrées à partir de quadrats de 1 m x 5 m le long du transect. Les relevés photographiques ont utilisé un quadrat de 0,5 m x 0,5 m placé tous les 5 m le long du transect. Des différences significatives ont été observées entre toutes les méthodes dans le nombre d'espèces d'invertébrés observées et entre la photo et d'autres méthodes dans le nombre d'espèces d'algues observées. Les dénombrements d'espèces étaient les plus élevés avec l'observation directe, suivie de vidéos puis de photos. Nous recommandons d'utiliser des méthodes d'observation directe par les plongeurs en faveur de la collecte de données vidéo et photo pour les futurs relevés de plongée sous-marine du MPO, car elles ont rapporté un nombre moyen plus élevé d’observations d'espèces et ont nécessité moins de temps et d'argent.

INTRODUCTION

Surveying shallow benthic habitat in British Columbia (BC) is difficult and expensive because of the vast amount of shoreline (>27,000km) and the remoteness of a large portion of the coast. With few exceptions, shallow benthic habitat analyses have been conducted over small spatial extents and at fine scales (Gregr et al. 2013). As a result, a frequent question asked by nearshore biologists in the region is how to make subtidal surveys be as consistent, cost-effective and accurate as possible while trying to maximize spatial coverage. Surveying the nearshore using SCUBA diving is time consuming, has risks associated with conducting field work in remote locations, and is not feasible in all areas of the coast due to access (e.g. high wave/surge areas). On most past dive surveys conducted by Fisheries and Oceans Canada (DFO), data were recorded in-situ by divers on data sheets. There are two disadvantages of this direct observation survey method, 1) you cannot review the accuracy of the observations post-hoc and 2) you cannot record any new observations (e.g., for any additional species or species groups) after the survey is completed. In contrast, data collected using imagery tools (videos and photos) provide a more permanent record that would be available for later scrutiny. This has led to the collection of permanent records of transects through videos/photos in order to address the question whether video/photo would be preferable to SCUBA direct observation surveys in terms of their capacity to identify species presence while considering time and cost efficiency.

In 2013, DFO initiated an ongoing habitat mapping program to survey and map the nearshore on the central and north coast of BC. The purpose of the habitat mapping survey was to document and record algae and marine invertebrate species assemblages in a variety of shallow benthic habitat types. The results of habitat mapping surveys conducted in 2013 to 2015 are described in Davies et al. (2018). As a part of the habitat mapping work, a study was conducted in 2013 to answer the question surrounding the relative effectiveness of different dive survey methods. Dive transects were surveyed with each of three different methods: underwater video (“video”), underwater still images (“photo”) and direct diver observations (“diver”). Relative costs of each method were compared by estimating the dive time and data processing time for each method (video, photo and diver). The total number of algae and invertebrate species observed by each method was used as a measure of effectiveness although other metrics such as percent cover might give different results. The results of this evaluation are the focus of this report.

METHODS

SURVEY METHODS

Two survey areas were selected in BC’s North coast; Principe Channel and Squally Passage (Fig. 1). Because the relationship between substrate type (habitat) and community structure were of interest, the BC Physical Shore-zone Mapping system was used to pre-stratify transect sites so that a variety of substrates would be covered by the survey. Sites were selected within three shore-zone types: rock cliff, rock with gravel beach, and sand flat. For each survey area, a minimum of five sites were randomly chosen from each shore-zone type. However, the coastal class assignment did not always match what was observed in the field, especially for rock with gravel beach, and so the results were not grouped by shore type during analysis. Seventeen transects were completed in Principe Channel and 21 transects were completed in Squally Passage in September, 2013.

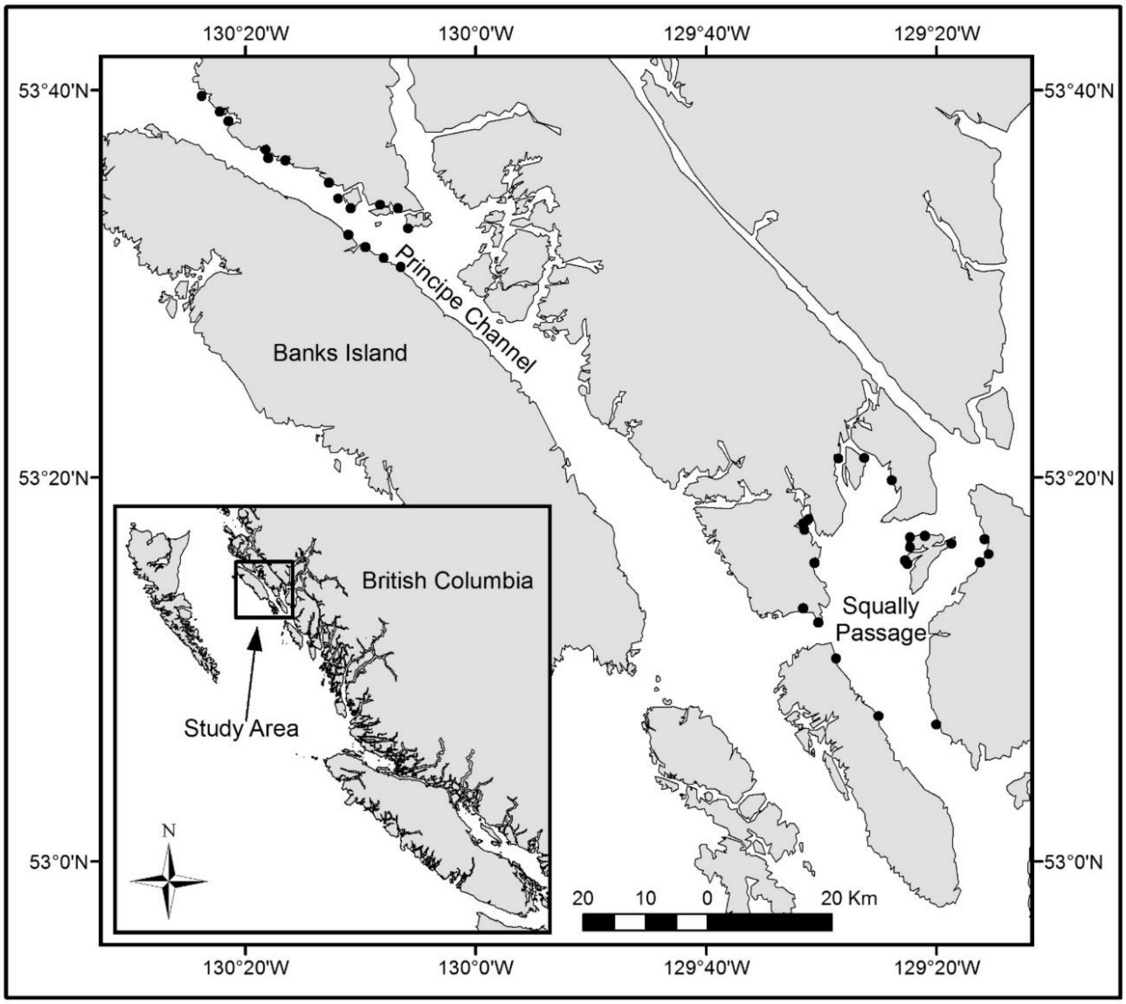


Figure 1. Map of the transect locations in survey areas

At each site, a transect line was deployed from the dive skiff, perpendicular to shore, from shallow water to 18m depth at the given location. A marker float was attached to the deep end of each transect. Transect length was thus dependent on the slope at the site. Transect lines were made of 25m sections of lead-core rope marked every 5m with cable ties and rope sections were connected with c-clips. In cases where transect length exceeded 150m, every second quadrat was surveyed (see Appendix 3 for total surveyed transect lengths). Latitude and longitude of the shallow and deep ends of each transect were recorded from the boat's GPS (Davies et al. 2018).

Each transect was swum twice by experienced SCUBA divers, from deep to shallow, up to 0 foot depth on divers' depth gauges when possible (depending on ocean conditions), first to record the video and capture photos and a second time to record in-situ observations on data sheets (direct diver observations). During the first pass, one diver recorded video for a 1m width along one side of the transect line while the other diver took photographs on the other side of the transect line. The video footage was recorded on a Canon HF G20 digital camcorder equipped with a Raynox 0.7x wide angle conversion lens housed in an Ikelite housing with wide angle port. Lighting was provided by twin Green Force Squid LED 1850 lumen lights powered by Green Force Flexi II batteries, at a cost of approximately $7,000. The still camera system used was a Canon Rebel XT (a.k.a. 350D) digital SLR camera with Canon EF-S 11-22mm wide angle lens, housed in an Ikelite housing with 8" dome port and two Ikelite DS 125 sub-strobes, at a cost of approximately $10,000. Perpendicular still photos were taken of a 50 x 50 cm quadrat placed on the substrate at every 5m mark along the transect (Fig. 2). This quadrat size was chosen to minimize the water distance between the quadrat and the camera to ensure picture clarity. Only one photograph was taken, rather than several within the same 5m length of transect, because the video and photo team had to work at the same pace so as not to stir up the bottom and decrease visibility for the other recording method.

The methodology was such that identical areas were not surveyed for all data types. Figure 2 visually represents the surveyed area for each of the diver, video, and photo methods. While the video and diver methods had comparable quadrat sizes surveyed, the photo survey had a much smaller area captured per quadrat.

During the second pass, one diver recorded algae and substrate data for a 1m width along one side of the transect while the other diver recorded invertebrate data for a 1m width on the other side of the transect (see details below). Dive times for each pass were recorded. Since most of the species of interest in this survey were non-motile or of low motility, perhaps with the exception of a few crab species (e.g. *Metacarcinus magister, Cancer gracilis*), it was assumed that swimming each transect twice would not affect which species would be encountered on the second pass. During the second pass, divers had the opportunity to move aside algae to look for organisms, which wasn't possible with video and photo methods during the first pass.

On the second pass, the video survey side of the transect was swum by the diver recording substrate and algae and the photo survey side by the diver recording invertebrate species. For this reason, the algae data from the video method was considered comparable with direct diver observations for a given transect and the invertebrate data from the photo method was considered to be comparable to the direct diver observations for a given transect. However, since the data were only presence information, and not counts, and each side of the transect was immediately adjacent to the other, the species composition was assumed to be similar on either side of the transect line. Therefore, substrate, algae and species data were assumed to be comparable by the different survey methods across all transects.

For the direct diver observation method, one diver recorded depth, time, three dominant substrate types and their percentage, and noted presence data for 59 species or species groups of algae (Davies et al. 2018). Algae that could not be reliably identified to species underwater were identified to genus or by a combination of colour (brown, green or red) and morphology (foliose, branched or filamentous), or a single code was used for similar looking species or genera (e.g., *Cryptopleura sp*. and *Polyneura sp*.), which increased the number of possible algae codes to 70 (Appendix 1). The percent cover of all species of algae combined were recorded, within the following categories: canopy (>2m), understory (30cm to 2m), turf (0 to 30cm) and encrusting. The total percent cover per quadrat could be over 100% because of the layering of algae of the different categories.

The second diver recorded the presence of 102 benthic marine invertebrate species/groups (Davies et al. 2018). In addition, relative abundances were recorded for a subset of 15 target invertebrate taxa; however, only presence data were used for our analyses. The invertebrate species/groups list was selected prior to the survey with the following considerations: 1) the list needed to be manageable by divers and so was restricted to approximately 100 species/groups, 2) species/groups needed to be readily identifiable underwater by divers, and 3) divers with various levels of taxonomic expertise needed to be able to identify selected species/groups accurately. Invertebrate species and groups identified within the 2013 survey are listed in Appendix 2.

Of the 38 transects surveyed in the field, 17 were randomly selected for video and photo annotation the following year. Each of the videos and photos were viewed separately for invertebrate and habitat/algae data. Corresponding data sheets filled in, without the use of any digitizing software, by a technician who had experience as one of the divers in the 2014 version of the survey. Video and photo transects excluded from the survey were used as learning tools prior to beginning the photo and video review. Field protocol was followed as closely as possible and the same data sheets and species lists were used as for the diver visual survey. To assess the consistency of the annotation, nine video and eight photo transects were re-annotated 5 to 8 years after the photos and videos were recorded by two different annotators who were divers with significant experience with diving in this series of surveys, one of whom had been part of the 2013 survey. The same method was used as in the initial annotation except that the lab time taken for the second group of annotators to view the photos and videos and fill in the data sheets was also recorded and subsequently extrapolated to calculate additional lab time requirements. The smaller data set from the second, more experienced group of annotators was then compared with the original diver data.

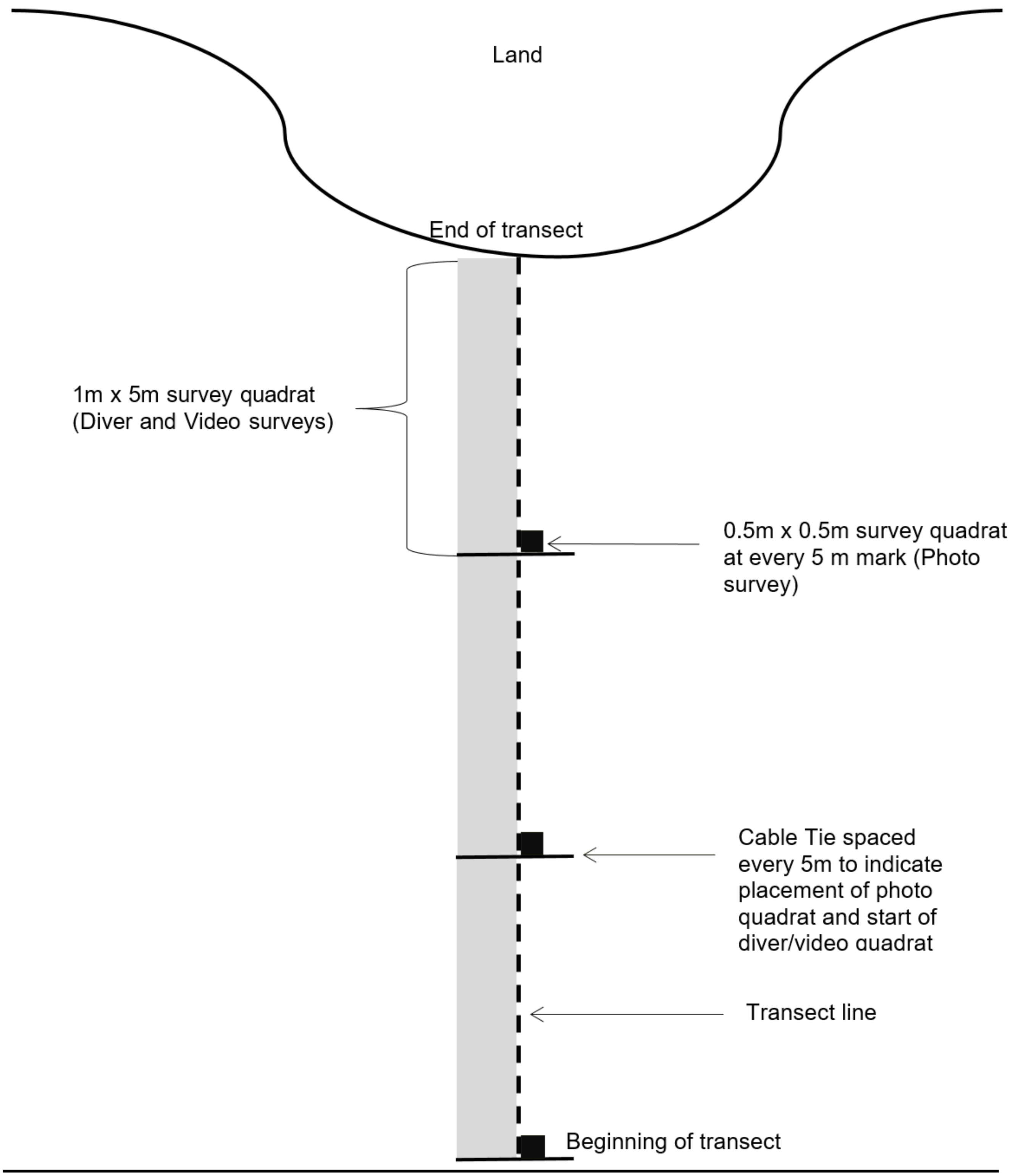


Figure 2. Diagram representing survey area for diver, video, and photo survey methods.

ANALYTICAL METHODS

All data were entered into an Access database. Depth data were corrected for tide height. Statistical analyses were subsequently performed in version 4.0.2 of R with the RStudio user interface.

We tested the null hypothesis that there was no difference in dive times between methods using a paired T-test. Dive times from 30 sets of dives were used (Appendix 6). A set represented the dive times from the first pass (video/photo) and the second pass (direct diver observation) of the transects.

The total data collection time required for photo and video methods were estimated based on the amount of time needed for imagery annotation by our second group of annotators for 8 transects (Appendix 3) compared with the relative duration it took divers to complete the second pass (direct diver observation) for those same transects (Appendix 5). Direct diver observation dive times (as well as video/photo recording dive times) were multiplied by 2 since there were two divers; one on either side of the transect line. Since data from all three survey methods were recorded on the same type of form, the data entry times were expected to be the same regardless of the method and thus were not considered in the comparison.

Species data were initially grouped for analyses by transect for each survey method and species type (algae or invertebrate). Substrate category was summarized using categories defined by Gregr et al. (2013) (Table 1). Quadrats within each transect were then assigned to substrate and depth categories. Species data were subsequently grouped by category within each transect for more detailed analysis, so that the number of comparisons among category groupings was determined by the number of transects containing that category.

Table 1. Classification breakdown for survey method, species type, substrate category (Gregr et al. 2013), and depth category.

Survey Method	1: Diver Observations (1m x 5m) 2: Video Footage (1m x 5m) 3: Still Photos (0.5m x 0.5m)
Species Type	Algae Invertebrates
Substrate Category	1a: Hard, bedrock dominant 1b: Hard, boulder dominant 2a: Mixed, dominantly soft with patchy cobble and/or gravel 2b: Mixed, sand to pebbles 3a: Soft, shell to sand 3b: Soft, mud
Depth Category	0: Intertidal 1: 0m – 5m 2: 5m – 10m 3: 10m – 20m

The total number of invertebrate and algae species in each transect, depth category, and substrate category were calculated (Appendices 3 and 4). Since the data were presence, each record could represent multiple individuals.

The number of transects annotated for our method comparison was less than 30, as were the number comparisons between categories, so non-parametric tests were applied to species data, using the “tidyverse”, “ggpubr”, and “rstatix” packages in R. Friedman analyses of variance were used to compare the total number of species recorded by transect, depth category and substrate type among survey methods. Wilcoxon signed rank tests were then used to test for differences between pairs of survey methods. Due to the paired nature of the Wilcoxon tests, zeros were used where null values existed in some of the depth category comparisons. The null hypothesis in all cases was that there was no difference between methods. The Wilcoxon test included a Bonferroni adjustment because there were multiple comparisons made within the same dataset. The p values from the Bonferroni adjustment were used for inference, but the p values without the adjustment are included for reference. Note that the Bonferroni correction is a conservative adjustment to reduce the likelihood of making a type 1 error (finding a significant difference when one does not actually exist). Graphs showing results were generated using the “ggplot2” and “reshape2” packages in R.

To assess whether our results were sensitive to the selection of annotators, we subsequently compared annotations among annotators (see survey methods section above) for identical transects where overlap existed (eight transects for photos and nine transects for videos). A Wilcoxon signed rank test on paired samples was performed to compare the total number of invertebrate and algae species identified per transect between annotators. The time to complete the annotation work was only recorded by the second group of annotators, thus no comparison of efficiency could be made between annotators on the basis of experience.

Further, a Wilcoxon signed rank test on paired samples was performed to compare the total number of invertebrate and algae species identified on photo and video by the experienced annotators compared to the diver data for the same transects. Since the data available annotated by our experts were for fewer transects than the work conducted by the original annotator, and were limited to only one of the two survey areas studied, the original video and photo annotation data was used for our analysis of depth and substrate categories and for constructing the species accumulation curves.

Combined invertebrate and algae species lists from all survey methods and areas were exported from Access and transformed into species by transect matrices created using “dplyr” and “reshape2” packages in R. Species accumulation curves were then generated using the “vegan” package in R.

RESULTS

GENERAL TRENDS

Transects used in our comparison ranged in total length from 20 m to 265 m (Appendix 3), with an average length of 72.6 m. Quadrats were surveyed from 4 m above Chart Datum to 17 m below once tide corrections were applied (Appendix 3).

Dive times required to complete 30 of the transects for photo/video surveys ranged from 9 to 45 minutes per transect, with an average dive time of 22.1 minutes, while visual diver survey times for the same transects ranged from 11 to 51 minutes, with an average of 23.8 minutes per transect (Appendix 6). There was no significant difference in field times required to complete the photo/video and visual survey dives (Paired T-test, t= -1.2733, df=29, p=0.213).

It took nearly the same amount of time to annotate the photos and videos for the eight transects our experts analysed for the annotator comparison as it did for the divers to swim the same transects for the direct diver observation survey (0.78 times for photos and 0.93 times for video; see Appendix 5 for details). The total direct diver observation time for the two areas in this survey was 1,490 minutes (24.8 hours). Based on the expert annotation times, if all the transects had been annotated, it would have required 1,162 minutes (19.4 hours) of photo annotation or 1,386 minutes (23.1 hours) of video annotation post-survey in addition to the dive time spent collecting the photos and video recordings (25.1 hours).

A Friedman analysis of variance comparing the total number of species per transect by survey method indicated that there was a significant difference between survey methods for both invertebrates (F_r=31.4, n=17, df=2, p<0.0001) and algae (F_r=10.9, n=17, df=2, p=0.0044). Wilcoxon signed rank tests applied to data pairs found significant differences between all survey methods for invertebrates and between photo surveys and diver as well as between photo and video surveys for algae (Table 2, Fig. 3).

Table 2. Summary of Friedman ANOVA and Wilcoxon signed rank tests for total numbers of algae and invertebrate species per transect for each survey method.

				Algae			Invertebrates		
Level	**Test**	**Survey group**	**n**	**Test Statistic**	**p value**	**p adj. value Bonferroni**	**Test Statistic**	**p value**	**p adj. value Bonferroni**
Totals	Friedman	all; df =2	17	Fr = 10.9	**0.0044****		Fr = 31.4	**0.0000****	
	Wilcoxon	diver-video	17	W = 57	0.438	1	W = 117	**0.001****	**0.004****
		diver-photo	17	W = 130	**0.013***	**0.038***	W = 153	**0.000313****	**0.000939****
		video-photo	17	W = 104	**0.001****	**0.004****	W = 153	**0.000295****	**0.000885****

* 0.05 level of significance, **0.01 level of significance. Wilcoxon p values include a Bonferroni adjustment.

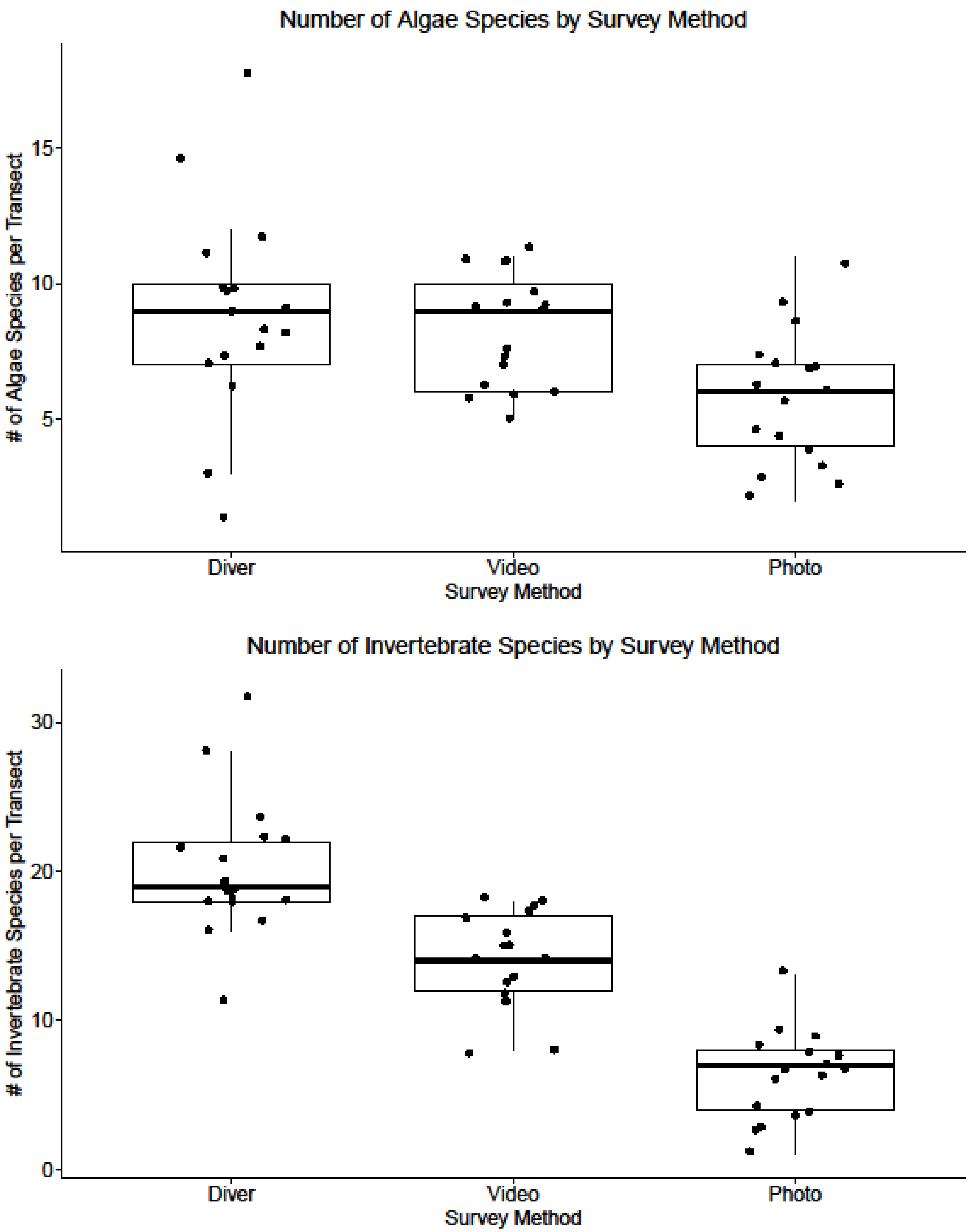


Figure 3. Boxplots of numbers of algae and invertebrate species recorded based on survey method. For each boxplot, the thick line in the box corresponds to the median and the 25% and 75% quartiles are denoted by the upper and lower limits of the box. Points are values from each transect; n=17.

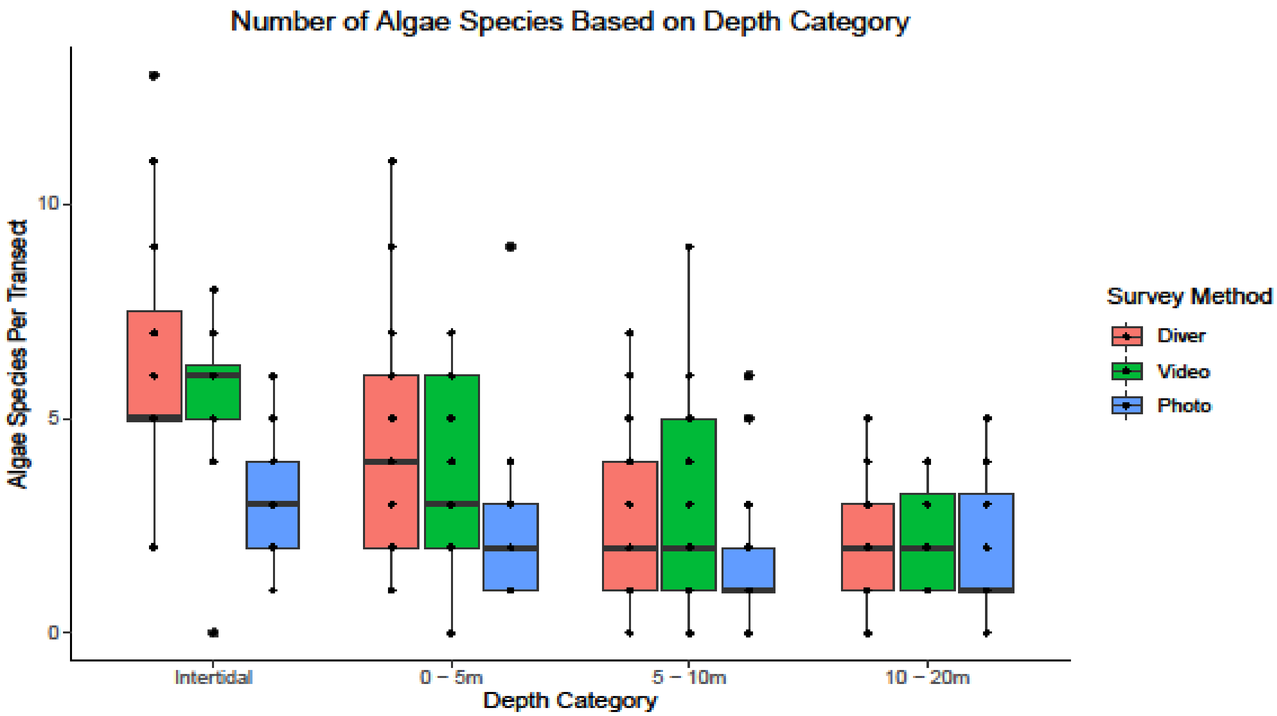
DEPTH CATEGORY

A Friedman analysis of variance comparing the total number of species counted per transect per depth category across survey methods indicated that there were significant differences between survey methods for algae in the two shallowest depth categories and for invertebrates in all depth categories (Table 3). Subsequent Wilcoxon signed rank tests showed significant differences in depth category 0 between diver-photo and video-photo surveys for algae, and between all categories for invertebrates. In depth category 1, there was significant difference between diver-photo methods for algae and between all survey methods for invertebrates. Depth category 2 had no significant differences among methods for algae and but had significant differences between all methods for invertebrates. Depth category 3 had no significant differences between methods for algae, and significant differences between diver-photo and video-photo surveys for invertebrates (Table 3, Fig. 4).

Table 3. Summary of Friedman ANOVA and Wilcoxon signed rank tests for total numbers of algae and invertebrate species per transect by survey method based on depth category.

				Algae			**Invertebrates**		
Depth Category	**Test**	**Survey group**	**n**	**Test Statistic**	**p value**	**p adj. value Bonferroni**	**Test Statistic**	**p value**	**p adj. value Bonferroni**
0	Friedman	all; df =2	12	Fr = 13	**0.00147****		Fr = 16.0	**0.000328****	
Intertidal	Wilcoxon	diver-video	12	W = 36	0.407	1	W = 73.5	**0.007****	**0.022***
		diver-photo	12	W = 76	**0.004****	**0.012***	W = 66	**0.004****	**0.011***
		video-photo	12	W = 2.5	**0.004****	**0.013***	W = 1.5	**0.009****	**0.026***
1	Friedman	all; df =2	17	Fr = 12.9	**0.00159****		Fr = 30.7	**2.11 e^-7****	
0m - 5m	Wilcoxon	diver-video	17	W = 71	0.076	0.229	W = 136	**0.000471****	**0.001****
		diver-photo	17	W = 83	**0.009****	**0.028***	W = 153	**0.000308****	**0.000928****
		video-photo	17	W = 18.5	**0.034***	0.102	W = 5	**0.002****	**0.006****
2	Friedman	all; df =2	17	Fr = 4.41	0.11		Fr = 25.1	**0.00000361****	
5m - 10m	Wilcoxon	diver-video	17	W = 43.5	0.914	1	W = 71	**0.0130***	**0.04***
		diver-photo	17	W = 68.5	0.111	0.333	W = 153	**0.000315****	**0.000945****
		video-photo	17	W = 2.5	**0.019***	0.058	W = 1.5	**0.000617****	**0.002****
3	Friedman	all; df =2	16	Fr = 2.51	0.285		Fr = 22.9	**0.0000107****	
10m - 20m	Wilcoxon	diver-video	16	W = 43	0.549	1	W = 44	0.944	1
		diver-photo	16	W = 52.5	0.299	0.897	W = 105	**0.001****	**0.003****
		video-photo	16	W = 12.5	0.13	0.39	W = 0	**0.00046****	**0.001****

* 0.05 level of significance, **0.01 level of significance



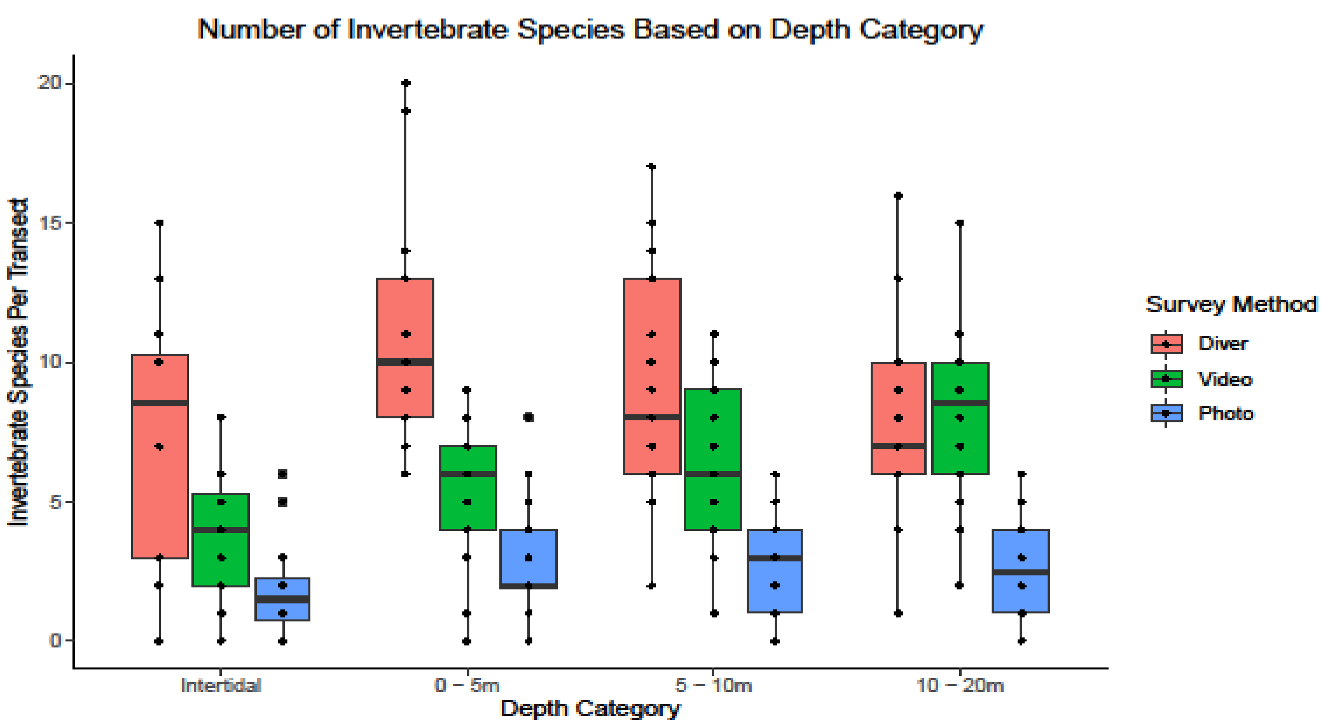


Figure 4. Boxplots of numbers of algae and invertebrate species recorded based on survey method according to depth category. For each boxplot, the thick line in the box corresponds to the median and the 25% and 75% quartiles are denoted by the upper and lower limits of the box. Points show range of data; some points are superimposed on others.

SUBSTRATE TYPE

Substrate type varied within transects. Similar to the depth categories analysis, transects were subdivided into substrate types for analysis. A Friedman analysis of variance comparing the total number of species counted per substrate type per transect across survey methods indicated that there were significant differences between methods within some substrate types for both invertebrates and algae. Differences between methods in the number of species were found in categories 1a, 2a, and 2b for algae and in categories 1a, 1b, and 2b for invertebrates (Table 4). Subsequent Wilcoxon signed rank tests found significant differences between the diver-photo and video-photo methods in the number of algae species recorded in substrate category 1a (Table 4), but no significant differences in the number of algae species recorded in other substrate categories. There were significant differences between all survey methods in substrate category 1a for invertebrates. In substrate category 1b, there was significant difference between photo and diver methods and between photo and video methods for invertebrates, but no difference between diver and video methods. There were no significant differences between survey methods in number of invertebrate species recorded for substrate categories 2a, 2b, 3a and 3b (Table 4, Fig. 5). Note that the sample size for substrate 3b was too small to make any meaningful comparisons, and that only divers identified substrate 2b in their records (Appendix 4).

Table 4. Summary of Friedman ANOVA and Wilcoxon signed rank tests for total numbers of algae and invertebrates per transect by survey method based on substrate type components within each transect.

				Algae			Invertebrates		
Substrate Type	**Test**	**Survey group**	**n**	**Test Statistic**	**p value**	**p adj. value Bonferroni**	**Test Statistic**	**p value**	**p adj. value Bonferroni**
1a	Friedman	all; df =2	15	Fr = 17.2	**0.000186****		Fr = 22.8	**0.000011****	
	Wilcoxon	diver-video	15	W = 92.5	0.064	0.192	W = 99	**0.004****	**0.011***
		diver-photo	15	W = 104	**0.001****	**0.004****	W = 119	**0.000883****	**0.003****
		video-photo	15	W = 78	**0.002****	**0.007****	W = 91	**0.002****	**0.005****
1b	Friedman	all; df =2	14	Fr = 1.42	0.491		Fr = 7.58	**0.0225***	
	Wilcoxon	diver-video	14	W = 27	0.621	1	W = 51.5	0.109	0.327
		diver-photo	14	W = 56.5	0.46	1	W = 95.5	**0.008****	**0.023***
		video-photo	14	W = 79	0.1	0.3	W = 91	**0.017***	**0.05***
2a	Friedman	all; df =2	6	Fr = 9.1	**0.0106***		Fr = 4.3	0.116	
	Wilcoxon	diver-video	6	W = 0	**0.026***	0.079	W = 4	0.203	0.609
		diver-photo	6	W = 4	0.773	1	W = 5	0.423	1
		video-photo	6	W = 15	0.054	0.164	W = 15	0.059	0.177
2b	Friedman	all; df =2	6	Fr = 12	**0.00248****		Fr = 12	**0.00248****	
	Wilcoxon	diver-video	6	W = 21	**0.034***	0.068	W = 21	**0.035***	0.071
		diver-photo	6	W = 21	**0.034***	0.068	W = 21	**0.035***	0.071
		video-photo	6	W = 0	N/A	N/A	W = 0	N/A	N/A
3a	Friedman	all; df =2	13	Fr = 1.68	0.433		Fr = 4.87	0.0876	
	Wilcoxon	diver-video	13	W = 10.5	0.159	0.477	W = 31	0.34	1
		diver-photo	13	W = 20.5	0.776	1	W = 57	**0.036***	0.109
		video-photo	13	W = 33.5	0.21	0.63	W = 75.5	**0.038***	0.115
3b***	Friedman	all; df =2	2	Fr = 1	0.607		Fr = 2	0.368	
	Wilcoxon	diver-video	2	W = 1	1	1	W = 1	1	1
		diver-photo	2	W = 2	1	1	W = 1	1	1
		video-photo	2	W = 0	1	1	W = 0	N/A	N/A

* 0.05 level of significance, **0.01 level of significance. Wilcoxon p values include a Bonferroni adjustment.
***Note that sample size for category 3b is too small to provide meaningful results. ****Note that some substrate categories were not recorded by all survey types. A "0" was used in this case for the analysis to make Wilcoxon paired sample tests viable.

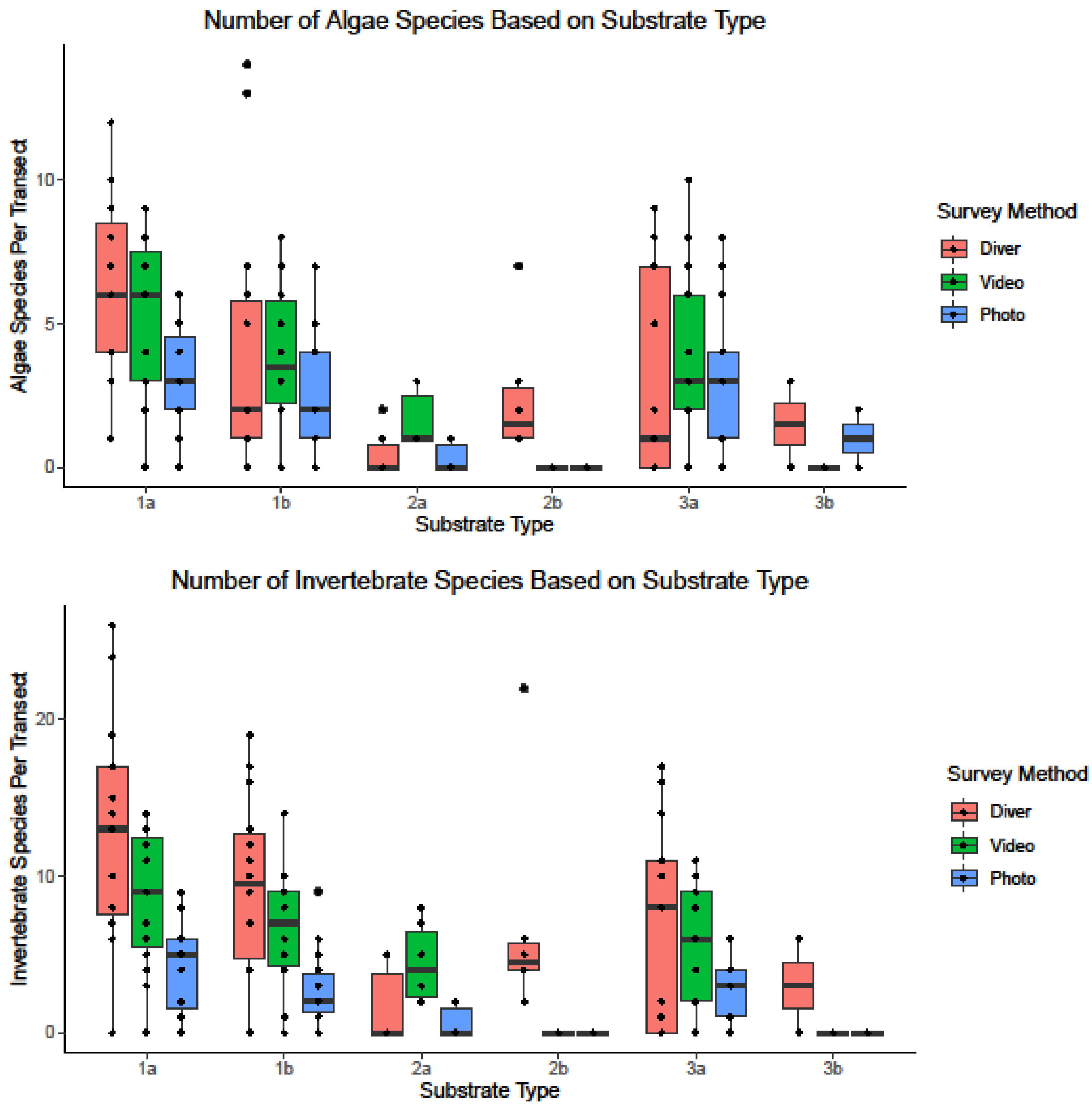


Figure 5. Boxplots of numbers of algae and invertebrate species recorded based on survey method according to substrate type. Substrate types are as follows: 1a: hard, bedrock dominant, 1b: hard, boulder dominant, 2a: mixed, dominantly soft with patchy cobble and/or gravel, 2b: Mixed, sand to pebbles, 3a: soft, shell to sand, 3b: soft, mud. For each boxplot, the thick line in the box corresponds to the median and the 25% and 75% quartiles are denoted by the upper and lower limits of the box. Points show range of data; some points are superimposed on others.

ANNOTATOR BIAS

Wilcoxon signed rank tests on paired samples were performed on the photo data for eight transects and for video data for nine transects of the same footage annotated by annotators with different levels of scientific diving and thus species identification experience. The experienced annotators were the second group who had viewed the photos/videos and both had several years of experience diving in this specific survey series. Experienced scientific divers acting as annotators documented significantly more species per transect than inexperienced annotators. There were significant differences observed in the total number of species recorded per transect in the photo data for both algae and invertebrates. Significant differences were also observed in the total number of algae species recorded per transect in the video data for both algae and for invertebrates (Table 5, Fig. 6).

Table 5. Wilcoxon paired sample test results for total numbers of algae and invertebrates per transect for experienced vs. new annotator.

				Algae		Invertebrates	
Level	**Test**	**Comparison**	**n**	**Test Statistic**	**p value**	**Test Statistic**	**p value**
Totals per Transect	Wilcoxon	Experienced vs. new, photo	8	V=0	**0.02014***	V=0	**0.01391***
	Wilcoxon	Experienced vs. new, video	9	V=0	**0.009****	V=3.5	**0.02812***

*0.05 level of significance, **0.01 level of significance

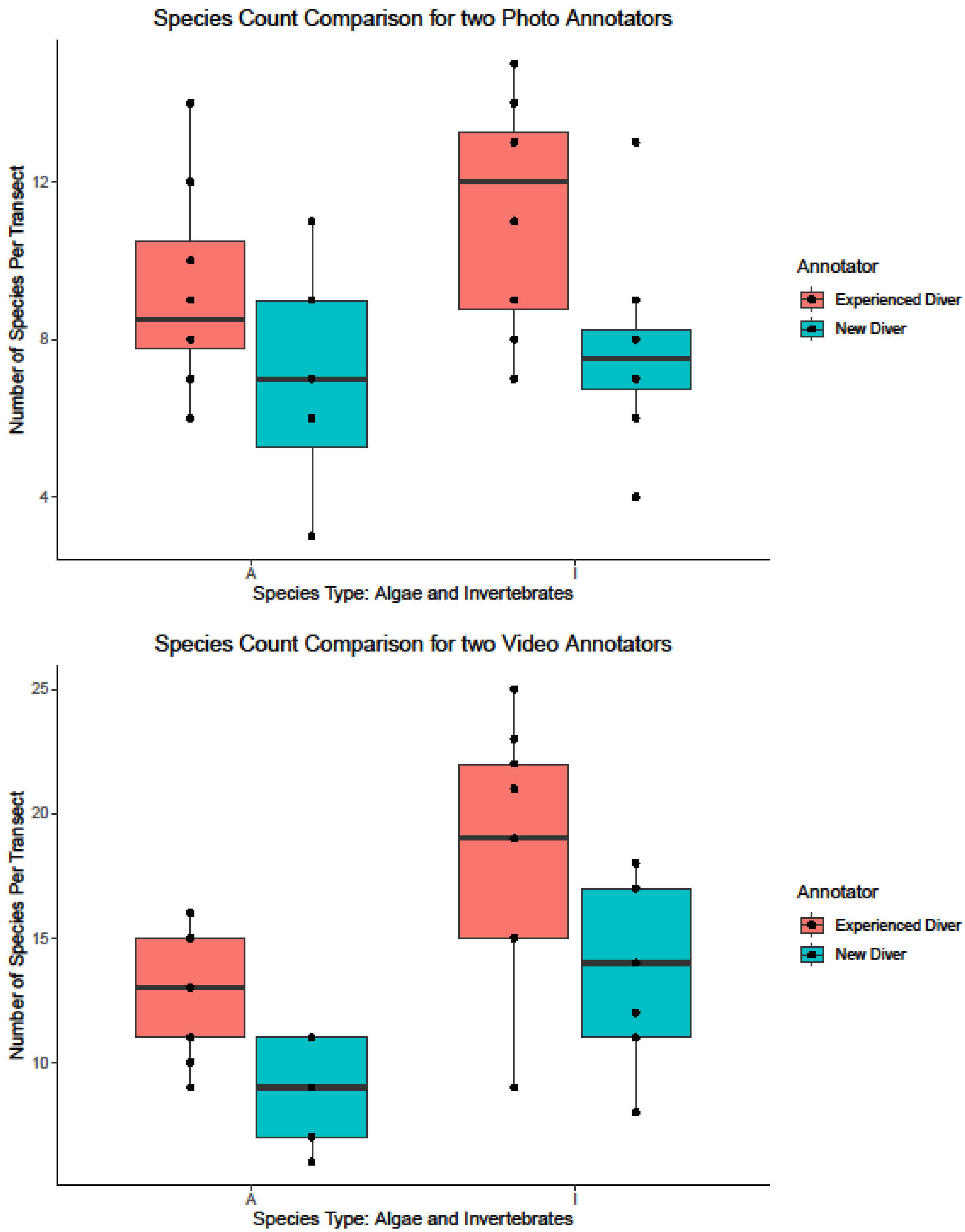


Figure 6. Comparison of number of algae (A) and invertebrate (I) species documented for the same transects by two photo and by two video annotators with different levels of diving experience. For each boxplot, the thick line in the box corresponds to the median and the 25% and 75% quartiles are denoted by the upper and lower limits of the box. Points show range of data; some points are superimposed on others.

We subsequently used only our second, smaller data set annotated by our experts to compare with the identical diver transects to see how data from annotators who had dived on multiple surveys would compare with diver data from the first survey conducted. With regards to the photo data, a significantly higher number of invertebrates was detected by divers, but a significant difference was not detected for algae (Table 6, Fig. 7). In the video data, the annotator detected significantly more algae species per transect than did the divers, but there was no significant difference detected between diver and video for invertebrates (Table 6).

Table 6. Wilcoxon paired sample test results for total numbers of algae and invertebrates per transect for expert annotator vs. diver data.

				Algae		**Invertebrates**	
Level	**Test**	**Comparison**	**n**	**Test Statistic**	**p value**	**Test Statistic**	**p value**
Totals per	Wilcoxon	diver-photo expert	15	V=46.5	0.9719	V=120	**0.0007****
Transect	Wilcoxon	diver-video expert	9	V=3.5	**0.0491***	V=3.4	0.1913

*0.05 level of significance, **0.01 level of significance

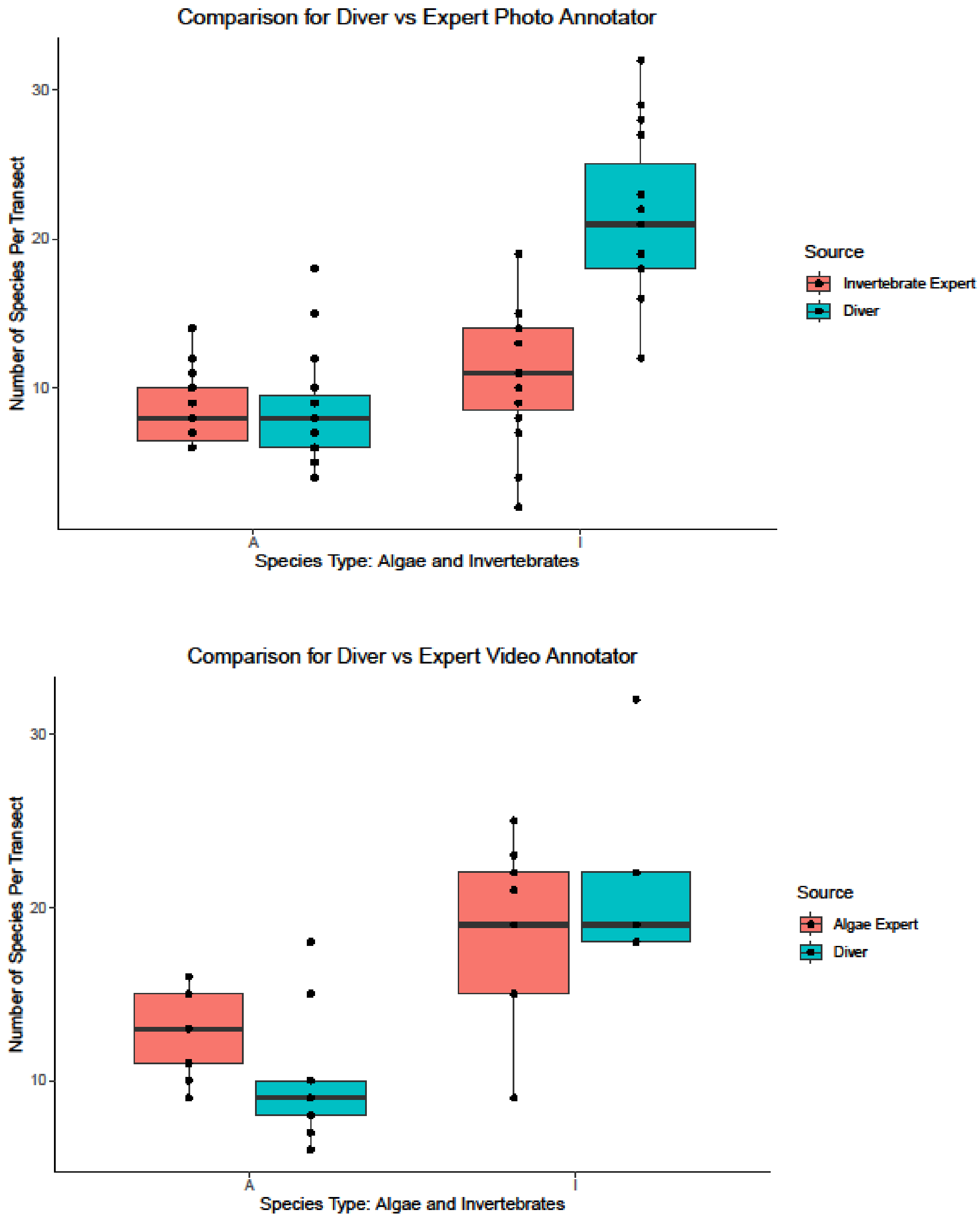


Figure 7. Comparison of number of algae (A) and invertebrate (I) species documented for the same transects by one video and one photo annotator with high expertise compared with the diver data. For each boxplot, the thick line in the box corresponds to the median and the 25% and 75% quartiles are denoted by the upper and lower limits of the box. Points show range of data; some points are superimposed on others.

SPECIES ACCUMULATION CURVES

Species accumulation curves were constructed, for algae and invertebrate species combined, using the 17 transects sampled by all methods in order to see whether similar trends existed (Fig. 8). Few additional species were detected after approximately ten transects for the photo and video survey. The total number of species detected was also lower on the photo and video surveys than on the diver survey. The diver survey had the most species detected, but did not reach the number of species on the target list. This indicates that some species on the target list were never seen on the 2013 transects, likely due in part to a relatively small sample size and also maybe because not all habitats were surveyed.

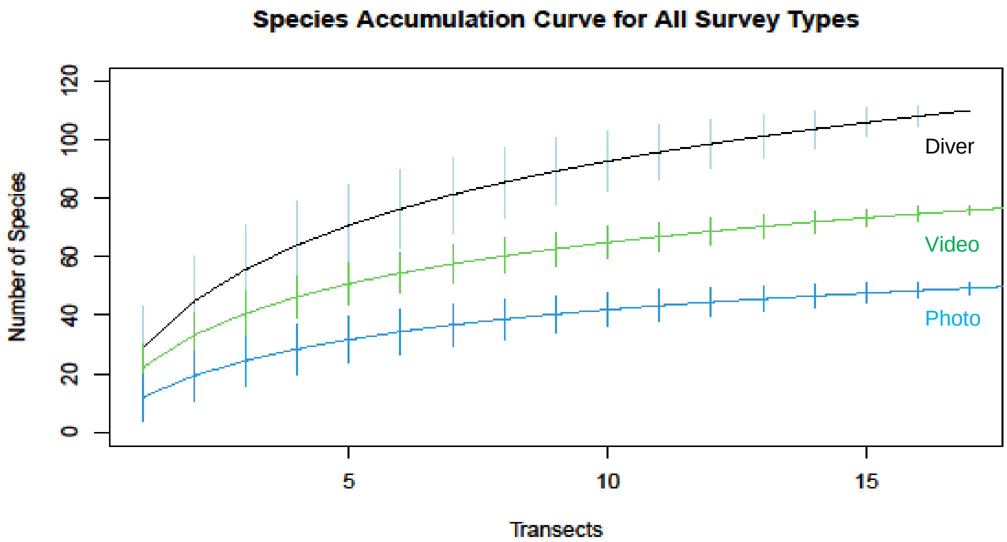


Figure 8. Species accumulation curves for algae and invertebrates combined for different survey methods where # of transects = 17. Vertical lines indicate confidence intervals based on the standard error of the estimate. The Y axis denotes the cumulative number of species observed.

A species accumulation curve for both algae and invertebrate species, which incorporates all the transects completed by the diver survey in the two survey areas is shown in Figure 9. The number of species detected was not significantly different in the two areas, although a comparison of species composition was not made. Species accumulation curves subdivided into the two geographical areas show a similar initial trend in the two areas, although the Principe Channel curve has a slightly steeper initial increase in species number compared with the Squally Channel curve. The Principe Channel curve appears to start leveling off sooner, with the Squally Passage curve continuing to increase (Fig. 9). This suggests that species richness and homogeneity may be different in the two areas and that more transects may be needed to capture the full species assemblage depending on the habitat diversity of a given area.

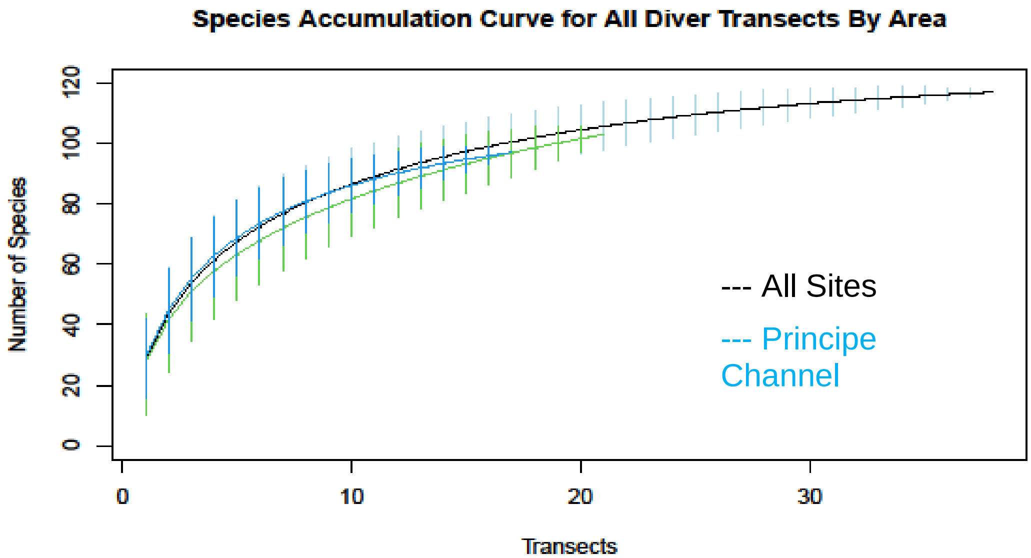


Figure 9. Species accumulation curve for algae and invertebrates combined for diver survey for all transects sampled within the two areas, where # of transects = 38 total; 17 for Principe Channel and 21 for Squally Passage. Vertical lines indicate confidence intervals based on the standard error of the estimate. The Y axis denotes the cumulative number of species observed.

DISCUSSION

Studies comparing the use of visual survey methods related to temperate nearshore invertebrates and algae are rare – with the exception of Leonard and Clarck (1993) - most comparative studies are conducted in coral reefs (Mantellato et al. 2013 and references within) or deep ecosystems (Dunham et al. 2018; Bethoney et al., 2019). Our results indicate that direct observation by divers is more efficient than through annotation of video and photos for presence/absence species detection, especially for invertebrates. The comparison in the annotations between new and experienced biologists/divers suggest that training, and perhaps diving experience, are important in order to detect all species on the target list. However, no method detected all the species on the target list which could be because sample size was small or that not all habitats were sampled during this survey so detection of some rare species was unlikely.

The field time required to complete the three different survey methods in this study was not statistically different between methods. This is in contrast to other studies which have reported visual direct observation surveys taking longer to complete than photo or video surveys (Mantellato et al. 2013 and references within). Additional processing time is required to annotate photo and video data. In this study, approximately the same amount (0.93) of time as the dive time required for the diver observation method was required to annotate video data and 0.78 of the diving time required for the diver observation method was required to annotate photo data (Appendix 5). Two divers are required on each dive for safety reasons to make the photo or video recording and each recording must be viewed twice by the annotator - once for invertebrates and once for algae. Our results are relatively conservative compared with Tissot (2008), who noted that video analysis could take 5 to 10 times longer than the time required to make the video recording from a submersible. Mantelatto et al. (2013) found in their invasive coral study that visual census compared with photo and video surveys required the least amount of time to conduct once post-processing time was factored in. Magorrian and Service (1998) and Leonard and Clark (1993) also noted substantial additional time processing video/images as well as additional costs in procuration and maintenance of photographic equipment and digitising software. Photographic and video methods also require additional time in the field to download images/videos, charge batteries and put the equipment back together for the next day.

The three types of survey methods in our study produced different qualities of data. Based on the initial larger set of annotated photo/video data, the diver surveys outperformed both other survey methods in detecting invertebrates (Table 2, Fig. 3), although video and diver surveys produced comparable results in detecting algal species/groups, except at shallower depths where algae tends to be more abundant and species rich. The photos were the least effective method at detecting organisms. Despite the high resolution image available, photographs covered a much smaller area per quadrat compared with diver and video methods (Fig. 2), and obscuring algae could not be moved aside, which predictably led to significantly less understory algal and invertebrate species being recorded. As Parravicini et al. (2009) noted in their study of Mediterranean rocky reef areas, increasing the number of photographs in sampling protocols would increase accuracy, but this would require considerably more field effort for image procurement and annotation time. Annotators in this study noted that the low resolution of video limited the detection and identification of small animals and algal species, as documented by Edmunds et al. (1998) and Leujak and Ormond (2007). Leonard and Clarke (1993) in their study of temperate red algae noted that video was not adequate to differentiate between species, which could be only be identified by close examination of specimens. Most studies examining coral reef composition and recruitment found that diver visual surveys outperformed photo and video surveys in terms of data quality (Burgess et al., 2010; Edmunds et al., 1998; Leujak and Ormond, 2007; Mantelatto et al., 2013). However, Dumas et al. (2009) in their study of habitat structure and Deter et al. (2012) in their study of vertical distributions in corals found photographs to be adequate for their needs, noting however, that rare organisms might be missed by still photos.

Unsurprisingly, depth and substrate both had an effect on the number of species detected by each method based on our initial, larger annotated data set. The higher abundance of algae found at shallower depths can obscure invertebrates and smaller algae in photographs and video, but can be moved aside by divers. The photo survey consistently returned significantly fewer numbers of invertebrate species than other survey methods in all depth categories. While this was due in part by the small quadrat size of the photo method, fewer invertebrates where detected in the video as well when compared to diver observations. This finding suggests that video methods could be a useful tool in documenting deeper water invertebrate assemblages, for example in depths that are beyond the range for safe diving, where algae cover is lower and water clarity is often better.

Differences were also notable among the number of invertebrate species recorded in hard rocky substrates between all survey methods (Table 4, Fig. 5). This is likely due to the fact that algae are abundant in these environments and obscure invertebrates in photos and videos and also because bedrock and boulder habitat are more structurally complex than finer substrates. The complex substrate creates habitat for more species than the simpler substrate types and specimens that would be seen by a diver could be missed in photographs or video recordings because the organisms are hidden under or behind rocks.

In addition to species detection, substrate type was also affected by obstruction by algae cover in photos and videos. Divers and the initial video and photo annotator did not consistently identify the same substrate types. There were substrate type categories which were detected by one method but not by the others; for example substrate types 2b and 3b were only recorded by divers (Appendix 4).

There are additional constraints that we found in our study with photo and video methods compared with direct diver observation methods. Annotators' ability to detect and identify organisms is highly dependent on their ability to identify organisms based on partial glimpses, which is only gained through experience in the field. Divers are able to identify objects that are too small to detect on photos and videos and are able to move algae that is obscuring organisms to clarify identification. Therefore, while it is possible to obtain high quality invertebrate and algae data from nearshore video surveys, it would be difficult for an annotator to obtain the species identification experience required without the practice gained from participating in dive surveys using direct observation methods. Annotators watching video have a limited ability to detect differences between some species and are unable to properly sample layers within a kelp forest. In physically complex habitats, depth-of-field is a limitation because the entire quadrat area cannot be in focus. The distance of the camera from target organisms affects whether or not they are in focus. Technical problems with video equipment resulted in loss of data for one transect when the lighting system failed, affecting the ability of the annotators to identify organisms. In areas of high algal cover, the substrate is not visible, resulting in missing data (e.g. substrate) and associated invertebrates can be completely hidden. The ability to detect small and/or cryptic species is reduced with photographic and video methods compared to visual surveys as is the ability to tell whether gastropods, barnacles and tube worms are alive or dead. Buried bivalves, such as geoducks, horse clams, and cockles appear similar on film but can be distinguished by divers in the field based how they respond to touch. Differentiating between attached and drift algae species is difficult with photo/video methods, and the inability to handle algae on photos and videos makes identification of similar-looking species uncertain. Algal canopy cover cannot be estimated from photographs or video because the camera is aimed downwards at the substrate where the majority of invertebrates and algal species are located. The swimming speed of the video operator can also affect the interpretation of the video footage because organisms cannot easily be identified if they are not captured on video for an adequate length of time since images are blurry when paused. The visibility levels in the water affect the efficiency of the lighting system because suspended particles can reflect light, further exacerbating the issue of discernibility. As a result, video can only be recorded within certain visibility levels. Capturing steady video and or ensuring photos are in focus is especially challenging when working in high surge conditions.

In addition to the field technical limitations of video and photo surveys, as technology evolves, keeping visual records current and useable can be a challenge, as older footage may not be compatible with future hardware or software and can get lost or corrupted. Video footage requires extensive post-survey processing (Leonard & Clark, 1993) and as a result, time and resource constraints for the annotation of filmed footage can delay the availability of survey results. Digital video files are also very large and require significant storage space, creating additional data management needs. Some invertebrates have annual migrations and algae have distinct growing seasons. If the purpose of video documentation is to have a time series for future reference, considering spatial and seasonal variation of target organisms and what information is required are essential for planning visual surveys (Schoening et al. 2017, Tissot 2009).

Other photographic acquisition techniques exist that do not require divers. Small drop cameras have been used for substrate mapping at depths of up to 60 m to extend the reaches of dive surveys (Davies et al. 2018). Work using small drop cameras as a means of assessing invertebrate populations has been undertaken by Bethoney et al. (2019) for scallops and Rooper et al.(2021) for abalone. For marine invertebrate assessments, small drop cameras were suggested (Davies et al. 2018) as a means to supplement dive surveys rather than as a replacement. The relatively small quadrat size associated with drop cameras requires that large number of sample photos be taken to effectively sample populations (Bethoney et al. 2019). Rooper et al. (2021) were only able to use about 2% of the photos they collected due to issues with lighting or camera placement, as well as problems with kelp fronds obscuring the images. Areas with high algal cover would be extremely challenging to survey with this method because the drop camera could easily become entangled in algae, algae would likely obscure many images, and because the camera would not be able to effectively capture different algal layers in addition to organisms inhabiting the substrate.

The use of Remotely Operated Vehicles (ROV’s) or small Autonomous Underwater Vehicles (AUV’s) has been suggested as a way to decrease diver time and still gather video footage (Perkins et al. 2016). These technologies have been successfully used to monitor deep water eelgrass beds (Yamamuro et al. 2003) and burrowing megafauna in unvegetated muddy substrates (Parry et al. 2002). However, for kelp surveys, ROV’s are not practical because of their large size and their likelihood of becoming entangled in kelp forests. Operating an ROV in the nearshore shallow waters requires the support vessel to operate close to shore which can be challenging in some weather conditions. ROV’s would be difficult to manoeuver in high surge areas and high current areas and the ROV pilots could have the potential to lose control of the ROV in these conditions (Tammy Norgard, DFO, 3190 Hammond Bay Rd, Nanaimo BC, pers. comm.). Boavida et al. (2016) highlighted the difficulty in operating ROV’s in the presence of poor weather conditions and in areas of high current. Although AUV’s are smaller, they still require calm water, they cannot move algae out of the way for filming and may get entangled in kelp. This suggests that to procure video footage in shallow water and/or kelp beds, divers are required. Since divers making direct in-situ observations require about the same dive time as a diver capturing images or video, and that video and photo methods have additional equipment costs and additional time requirements for post-processing and imagery annotation, the direct diver method is the most efficient survey method for nearshore temperate ecosystems. This study showed that photo and video methods would require approximately twice the labour than direct diver observations (to annotate for both algae and invertebrates) while producing data of inferior quality to direct diver observations.

Our study found significant discrepancies among annotators, reflecting the level of diving expertise (Table 5, Fig. 6). Inter-annotator consistency has been documented in other studies and found to be related to the complexity of the system under observation as well as annotator experience. Ninio et al. (2003) found fairly good agreement among annotators in their studies of corals when comparing broad taxonomic groups as did Mabrouk et al. (2014) in their examination of the composition of the substrate under aquaculture fish pens. However, Dunham et al. (2018) documented variability among annotators in their study of glass sponge systems, emphasizing the need for rigorous field training for annotators in order to establish consistency of interpretation. Durden et al. (2016) suggested that variation among annotators could introduce significant bias to data and that this could lead to false conclusions.

We revisited the photo and video comparison with the diver data using the second dataset compiled by our experienced divers acting as annotators. We did not perform the full analysis with substrate and depth categories because of the reduced sample size. When comparing photo and diver surveys, divers detected significantly higher number of invertebrates than the photo annotator, but there was no significant difference for algae between the two methods (Table 6, Fig. 7). There were also no significant differences in the number of invertebrate species detected in the comparison between the video annotation and visual diver survey. This is especially interesting when considering that the video footage was recorded on the same side of the transect line that had been documented by the diver for algae. The fact that there was no significant difference in the number of invertebrate species recorded between our expert annotator and the direct diver observations supports our assumption that the species assemblages were comparable on either side of the transect line. Interestingly, the video annotator, who was an algae expert, identified more algal species than the divers did (Table 6, Fig. 7). This suggests that the divers needed more experience identifying algal species in 2013. In fact, this was determined at the time of the survey and subsequently an in-house guide to algae identification was produced for use in future years. Consequently, it is likely that the algae species presence data was underestimated by divers. Williams et al. (2006) noted that experience bias among divers occurred in their study and that this could lead to inaccuracies in data in a time series as divers gained more experience. Our second group of annotators had many years of field experience conducting this specific type of survey when they performed the annotation work. As a result, they were used to looking for the organisms specific to the algae and invertebrate lists. As a result, their data may show experience bias as well. It would be useful to redo this experiment now that field divers have more experience with this type of survey and assess if their observations would be more comparable to those of our expert annotators.

Variation in data quality has been documented in the field among divers for fish identification (Bernard et al. 2013, Williams et al. 2006), for sampling protocols with fish (Watson & Quinn 1997), for coral surveys (Beijbom et al., 2015; Howell et al., 2014), for intertidal sampling (Meese and Tomich 1992), and for estimating benthic invertebrate abundance (Benedetti-Cecchi et al. 1996), which is a compelling argument for using photographic or video data. Video and photographic methods allow for a single annotator to record data for an entire survey which may provide more consistency over several divers recording data in direct observation diver surveys. The variability between divers may be an important source of uncertainty and should be examined, possibly by swimming replicate transects randomly throughout future surveys.

The three methods had different maximum number of species detected, this suggests that the different methods have different detection capacities (also shown in Cox et al. 2017) and supports the conclusion that, based on the larger, initial data set, diver surveys produced the most complete species inventory of the three methods. When species accumulation curves are generated based on the diver data only from all 37 transects sampled in both survey areas, species continue to accumulate with increasing number of transects (Fig. 9). Future work is needed to determine the minimum number of sample transects that are required to adequately capture all habitats in a study area given its habitat diversity. We recommend regional species accumulations curves be calculated, using the direct diver observation data from hundreds of transect collected on coast-wide surveys between 2013 and 2019, to determine the optimal number of transects needed for future surveys.

The direct diver observation method provided more a complete species inventory and at lower cost compared with diver operated video and photography methods. Results from this study suggest that video methods may be useful in some habitats, i.e., at depths where little algae is present, but have limitations in shallow water especially in kelp beds where direct diver observation is more effective for studies interested in species detection. The lack of permanent visual records is a flaw of only conducting diver direct observation surveys and including a visual record would be useful if long term record of abundance metrics were of interest, for reference and quality control, or as a training tool for new divers, providing that funding for the additional field and processing costs is available. However, we argue that the superior data quality and cost effectiveness of the direct observation method for conducting species inventories make up for the lack of permanent record, providing that the divers have the necessary species identification knowledge. Species identification expertise is required for collection of data regardless of whether it occurs in the field or in post-processing.

Preliminary results from this study were used to inform the choice of survey methods used in the habitat mapping surveys that were undertaken in BC between 2014 and 2019. For these surveys, only the direct diver observation method was used since it generated the best data for the lowest cost. This allowed each transect to only be swum once, as opposed to repeating the process with the video and photo equipment, thereby increasing the number of transects that could be surveyed.

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APPENDICES

Appendix 1. List of Target Algae Species and Groups.

Algae Species Code	Latin Name	Common Name
AA	*Alaria nana*	
AB	*Agarum clathratum*	
AC		Articulated Corraline Algae
AF	*Agarum fimbriatum*	
AG	*Agarum sp.*	
AL	*Alaria sp*	
AM	*Alaria marginata*	
AP	*Acrosiphonia*	Green Rope
BB		Brown Branched
BF		Brown Foliose
BH		Brown Filamentous, includes Diatom Mats
BP	*Botryocladia pseudodichotoma*	Sea Grapes
BT	*Beggiatoa*	Bacterial mats
CF	*Codium fragile*	
CG	*Cystoseira geminata*	
CL	*Cladophora*	
CN	*Constantinea sp*	
CO	*Costaria costata*	
CP	*Colpomenia*	Bulb Seaweed
CR	*Cryptopleura sp, Polyneura sp*	
CS	*Codium setchellii*	
CY	*Cymathere triplicata*	
DA	*Desmarestia aculeata*	
DB	*Dictyota binghamiae*	
DE	*Desmarestia sp*	
DF	*Desmarestia foliacea*	
DG	*Derbesia marina*	Green sea grapes
DL	*Desmarestia ligulata*	
DM	*Desmarestia munda*	
DN	*Dictyoneurum californicum*	
DV	*Desmarestia viridis*	
EG	*Egregia menziesii*	
EI	*Eisenia arborea*	
EN		Encrusting Algae
FA	*Gloiocladia*	Blue iridescent red algae
FU	*Fucus distichus*	
GB		Green Branched
GF		Green Foliose
GH		Green Filamentous

GI	*Chondracanthus*	
GR	*Gracilaria pacifica, Sarcodiotheca spp*	
HA	*Haloscaccion glandiforme*	
HE	*Saccharina sessilis*	
IR	*Mazzaella sp*	
LA	*Laminaria sp*	
LE	*Leathesia difformis*	
LF	*Laminaria farlowii*	
LG	*Saccharina groenlandica*	
LO	*Lessoniopsis littoralis*	
LS	*Saccharina latissima*	
LT	*Laminaria setchelii*	
LY	*Laminaria yezoensis*	
MA	*Macrocystis pyrifera*	
NA	*Neorhodomela*	Black Pine
NT	*Nereocystis leutkeana*	
OP	*Opuntiella californica*	
PH	*Phyllospadix sp*	
PL	*Pleurophycus garderni*	
PO	*Porphyra sp*	
PR	*Prionitis sp*	
PT	*Pterygophora californica*	
PV	*Pelvetiopsis*	
RB		Red Branched
RF		Red Foliose
RH		Red Filamentous
SA	*Sargassum muticum*	
SL	*Scytosiphon lomentaria*	
SU	*Sparlingia pertusa*	
UL	*Ulva sp, Monostroma sp, Ulvaria sp, Enteromorpha sp*	
ZO	*Zostera sp*	Eelgrass

Appendix 2. List of Target Invertebrate Species and Groups.

Invertebrate Species Code	Latin Name	Common Name
AA	*Anthopleura artemisia*	Burrowing anemone
AB	*Balanus sp*	Acorn barnacle
ABL	*Haliotis kamtschatkana*	Abalone
AG	*Pomaulax gibberosa*	Red turban snail
AM	*Asterina miniata (Patiria miniata)*	Bat star
BA	*Epiactis libethae, Epiactis prolifera*	Brooding / Profilerating anemone
BB	*Disporella separata*	Purple(blue) encrusting bryozoan
BC	*Saxidomus gigantea*	Butter clam
BRE		Bryozoan - Erect
BRF		Bryozoan - Flat
BS	*Staurocalyptus dowlingi*	Boot sponge
BT	*Tegula funebralis*	Black turban snail
CA	*Cribribnopsis fernaldi*	Crimson anemone
CB	*Cancer branneri*	Hairy cancer crab, furrowed rock crab
CF	*Cnemidocarpa finmarkiensis*	Broad base tunicate
CG	*Cancer gracilis*	Cancer gracilis
CI	*Ciona savignyi*	Ciona savignyi, sea vase
CN	*Hermissenda crassicornis*	Crassicor, opalescent nudibranch
CO	*Clinocardium nuttallii*	Cockle
CP	*Crossaster papposus*	Rose star
CR	*Florometra serratissima*	Crinoids
CS	*Ceramaster patagonicus, C. arcticus*	Cookie star
CT		Crab Other
CU	*Pteraster tesselatus, P. militaris*	Cushion (slime) star
DA	*Dirona albolineata*	Dirona, frosted nudibranch
DC	*Cancer magister*	Dungeness crab
DD	*Didemnum carnulentum*	White crust tunicate
DI	*Dendronotus iris*	Dendroid (giant) nudibranch
FD	*Eudistylia sp*	Feather duster worm
FE	*Urticina piscivora*	Fish eating (rose) anemone
FS	*Fusitriton oregonensis*	Fusitriton
FT	*Chelyosoma productum*	Flat Top Tunicate
FW	*Dodecaceria concharum, Dodecaceria fewkesi*	Filament worm
GA	*Anthopleura xanthogrammica*	Green surf anemone
GB	*Balanus nubilis*	Giant barnacle

GC	*Cryptochiton stelleri*	Gumboot chiton
GDK	*Panopea generosa*	Geoduck
GF	*Pododesmus macrochisma*	Green false-jingle
GPA	*Metridium farcimen*	Giant plumose anemone
GS	*Neoesperiopsis digitata*	Glove sponge
GSU	*Strongylocentrotus droebachiensis*	Green urchin
HA	*Halocynthia aurantium*	Sea peach
HC	*Phyllolithodes papillosus*	Heart crab
HF	*Stylaster spp.*	Hydrocoral - Flat
HM	*Telmessus cheiragonus*	Helmet crab
HR	*Henrica spp*	Blood star
HS	*Pandalus hypsinotus*	Humpback shrimp
HSC	*Tresus capax, Tresus nuttallii*	Horse clam
HY		Hydrozoans
KC	*Pugettia producta*	Kelp crab
KL	*Fissurellidea bimaculata*	Keyhole limpet
LC	*Katharina tunicata*	Black leather chiton
LH	*Ceratostoma foliatum*	Leafy hornmouth
LP	*Leptasterias sp*	Six-armed star
LS	*Dermasterias imbricata*	Leather star
MC	*Mytilus californianus*	California Mussel
ME	*Melibe leonina*	Melibe, hooded nudibranch
MT	*Evasterias troschelii*	Mottled star
MU	*Mytilus sp.*	Mussels
NS	*Pandalus danae*	Coonstripe shrimp
OB		Other barnacle
OCC	*Balanophyllia elegans*	Orange cup coral
OD	*Dirona pellucita*	Orange Dirona
ORC	*Cucumaria miniata*	Orange cuke
OT	*Metandrocarpa taylori*	Orange social tunicate
PA	*Urticina crassicornis*	Painted anemone
PB	*Pisaster brevispinus*	Giant pink star
PC	*Psolus chitonoidea*	Psolus, creeping pedal sea cucumber
PI	*Zirfaea pilsbryi*	Piddock
PN	*Orthasterias koehleri*	Painted Star, Rainbow Star
PO	*Pisaster ochraceus*	Ochre star
PR	*Calliostoma annulatum*	Purple Ring Snail
PS	*Lopholithodes mandtii*	Puget sound king crab
PT	*Anthopleura elegantissima*	Pink tip anemone
PU	*Strongylocentrotus purpuratus*	Purple urchin
PYC	*Pycnopodia helianthoides*	Pycnopodia
RR	*Cancer productus*	Red rock crab

RS	*Crassadoma gigantea*	Rock scallop
RSC	*Parastichopus californicus*	Red sea cuke
RSU	*Strongylocentrotus franciscanus*	Red urchin
RT	*Tegula pulligo*	Brown (dusky) turban
SF	*Myxicola infundibulum*	Slime-tube feather duster
SN	*Pandalus platyceros*	Spot prawn
SO	*Solaster endeca, Solaster stipmsoni, Solaster paxillatus, Solaster dawsoni*	Solaster
SP	*Ptilosarcus gurneyi*	Sea pen
SPE		Sponge - Erect
SPF		Sponge - Flat
SR	*Urticina columbiana*	Sand-rose anemone
SS	*Chlamys hastata, Chlamys rubida*	Swimming scallop
ST	*Styela clava*	Invasive stalked tunicate
SY	*Hippasteria spinosa*	Spiny Red Star
TA	*Pachyceryanthus fimbriatus*	Tube dwelling anemone
TW		Calcareous tubeworm
UC	*Cryptolithodes sitchensis, Cryptolithodes typicus*	Umbrella crab / Buterfly crab
VS	*Mediaster aequalis, Gephyreaster swifti*	Vermillion star
WS	*Urticina lofotensis*	White spot anemone
XH	*Pagurus stevensae*	Stevens' hermit crab
ZO		Zooanthids
ZS		Brittle Star – Other

Appendix 3. Summary of the total number of species per transect and site description details.

Location	Transect #	Survey Method	# of Species Per Transect		Survey Time (min)	Transect Length (m)	Quadrats Surveyed	Depth* (m)		Annotator	
			Algae	Invert				Min	Max	New	Expert
Principe Channel	**2**	**Diver**	8	22	32						
		Video	9	11	32	100	Every second quadrat	0	12	✓	✓
		Photo	9	4	32						
	5	**Diver**	9	18	15						
		Video	9	14	15	50	Every quadrat	-2	16	✓	✓
		Photo	7	9	15					✓	✓
	6	**Diver**	18	32	24						
		Video	11	17	16	55	Every quadrat	-3	14	✓	✓
		Photo	9	13	16					✓	✓
	11	**Diver**	15	22	32						
		Video	11	17	27	45	Every quadrat	-2	15	✓	✓
		Photo	6	7	27					✓	✓
	13	**Diver**	8	22	36						
		Video	6	8	36	265	Every second quadrat	-4	13	✓	✓
		Photo	7	4	36					✓	
	16	**Diver**	6	18	17						
		Video	6	18	29	50	Every quadrat	-3	17	✓	✓
		Photo	3	8	29					✓	✓
	21	**Diver**	10	19	18						
		Video	7	11	14	25	Every quadrat	1	13	✓	✓
		Photo	3	6	14					✓	✓
	25	**Diver**	9	18	19						
		Video	9	18	23	50	Every quadrat	-4	15	✓	✓
		Photo	7	8	23					✓	✓
	27	**Diver**	7	19	31						
		Video	11	12	33	140	Every quadrat	-3	10	✓	✓
		Photo	11	7	33					✓	✓
Squally Passage	**111**	**Diver**	10	21	22						
		Video	11	16	20	55	Every quadrat	-3	12	✓	
		Photo	7	6	20					✓	
	113	**Diver**	10	19	15						
		Video	6	13	14	30	Every quadrat	-1	16	✓	
		Photo	3	3	14					✓	
	117	**Diver**	3	18	11						
		Video	6	8	20	40	Every quadrat	-3	16	✓	
		Photo	6	4	20					✓	
	119	**Diver**	1	11	13						
		Video	5	15	13	25	Every quadrat	0	16	✓	
		Photo	2	1	13					✓	
	123	**Diver**	7	16	16						
		Video	7	15	16	35	Every quadrat	-4	15	✓	
		Photo	6	7	16					✓	
	124	**Diver**	8	24	13						
		Video	9	14	12	25	Every quadrat	-2	16	✓	
		Photo	4	9	12					✓	
	131	**Diver**	11	28	50						
		Video	10	18	51	225	Every second quadrat	-1	16	✓	
		Photo	5	3	51					✓	
	135	**Diver**	12	17	11						
		Video	8	13	10	20	Every quadrat	-4	12	✓	
		Photo	4	8	10					✓	

*All depths are corrected for tides. Negative values represent distance above Chart Datum

Appendix 4. Summary of the number of species per depth and substrate categories by transect.

Location	Transect	Survey Type	Species Encounters per Depth Category*								Species Encounters per Substrate Category**											
			Algae				Invertebrates				Algae						Invertebrates					
			0	1	2	3	0	1	2	3	1a	1b	2a	2b	3a	3b	1a	1b	2a	2b	3a	3b
Principe Channel	2	Diver	-	6	3	3	-	11	9	13	1	2	-	1	8	-	6	4	-	2	16	-
		Video	-	7	5	4	-	4	4	8	2	3	-	0	8	-	4	1	-	0	9	-
		Photo	-	9	2	4	-	1	2	2	2	0	-	0	8	-	0	0	-	0	4	-
	5	Diver	5	2	1	3	3	13	6	10	9	2	0	1	-	-	14	9	0	5	-	-
		Video	6	2	1	3	1	7	6	9	8	2	1	0	-	-	9	9	3	0	-	-
		Photo	3	1	0	4	1	4	3	6	6	0	1	0	-	-	9	1	2	0	-	-
	6	Diver	11	11	4	2	15	20	14	9	9	14	-	-	0	-	26	16	-	-	0	-
		Video	8	6	2	1	5	6	10	8	8	8	-	-	0	-	14	8	-	-	0	-
		Photo	6	3	1	1	1	8	6	4	5	4	-	-	4	-	5	9	-	-	6	-
	11	Diver	13	7	5	1	11	8	10	10	4	13	0	-	8	-	7	19	0	-	11	-
		Video	6	6	4	2	5	7	10	10	3	7	1	-	7	-	7	9	7	-	10	-
		Photo	5	1	0	1	3	2	4	2	0	4	0	-	3	-	4	4	0	-	4	-
	13	Diver	2	3	6	3	2	9	17	6	4	0	-	-	7	3	10	0	-	-	17	6
		Video	0	0	5	4	0	0	5	6	0	0	-	-	6	0	0	0	-	-	8	0
		Photo	1	3	3	4	1	0	2	3	0	2	-	-	6	0	0	1	-	-	3	0
	16	Diver	5	3	0	1	3	11	8	7	6	1	0	-	0	-	17	7	0	-	0	-
		Video	6	3	1	2	4	9	8	11	4	4	1	-	0	-	12	10	8	-	0	-
		Photo	1	2	1	0	2	6	4	4	2	2	0	-	0	-	6	5	0	-	3	-
	21	Diver	-	9	2	2	-	19	7	6	10	-	-	-	-	-	19	-	-	-	-	-
		Video	-	7	1	1	-	5	5	10	7	-	-	-	-	-	11	-	-	-	-	-
		Photo	-	2	1	0	-	3	5	0	3	-	-	-	-	-	6	-	-	-	-	-
	25	Diver	7	2	1	1	7	7	11	8	8	2	-	-	0	-	13	13	-	-	0	-
		Video	7	3	2	1	4	6	11	9	7	3	-	-	0	-	11	14	-	-	0	-
		Photo	4	1	2	1	0	2	4	5	5	4	-	-	1	-	8	2	-	-	3	-
	27	Diver	5	4	1	0	0	10	13	10	3	6	1	2	0	-	0	11	5	4	14	-
		Video	6	6	6	2	2	5	7	6	7	5	3	0	6	-	3	4	2	0	10	-
		Photo	4	4	6	5	0	4	5	3	2	7	0	0	7	-	2	2	0	0	6	-
Squally Passage	111	Diver	5	6	2	4	10	8	6	7	6	5	-	-	5	-	8	10	-	-	10	-
		Video	6	4	3	3	6	7	7	5	4	6	-	-	4	-	7	6	-	-	9	-
		Photo	2	4	3	2	2	2	1	1	4	1	-	-	4	-	1	2	-	-	3	-
	113	Diver	-	7	4	5	-	13	8	7	6	7	-	-	0	-	13	12	-	-	0	-
		Video	-	5	2	4	-	7	4	7	3	6	-	-	2	-	5	10	-	-	4	-
		Photo	-	2	1	0	-	2	0	1	2	2	-	-	0	-	2	2	-	-	0	-
	117	Diver	2	2	2	0	7	14	5	6	-	2	2	1	2	-	-	17	5	4	8	-
		Video	4	2	2	1	2	4	1	4	-	5	3	0	3	-	-	5	2	0	6	-
		Photo	3	1	2	1	0	2	2	2	-	4	1	0	1	-	-	3	2	0	0	-
	119	Diver	-	1	1	1	-	9	2	4	1	1	-	-	1	-	7	7	-	-	2	-
		Video	-	1	3	1	-	7	3	11	2	3	-	-	3	-	6	8	-	-	6	-
		Photo	-	1	1	1	-	1	0	1	1	1	-	-	1	-	0	1	-	-	1	-
	123	Diver	6	2	1	1	10	11	6	1	7	-	-	-	1	-	15	-	-	-	1	-
		Video	5	2	1	2	8	6	9	2	6	-	-	-	2	-	13	-	-	-	2	-
		Photo	4	2	1	1	5	5	0	1	5	-	-	-	1	-	6	-	-	-	1	-
	124	Diver	5	3	6	3	10	7	14	6	8	0	-	3	-	-	24	0	-	6	-	-
		Video	5	2	5	1	3	3	9	9	9	0	-	0	-	-	14	0	-	0	-	-
		Photo	2	1	1	1	2	2	3	6	4	1	-	0	-	-	6	6	-	0	-	-
	131	Diver	-	6	7	5	-	6	15	16	-	0	0	7	9	0	-	0	0	22	11	0
		Video	-	4	9	4	-	1	4	15	-	2	1	0	10	0	-	5	5	0	11	0
		Photo	-	4	5	3	-	1	0	3	-	5	0	0	4	2	-	3	0	0	1	0
	135	Diver	9	5	1	-	13	8	6	-	12	-	-	-	-	-	17	-	-	-	-	-
		Video	7	2	0	-	6	8	6	-	8	-	-	-	-	-	13	-	-	-	-	-
		Photo	3	1	1	-	6	5	5	-	4	-	-	-	-	-	8	-	-	-	-	-

*Null counts are recorded with a "0" while categories not recorded or outside of the survey area are recorded with a "-". **Note that some substrate categories were not recorded by all survey types. A "0" was used in this case for the analysis to make Wilcoxon paired sample tests viable.

Appendix 5. Dive survey times and annotation times by experts.

Transect #	Diver Survey Time (minutes)*	Video/photo Recording Dive Time (minutes)*	Expert Video Annotation Time (minutes)**	Expert Photo Annotation Time (minutes)**
2	64	64	73	46
5	30	30	31	55
6	48	32	48	32
11	56	54	32	22
13	72	72	75	-
16	34	58	37	35
21	36	24	16	15
25	38	46	36	24
27	62	66	68	58
Total Time Including Transect #13	440	446	416	-
Total Time Excluding Transect #13	368	374	341	287
Average Time Per Transect Excluding Transect #13***	46.0	46.75	42.62	35.88
Ratio of difference		446/440=1.01	42.62/46=0.93	35.88/46=0.78

*Note that there were 2 divers per dive so the original dive time was multiplied by 2.
**Note that the Video or Photo Annotation Times would be in addition to the Video/Photo Recording Dive Times.
***Transect 13 was excluded since no Photo Annotation was available for this transect

Appendix 6. Photo Video Dive Times and Direct Diver Observation Times used for T-Test

Transect #	Time Photo/ Video (min)*	Time Direct Diver (min)*
25	23	19
12	18	20
16	29	17
27	33	31
21	14	18
18	37	51
30	45	40
2	32	32
1	21	32
5	15	15
10	21	28
6	16	24
8	18	17
13	36	36
15	21	33
102	33	28
134	44	37
122	14	12
121	12	10
129	9	18
130	18	13
125	16	18
127	15	31
123	16	16
110	12	28
111	20	22
112	28	28
113	14	15
119	13	13
117	20	11
Average:	**22.1**	**23.8**

*Note that this time is for 2 divers working simultaneously so actual dive time is twice this amount.