EXAMINATION OF DIVER-OPERATED VIDEO SURVEYS AS A METHOD TO MONITOR KELP FOREST COMMUNITIES

by

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THESIS ABSTRACT

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In the Northeast Pacific, some kelp forests are shifting to urchin barrens due to ocean-warming events, predator releases, and overgrazing by the purple sea urchin (*Strongylocentrotus purpuratus*). In regions like Southern Oregon where scuba surveys are limited by season and surge, ecological data are sparse. To calibrate a more efficient, accessible survey method, we performed invertebrate and algae swath surveys using simultaneous manual and video methods at historical kelp forest transects in Oregon. Our kelp forest sample size was too low to draw significant conclusions about survey methods in such habitats. In urchin barrens, the video method captured more urchins on average than the manual method, with more disparity as urchin densities increased. Sea stars in barrens were underestimated using the video method, which may be remedied by adapting the survey protocol. There was no significant observer variation when quantifying urchins from video surveys. There was little difference in the average time required to complete data collection and extraction between methods. The video method required far less time underwater, highlighting the benefit of the video method in areas where diving is opportunistic. This thesis includes unpublished co-authored material with the Oregon Department of Fish and Wildlife and the Oregon Coast Aquarium.

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Dedicated to my parents, Amy and Steve Persad, who have supported each of my endeavors no matter how wild or seemingly improbable. My brothers Stephen and Spencer Persad are worth mentioning, for their support amidst ironic and often ignored attempts at providing a voice of reason.

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CHAPTER I

EXAMINATION OF DIVER-OPERATED VIDEO SURVEYS AS A METHOD TO MONITOR KELP FOREST COMMUNITIES

The data used for this chapter were collected in joint efforts with the Oregon Department of Fish and Wildlife and the Oregon Coast Aquarium. I was a contributing field scientist, the sole data analyst and writer for the purpose of this thesis.

Introduction

Majestic kelp forests are observable around the world, from temperate, rocky coastlines, to the Arctic, and even in deep-water tropical regions (Buschmann et al., 2007; Graham et al., 2007; Krumhansl et al., 2016). The significant ecological, social, and economic value of kelp forests is well established (Buschmann et al., 2007; California Department of Fish and Game, 2004; Dayton, 1985; Filbee-Dexter & Wernberg, 2020; Lee et al., 2021; Mooney & Zavaleta, 2016; Oregon Department of Fish and Wildlife, 2011; Rogers-Bennett & Catton, 2019). For example, the kelps (Order Laminariales) that structure these marine forests constitute a vital source of primary production in the ocean and facilitate biodiversity on par with coral reefs (Lamy et al., 2020; Novak et al., 2020; Schiel & Foster, 2015; Steneck et al., 2002). Kelp forests provide three-dimensional biogenic habitat to valued marine species (Miller et al., 2018; Morrison et al., 2008; Schiel & Foster, 2015; Teagle et al., 2017), subsidize nutrient-deficient regions through drift (Duggins et al., 1989; Filbee-Dexter et al., 2020; Krumhansl & Scheibling, 2012), and attenuate waves to reduce coastal erosion and provide refuge for marine life (Buschmann et al., 2007; Jackson, 1984; Pinsky et al., 2013; van Rooijen & Winter, 2019).

In recent years, the combination of ocean warming events, predator release, and increased herbivore abundance has threatened kelp forest populations in the Northeast Pacific, leading to the succession of desolate “urchin barrens” in many historical habitats (Berry et al., 2021; Krumhansl et al., 2016; McPherson et al., 2021; Rogers-Bennett & Catton, 2019; Rogers-Bennett & Okamoto, 2020). Such declines in kelp forest cover reiterate the importance of long-term monitoring programs that inform the management of these vital ecosystems (Finger et al., 2021; Gitzen et al., 2012).

Monitoring programs can be difficult to establish in some parts of the Northeast Pacific. Scuba surveys are often required to capture community-level trends. However, diving is limited to fair weather days, particularly in unprotected coastal waters of the Northeast Pacific. Diveable conditions are especially opportunistic in forests of *Nereocystis luetkeana* or “bull kelp,” which form canopies in regions with high wave action (Starko et al., 2020; Steneck et al., 2002). Weather limitations are compounded by the prolonged bottom time necessary to conduct scuba surveys (Beisiegel et al., 2017), and even further by the extensive training required to dive for science. These diving complications result in limited datasets for many bull kelp forest communities along the west coast of North America, especially in Southern Oregon, U.S.A. (Hamilton et al., 2020; Krumhansl et al., 2016).

When feasible, kelp forest surveys along the west coast of North America typically follow protocol described by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO, 2017), in which divers quantify the densities of common kelps and macroinvertebrate species through 30-meter transect swath surveys (Murray et al., 2006). More recently, diver-operated “video” surveys have been used as a supplement, or even substitute for the “manual” PISCO surveys (Amsler et al., in press; Hop et al., 2016; Leonard & Clark, 1993; Mallet & Pelletier, 2014). Typically, video surveys target a subset of the kelp and invertebrate species that manual surveys target, but videos allow scientists to later quantify organisms in a lab rather than *in situ*.

Comparatively, video surveys have some obvious limitations. Visual quality of videos can vary, and observers lose the ability to probe the environment to locate and identify target organisms (Leonard & Clark, 1993). Video and photo surveys tend to capture fewer algae and invertebrate species than manual surveys (Beisiegel et al., 2017; Charles et al., 2022; Leonard & Clark, 1993). The trade-off is that video surveys may increase the accessibility of kelp forest monitoring for a number of reasons. Bottom time for scuba divers is significantly reduced when recording video data, which increases opportunities to conduct replicate surveys that bolster the dataset (Leonard & Clark, 1993; Murray et al., 2006). Video surveys allow cognitively demanding tasks, like counting, measuring, and identifying organisms, to be performed in the safety of a lab instead of *in situ* (Leonard & Clark, 1993). Organism quantification, which is limited to a highly trained scuba diver when using the manual method, can be outsourced to analysts of varying expertise when using the video method. Finally, video surveys are permanent data that enable post-hoc evaluations (Charles et al., 2022; Leonard & Clark, 1993), and provide engaging material for science education and outreach.

Few publications were found to have formally assessed the use of video or image survey methodology for observing algae and invertebrates in kelp forest habitats (Beisiegel et al., 2017; Charles et al., 2022; Leonard & Clark, 1993; Mallet & Pelletier, 2014). For studies that did, the methodologies varied, and survey types were often evaluated for biases rather than discrepancies (Beisiegel et al., 2017; Charles et al., 2022; Leonard & Clark, 1993). My study aims to address this gap in the literature, calibrate the video survey method, and inform future kelp forest surveys in a manner that helps streamline and expand long-term monitoring efforts; especially in open-coast regions such as Southern Oregon. Thus, I investigated the following questions:

1) Within both kelp forests and urchin barrens, are the calculated densities of targeted kelps, sea urchins, and sea stars consistent between manual and video survey methods?

2) When extracting data from video surveys, is there significant variability between observers?

3) In terms of logistics, time required, and data output, what are the general advantages and drawbacks of the video survey method relative to the manual survey method?

Methods

Survey sites

In joint efforts with the Oregon Department of Fish and Wildlife (ODFW) and the Oregon Coast Aquarium (ORCAq) co-authors, kelp forest surveys were conducted at historical transect sites along the Southern Oregon coast in May, August, and September of 2022 (Table 1, Fig. 1).

Table 1. Survey location metadata. Asterisks denote sites for which coordinates are not exact.

Survey No.	Habitat	Region	Location	Site	Transect ID	Date	Latitude	Longitude
1	Urchin Barren	Southern Oregon	Charleston	Lighthouse Beach	LH01	8/31/22	43.34728	-124.377
2		Southern Oregon	Charleston	Lighthouse Beach	LH02	8/31/22	43.34593	-124.376
3		Southern Oregon	Charleston	Gregory Point	GP03	9/1/22	43.33978	-124.379
4		Southern Oregon	Charleston	Gregory Point	GP11	9/1/22	43.34076	-124.378
5		Southern Oregon	Brookings	Macklyn Cove	MC1	9/13/22	42.046167	-124.29515
6		Southern Oregon	Brookings	Macklyn Cove	MC2	9/13/22	42.046167	-124.29515
7		Southern Oregon	Brookings	Chetco Point	CPN2	9/13/22	42.04495	-124.292
8		Southern Oregon	Brookings	Chetco Point	CPN3	9/13/22	42.04495	-124.292
9		Southern Oregon	Brookings	Chetco Point	CPN4	9/15/22	42.045467	-124.29155
10		Southern Oregon	Brookings	Chetco Point	CPN5	9/15/22	42.045467	-124.29155
11		Southern Oregon	Brookings	Chetco Point	CPS1	9/14/22	42.042367	-124.288967
12		Southern Oregon	Brookings	Chetco Point	CPS2	9/14/22	42.042367	-124.288967
13		Southern Oregon	Brookings	Chetco Point	CPS4	9/12/22	42.0422	-124.2881
14		Southern Oregon	Brookings	Chetco Point	CPS5	9/12/22	42.0422	-124.2881
15		Southern Oregon	Brookings	Chetco Point	CPS9	9/14/22	42.04295	-124.288117
16		Southern Oregon	Brookings	Chetco Point	CPS10	9/14/22	42.04295	-124.288117
17	Kelp Forest	Southern Oregon	Newport	Gull Rock*	OTGR01_1	5/24/22	44.752239	-124.073953
18		Southern Oregon	Newport	Gull Rock*	OTGR01_2	5/24/22	44.752239	-124.073953
19		Southern Oregon	Newport	Gull Rock*	OTGR01_3	5/24/22	44.752239	-124.073953
20		Southern Oregon	Newport	Otter Rock*	OTOT01_1	5/24/22	44.7331	-124.069816

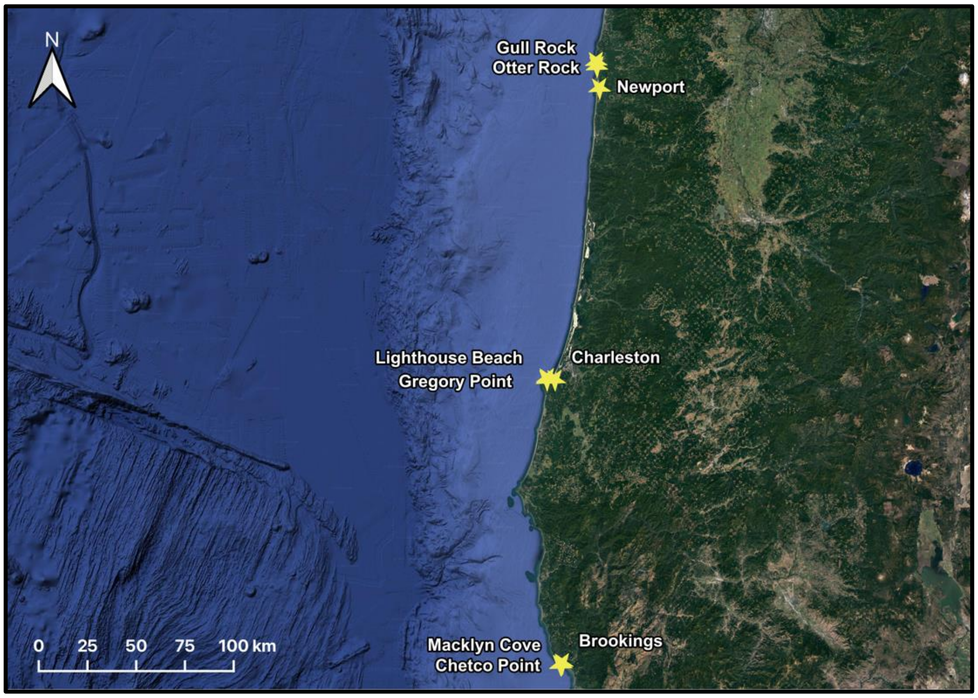

Figure 1. Survey sites in Southern Oregon, U.S.A.

Survey methodology

For a direct comparison between methods, manual and video swath surveys were conducted simultaneously by a team of two scuba divers. Manual surveys followed the PISCO invertebrate-algae swath method for kelp forests (2017), and video surveys were recorded with a camera rig equipped with a GoPro^{TM}, lights, and aligned lasers for scale (Fig. 2). Both survey methods quantified kelps and apparent macroinvertebrates (Table 3) within 1-meter on either side of the 30-meter transect tape (Fig. 3). Tasks requiring similar time and attention were divided evenly between the divers to ensure proximity between dive buddies and efficient data collection (Table 2). For each transect survey; region, transect name, date, coordinates, azimuth (compass heading), substrate type, start/end depths, diver initials, and visibility were recorded. To keep track of the paired survey data, manual data sheets with recorded metadata were pictured at the start of each transect video, and distinct transect IDs were created to link each video file name to the corresponding manual data.

Table 2. Simultaneous video and manual survey protocol described in terms of Diver 1 and Diver 2 swimming "OUT" from the anchor point and "BACK" on the left (L) or right (R) side of the 30m transect line. Pelagic videos were recorded with the lights off and the camera pointed straight ahead in the direction of travel while remaining 1m above the bottom. Benthic videos were recorded with the lights on and the camera pointed straight down at the benthos while remaining 1m above the bottom.

	OUT 1	BACK 1	OUT 2	BACK 2
DIVER 1	R - Record pelagic video	R - Record benthic video	R - Algae & invertebrate swath survey	L - Sea star swath
DIVER 2	L - Lay transect tape, notify Diver 1 at 30m	R - Follow & perform sea star swath	L - Algae & invertebrate swath survey	L - Follow & reel in transect tape

Figure 2. Camera rig used for video surveys. Equipped with lights, GoPro^{TM}, and aligned lasers. This system was modified from the rig originally described in Amsler et al. (in press).

Table 3. List of target organisms and survey locations where species are found.

Target Organisms	Common Name	Species	Location
Sea Urchins	Purple sea urchin	*Strongylocentrotus purpuratus*	All
	Red sea urchin	*Mesocentrotus franciscanus*	All
Sea Stars	Ochre star	*Pisaster ochraceous*	All
	Leather star	*Dermasterias imbricata*	All
	Blood star	*Henricia spp.*	All
Kelps	Bull kelp	*Nereocystis luetkeana*	All
	Broad-ribbed kelp	*Pleurophycus gardneri*	All
	Woody-stemmed kelp	*Pterygophora californica*	All
	Winged kelp	*Alaria marginata*	All
	Stiff-stiped kelp	*Laminaria setchellii*	All
	Five-ribbed kelp	*Costaria costata*	All
	Acid kelp	*Desmarestia spp.*	All

Video survey data extraction

There are challenges to capturing photos and videos along underwater transects. Videos may provide a greater survey area and additional context to the observer, but can be shaky or quickly-paced based on the surge conditions and diver operation (Charles et al., 2022). On the other hand, still photos provide a distinct frame from which to count organisms, but organisms can appear out of focus, or may be impeded by the reflection of light on particles in the water (Charles et al., 2022).

To account for challenges that both videos and photos present, each transect video was converted to 50 still images (Schimani et al., 2022). This created a discrete, stratified series of still frames which ensured replicability between observers, and simplified organism quantification and survey area measurements (Murray et al., 2006). Early subsampling experiments suggested that 50 images are near the maximum number of non-overlapping images that could reliably be extracted from each benthic video, which averaged ~4 minutes in duration. Still, analysts could refer back to survey videos to gain necessary context. For example, scrubbing through the video surveys was often necessary to confirm the position of the lasers, which could be difficult to distinguish in photos depending on turbidity and bottom composition. In addition, reviewing the videos enabled confirmation of organism identities, in the case that an individual appeared blurry or only partially within the image frame.

To extract images from each transect video, the total survey time (from start to end of the 30m transect tape) was divided by 50, yielding a randomized interval for capturing each image. Images were extracted using “VLC Open Source Media Player,” which contains a “Jump to Time” feature, allowing analysts to easily skip between time intervals; and a “Snapshot” feature, which can be programmed via “Settings” to automatically name each image according to transect ID, timestamp, and sequence.

At each time interval, the image was evaluated for useability before capturing. For urchin-dominated transects, at least $^2/_3$ of the image area must have met the following criteria: 1) photo depicts a relatively flat plane, 2) both lasers are visible on a relatively flat plane, 3) photo is clear enough to, at minimum, identify sea urchins (Fig. 4). For kelp-dominated transects, at least $^2/_3$ of the image area must have met the following criteria: 1) if substrate is not obstructed by kelp, it must depict a relatively flat plane 2) both lasers are visible on a relatively flat plane, 3) photo is clear enough to, at minimum, identify kelp and visible sea urchins (Fig. 4). If an image did not meet all of these criteria, it was omitted from the sample. If a single transect contained > 5 omitted images, the analyst would calculate a new time interval (in the same manner described previously) to sample the remaining images needed to equal 50 per transect. Overlapping timestamps were avoided during resample by scrubbing one second ahead if necessary.

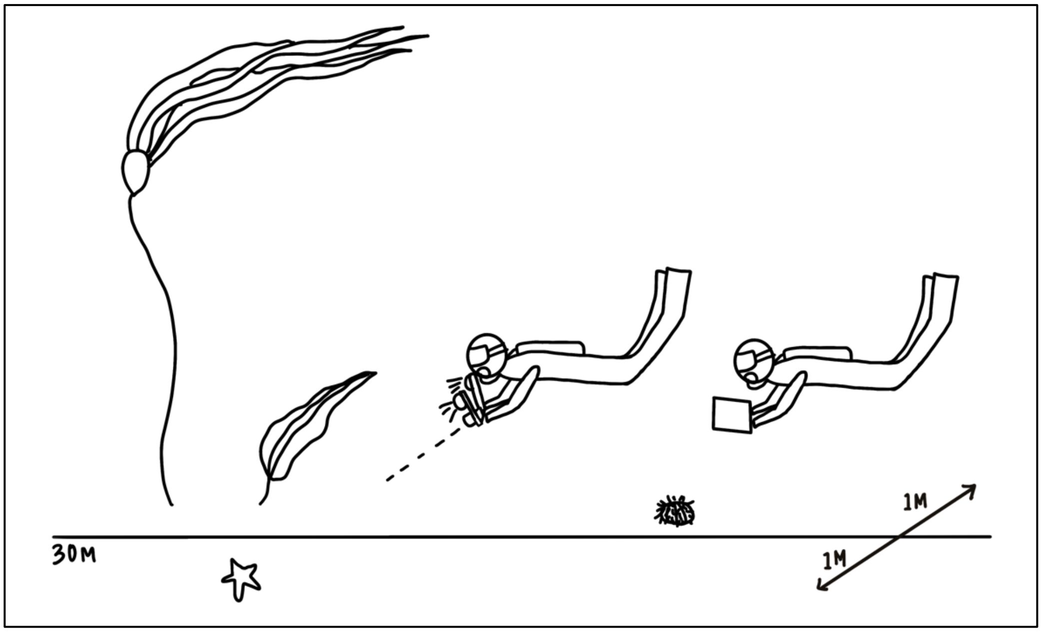

Figure 3. Depiction of simultaneous video and manual swath surveys, conducted within 1m on either side of the 30m transect line.

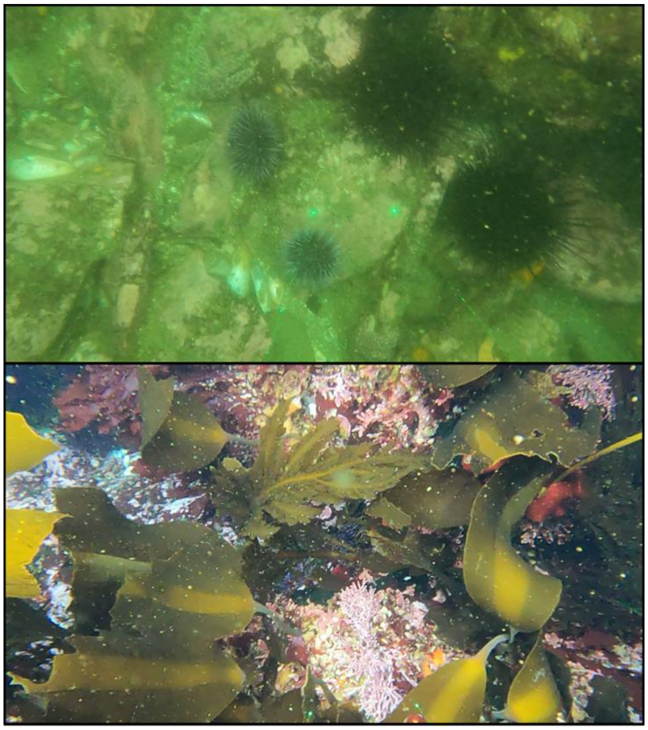

Figure 4. Images that met extraction criteria within an urchin barren (top) and a kelp forest (bottom).

Once video transects were converted to 50 still images, visibility for each image was scored on a scale of 1-3, where 1 = more than $^{2}/_{3}$ of the image area has such poor visibility that organisms would be difficult (but not impossible) to distinguish, 2 = $^{2}/_{3}$ or less of the image area has such poor visibility that organisms would be difficult (but not impossible) to distinguish, 3 = $^{1}/_{3}$ or less of the image area has such poor visibility that organisms would be difficult (but not impossible) to distinguish. At this stage, additional images were omitted but not resampled if visibility was so poor that urchins or substrate could not be distinguished.

Next, targeted kelps and macroinvertebrates were counted for each image (Table 3). Individual sea stars and sea urchins were generally easy to distinguish. Kelps were quantified by counting distinct holdfasts, stipes, and blades as individual organisms. The multi-point tool in the public domain image processing program Image J (Schneider et al., 2012) was used to keep track of individuals. Kelps in clusters where individuals were difficult to distinguish were estimated in multiples of 5. Identifying kelps to species was not always feasible due to image perspective and quality. Apart from *N. luetkeana* and *Pleurophycus gardneri,* which were often discernable, most kelps were grouped into an "unknown species" category. Finally, using the aligned lasers for scale, the area of each image was measured using set scale functions in Image J.

Data extraction

Species densities were calculated for manual and video survey transects by dividing the total number of individuals per transect by the total area surveyed (in meters squared) per transect (Murray et al., 2006).

In collaboration with Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site, preliminary transect videos were recorded and analyzed for the sole purpose of testing observer variation using the video method (n = 4). Multiple observers (n = 5) were virtually trained to identify and count sea urchins from still images. The observers then independently counted urchins for the same 4 transect videos.

Time was recorded as the unit of effort for each survey method. For the manual method, data collection and extraction were completed underwater and thus measured by the diver's bottom time. For the video method, data collection and extraction were measured by the amount of time required to: record a transect video, extract 50 still images per transect video, and count urchins for 50 images per transect.

Analyses

Density comparisons between methods were analyzed using a generalized linear mixed effects model with Poisson likelihood and log link from the “lme4” package in R. Specifically, the independent predictor variable was the survey method type, the dependent variable was total organisms counted, and transect was included as a random effect. The differences in area surveyed between methods were accounted for by offsetting with the log of the survey area. A null hypothesis of no difference in species densities between survey methods was tested using a likelihood ratio test comparing models with and without method as a predictor. Observer variation was tested using a linear regression model, with observer as the independent variable and number of urchins counted as the dependent variable.

Results

Urchin barren species densities

After omissions, an average of 48 images were analyzed per urchin barren transect. The average visibility score for all images within urchin barrens was 2.79 out of 3 (with 3 indicating the best visibility). Survey method had a significant effect on density data for purple (*S. purpuratus*) and red (*M. franciscanus*) urchins combined ($\chi^2 = 11.0$, df = 1, $P < 0.001$). In urchin barren transects ($n = 16$), the video method captured 4.7% more purple urchins (95% confidence interval = 0.96 to 8.6%), and 23.9% more red urchins (95% confidence interval 9.4 to 39.9%) on average than the manual method (Fig. 5).

Sea star densities within urchin barren environments differed significantly by survey method ($\chi^2 = 23$, df = 1, $P < 0.0001$). The video method consistently captured lower sea star densities than the manual method (Fig. 6). The video method captured

22.8% fewer *P. ochraceous* (95% confidence interval = -32 to -13%); 15% fewer *D. imbricata* (95% confidence interval = -37 to +12%); and 37% fewer *Henricia spp.* (95% confidence interval = -58 to -7%) on average than the manual method.

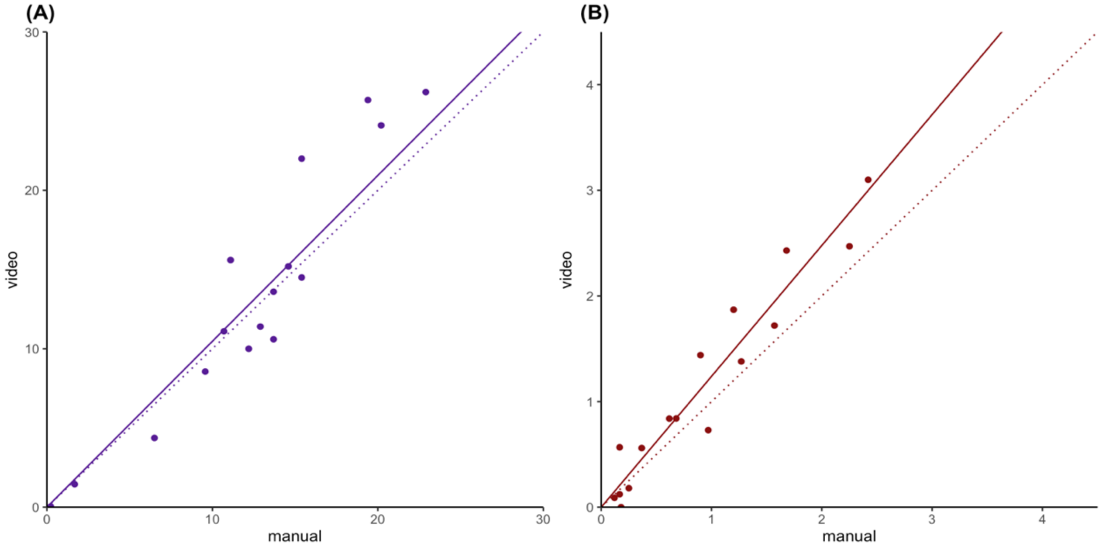

Figure 5. Differences in (A) purple urchin (p = 0.013) and (B) red urchin (p = < 0.001) densities (urchins per meter squared) between methods for all urchin barren sites (n = 16). The dotted line depicts the slope if densities between methods were even. The solid line is the slope of the observed data.

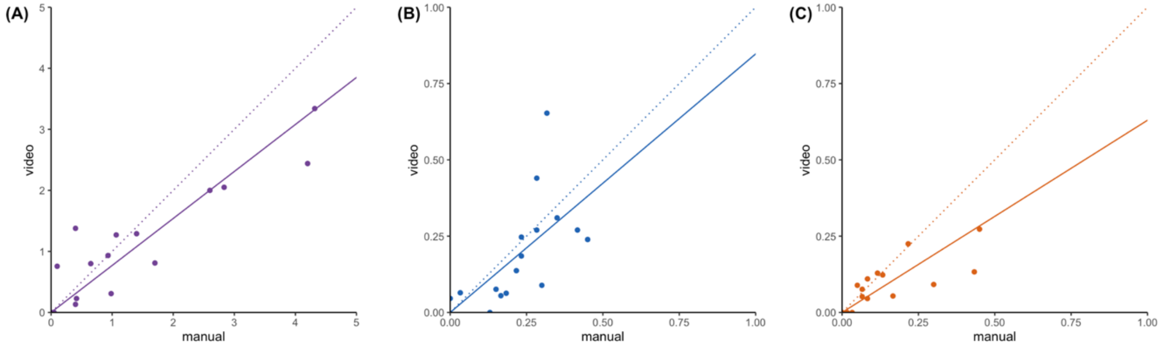

Figure 6. Density (stars per meter squared) comparison between methods for (A) *P. ochraceous* (p = < 0.0001), (B) *D. imbricata* (p = 0.25), and (C) *Henricia spp* (p = 0.022). The dotted line depicts the slope if densities between methods were even. The solid line is the slope of the observed data.

Kelp forest species densities

A minority of the historical Oregon transects surveyed for this study were current kelp forest habitats (n = 4 of 20). Such a low sample size may not warrant significant conclusions, but trends may be identified to guide future studies. Due to the low sample size and low species densities, red and purple sea urchins were grouped. On average, the video method recorded higher sea urchin (+30%), sea star (*P. ochraceous* = +114%, *D. imbricata* = +20%, *Henricia spp.* = +1212%), and kelp (*N. luetkeana* = +6%, *P. gardneri* = +170%, unknown kelps = +211%) densities than the manual method (Fig. 7, Fig. 8, Fig. 9).

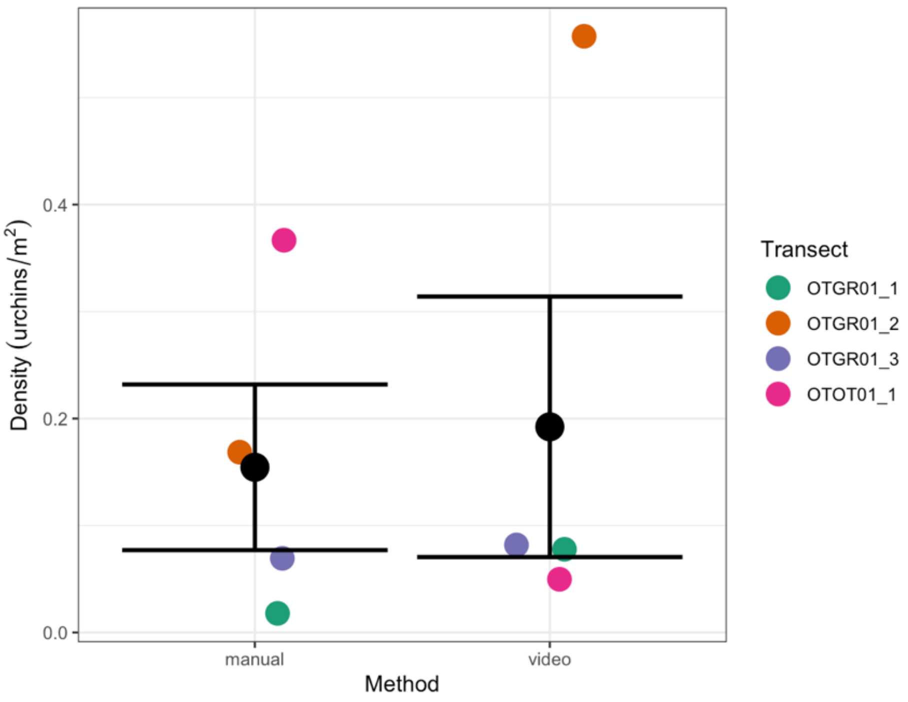

Figure 7. Average urchin densities observed in kelp forest transects between the manual and video method. The video method captured 30% more urchins on average than the manual method.

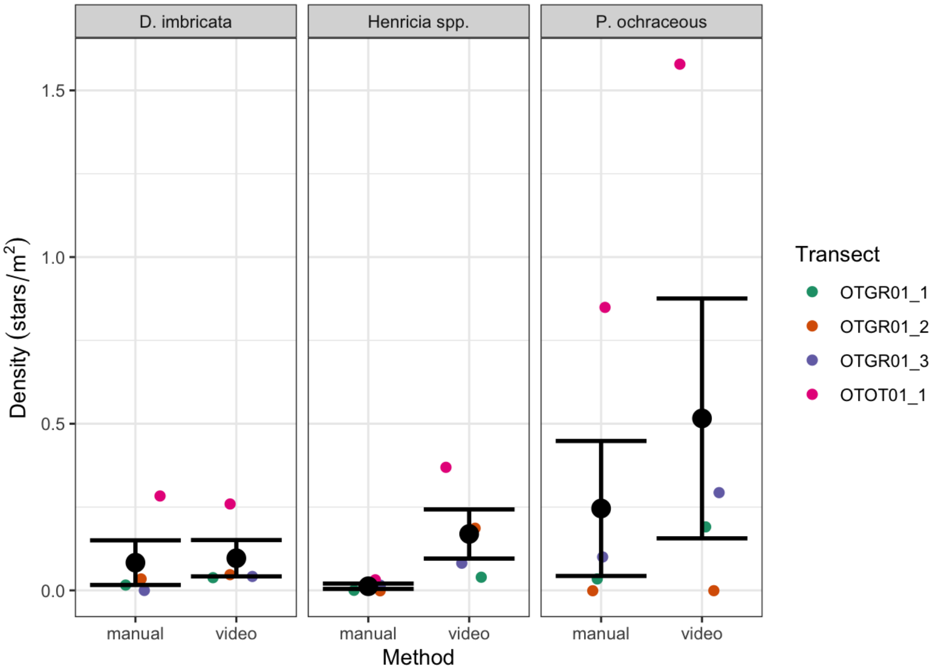

Figure 8. Average densities of 3 target sea star species within kelp forest transects. For all species, the video method captured higher densities of sea stars than the manual method (*P. ochraceous* = +114%, *D. imbricata* = +20%, *Henricia spp.* = +1212%).

Observer variation

Red and green (*Strongylocentrotus droebachiensis*) urchins were the most common urchin species in the Gwaii Haanas video transects used to test observer variation (n = 4). Amongst 5 observers with similar training and varying expertise, there was no significant difference in the number of green (p = 0.99) or red (p = 0.99) urchins counted per transect (Fig. 10).

Effort analysis

With all processes combined, the video method took an average of 7 minutes longer to accomplish similar tasks as the manual method (Table 4, Fig. 11).

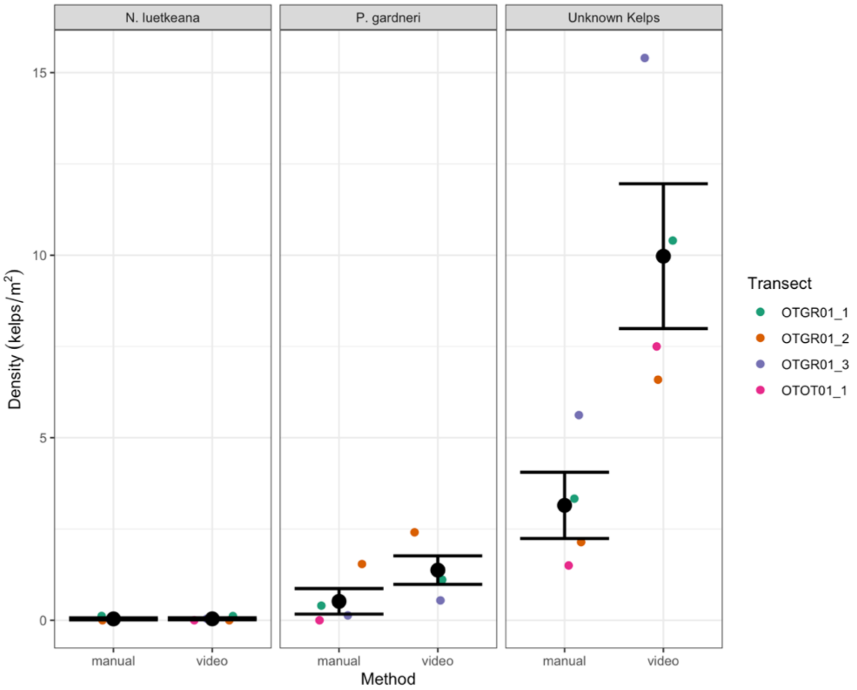

Figure 9. Average densities of 3 target kelp categories within kelp forests. For all species, the video method captured higher densities of kelps than the manual method (*N. luetkeana* = +6%, *P. gardneri* = +170%, unknown kelps = +211%).

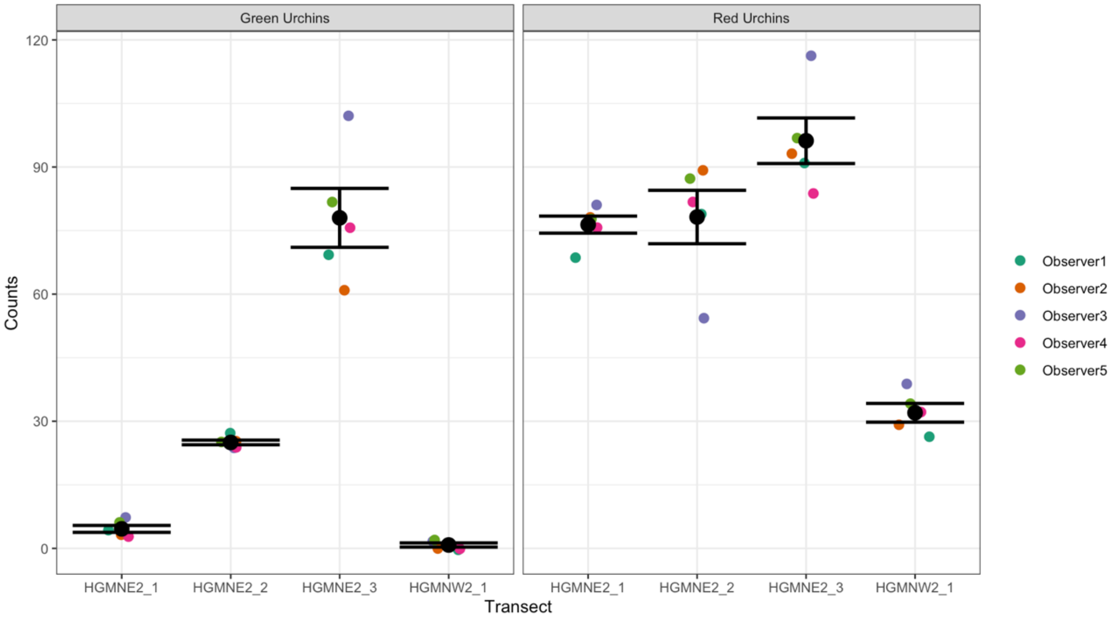

Figure 10. Colored points represent the number of urchins counted per transect (n = 4) per observer (n = 5). Black points represent mean urchins counted per transect with standard error bars. There was no significant difference in red or green urchin counts between observers (p = 0.99).

Table 4. Time required to complete all data-extracting tasks per transect survey per method. For some tasks, multiple participants independently performed the same tasks for multiple transects.

Method	Task	Participants	Transects	Average Minutes Spent per Transect
Video	Extract 50 images	3	36	17
Video	Count urchins for 50 images	3	18	39
Video	Swath survey	1	5	6
Manual	Swath survey	1	7	55
				Average Minutes Spent per Method (Total)
			Video	62
			Manual	55

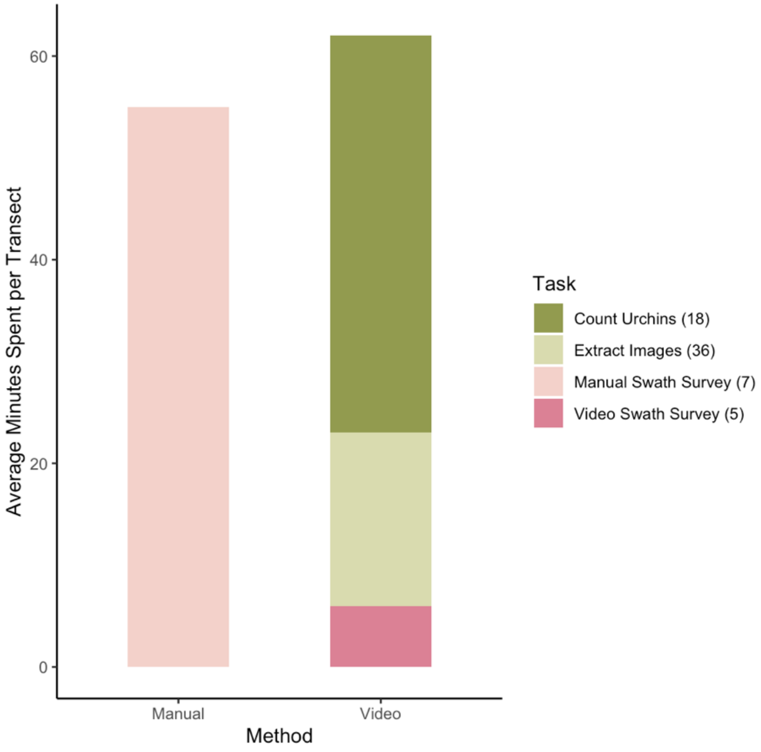

Figure 11. Bars depict the average minutes spent on each task per transect survey per method. Numbers in the task legend denote the number of replicates the effort data were averaged from. Some video method tasks were repeated for the same transects by multiple observers.

Discussion

Sea urchins in barrens

In urchin barrens, purple and red sea urchin densities remained relatively consistent between the video and manual method. The video method captured 4.7% more purple urchins and 23.9% more red urchins than the manual method. In Oregon, red urchins are rarer than purple urchins. The lower sample size of red urchins may account for the elevated disparity between methods compared to purple urchins (Murray et al., 2006).

It is unclear whether the video method or the manual method is more “reliable” for macroinvertebrate quantification in urchin barrens. Variability between observers has been documented using both video and manual methods to survey subtidal benthic organisms (Benedetti-Cecchi et al., 1996; Charles et al., 2022; Ninio et al., 2003), and can be attributed to factors like ecosystem complexity and experience of the analyst (Charles et al., 2022). Divers performing manual surveys are advantaged by the ability to probe the survey area. However, they face especially difficult conditions to dive for long periods of time due to the heavy surge, boulders, and cold water characteristic of Oregon (Montaño-Moctezuma et al., 2008). It is not unlikely that organisms could be miscounted in such a stressful environment (Benedetti-Cecchi et al., 1996). On the other hand, video surveys enable more efficient data collection underwater, and the ability to extract randomized, distinct images from which to count organisms. Still, the video method reduces visual quality, and eliminates the observer’s ability to manipulate the environment for identification, counting, and measurement of organisms (Charles et al., 2022).

Under the assumption that manual counts are more accurate than video counts, rugosity could be one factor causing the difference between methods. That is, the video method calculates two-dimensional measurements for images depicting a three-dimensional environment (Shortis et al., 2009). If the camera was not pointed directly at the bottom (which can occur due to surge), or if the bottom substrate was irregular, the measured image area could underestimate the total area surveyed and yield a higher density of urchins. Though rugosity is considered relatively negligible in manual surveys, maintaining a consistent survey area is easier with the use of visual cues like a meter stick. It is challenging to steadily operate a camera rig in heavy surge, which may result in some horizontal deviance from the intended survey area.

Under the inverse assumption that the video method is more reliable than the manual method, it is possible that divers miscounted urchins *in situ,* as mentioned previously. Due to environmental challenges, it would be fair to consider that manual urchin counts might yield more human error than counts from video (Benedetti-Cecchi et al., 1996). Testing observer variation using the manual method may shed light on the subject, but manual surveys are costly and arduous to perform (Leonard & Clark, 1993). Devoting time and resources to resurvey transects in areas where diving is opportunistic is unreasonable, especially in Oregon where many regions are ecologically data poor (Hamilton et al., 2020; Krumhansl et al., 2016).

Ultimately, purple urchins are a species of interest in Oregon and Northern California due to their exaggerated abundance, overgrazing on kelps, and subsequent formation of barrens (McPherson et al., 2021; Rogers-Bennett & Catton, 2019). Manual surveys are often taxing to perform in coastal urchin barrens. A difference of only 4.7%

purple urchins between methods suggests that the video method captures purple urchins well enough for accurate quantification in urchin barrens. Red urchins may also be targeted using the video method with the understanding that density might be slightly inflated compared to the manual method. For strict adherence to the manual method as a foundation, conversions could be performed to reduce the purple and red urchin abundances captured from video surveys by 4% and 24% respectively. It is clear that the use of video methodology increases the efficiency of urchin surveys in barrens and enables more replicates while still producing accurate results. Though size data were not evaluated in this study, video surveys can simplify the process of measuring organisms through still image analysis, as opposed to measuring animals by hand *in situ*.

Sea stars in urchin barrens

Within urchin barrens, the video method captured fewer sea stars across species than the manual method (*P. ochraceous*: -22.8%; *D.* imbricata: -15%; *Henricia spp*: -37%). This disparity could be due to sea star behavior. Previous studies have found an inverse relationship between predation pressure and structural complexity of the environment (Dahlgren & Eggleston, 2000; Rogers & Elliott, 2013). Particularly in the exposed rocky intertidal, sea stars tend to seek refuge in crevices or underneath rocks as an avoidance mechanism (Rogers & Elliott, 2013). In urchin barrens where there is no kelp to attenuate wave action nor to conceal individuals from predators, it is likely that macrofauna would loiter in less conspicuous areas than an exposed, horizontal rock face (Beisiegel et al., 2017). The current benthic video survey protocol does not capture vertical rock faces nor crevices well, whereas manual surveys allow for thorough investigation of the environment.

The disparity in sea star habitat captured between survey methods could be ameliorated in a number of ways. Using the current survey protocol, sea star densities could be converted to account for the underestimation compared to manual surveys. Alternatively, the video survey protocol could be altered to better record crevices and vertical rock faces. Simultaneous survey methodology could also be adapted to target sea urchins via video while targeting sea stars manually. To maximize efficiency and accuracy of surveys, it may be wise to distribute tasks between each survey method, favoring the field efficiency of the video method for abundant, time-consuming organisms like sea urchins, and using the manual method for relatively rarer, inconspicuous organisms that the video method may not capture well.

Algae in kelp forests

Survey sites were selected based on access to historical Oregon kelp forest transects rather than current habitat type. The majority of these transects were urchin barren environments, so kelp forests were inadvertently underrepresented in the sample (n = 4). With so few replicates, firm conclusions cannot be made about the use of video surveys in kelp-dominated habitats. Rather, inferences and suggestions may be derived to improve the video survey method for future studies in kelp forests.

Using the video method, individual holdfasts, stipes, and blades were counted as individual kelps. Kelps from the video method were overestimated compared to the manual method (*Nereocystis luetkeana* = +6%, *Pleurophycus gardneri* = +170%, unknown kelps = +211%). The success of previous macroalgal surveys using video and image-based techniques has been dependent on the survey environment, research goals, and nuances in methodology (Beisiegel et al., 2017; Hop et al., 2016; Leonard & Clark, 1993; Schimani et al., 2022). To maintain consistency with the manual method, my study aimed to quantify individual kelps from video surveys. Alternatively, quantifying kelps in terms of percent cover is common in the literature and might prove more effective than attempting to distinguish individual alga from images (Dethier et al., 1993; Hop et al., 2016; Leonard & Clark, 1993; Preskitt et al., 2004; Schimani et al., 2022).

Aside from the low sample size, the differences observed in kelp abundances could be partially due to the misidentification of species and miscalculation of individuals from the video surveys. According to manual survey data, *Laminaria setchellii* was common in the kelp forest transects. This kelp was rarely identifiable to species in the video surveys. It is likely that the ribbons of individual *L. setchellii* blades were counted as multiple individuals, which would contribute to the inflated quantification of unknown kelps. In many photos, *P. gardneri* grew densely. The methodology used to quantify such aggregations was to estimate individuals in multiples of five, which likely led to the overestimation of *P. gardneri*. *N. luetkeana* is relatively unique in appearance. The holdfast and stipe are quite recognizable amidst other brown algae, which is likely the reason why this species yielded the most consistent densities between methods.

Although pelagic videos were not analyzed in this study, they might provide a better avenue for determining macroalgal density. The pelagic view provides a different and perhaps easier perspective for distinguishing individual stipes, blades, and species of erect kelps (Bennett et al., 2016). One concern with using pelagic videos is that the survey area is difficult to measure. Stereo-video solves the area measurement issue, but is less accessible than standard video surveys as it requires additional costly equipment and software to perform (Goetze et al., 2019). In the absence of stereo-video technology, camera rigs akin to the one used for this study have been modified to include a 1m-wide PVC pipe visible in the image frame, providing a parameter within which to count kelps (Green et al., 2023). Ultimately, more data are needed to conclude whether video surveys are suited for quantification of target macroalgae in kelp forests.

Sea stars in kelp forests

Despite the low sample size, it is perplexing that the video method yielded greater sea star densities than the manual method (*P. ochraceous* = +114%, *D. imbricata* = +20%, *Henricia spp.* = +1212%), since the obstruction of image area by kelp blades is common (Charles et al., 2022). It is possible that divers underestimated sea stars due to algal coverage *in situ*, and that the video method happened to capture more exposed stars. More data are needed to make firm conclusions about sea star detection in kelp forests.

Sea urchins in kelp forests

Both methods captured low sea urchin densities in kelp forests (Fig.7). The decreased urchin densities could be due to kelp blade obstruction or simply to lower abundances within kelp forests relative to urchin barrens (Weitzman & Konar, 2021). The video method captured 30% more urchins than the manual method. Aside from the low sample size, one explanation for this inconsistency between methods is the obstruction of kelp blades (Charles et al., 2022). It is conceivable that kelp blade obstruction might cause increased variability of macroinvertebrate densities derived from kelp forests. More data are needed to solidify conclusions.

Observer variation

Five observers independently counted sea urchins for the same four Gwaii Haanas urchin barren transects. Red and green urchins were the most abundant species in the locations surveyed and thus were used to test observer variation. One observer was a graduate student who was familiar with invertebrates from both coursework and dive work. The remaining four observers were undergraduate students with varying degrees of familiarity with invertebrates. None of the observers were involved in collecting the video surveys. Observers were trained to identify and count urchins from pre-extracted images. Example urchin photos were supplied while training the observers, but there was no test of performance before they began independently counting urchins for the Gwaii Haanas transects. Amongst all observers, there was no significant difference in the number of red ($p = 0.99$) or green urchins ($p = 0.99$) counted per transect. This suggests that a wide variety of analysts can quantify urchins from video transects in urchin barrens, which is likely attributed to the low environmental complexity (Charles et al., 2022). The ability to outsource data extraction for the video method relieves cognitive demand from divers and reduces time underwater (Bohnsack, 1979), expanding the potential for replicate surveys in opportunistic regions (Leonard & Clark, 1993).

Effort analysis

Combining the time required to collect and extract data for both methods, I found that the video method took an average of 7 minutes longer than the manual method to complete data collection and extraction. I did not track the time required to digitally enter manual scuba data. Factoring in this additional step may alter the results in favor of the video method, as digital entry is built in to the counting process. In previous studies, the amount of time required to complete video versus manual surveys varied depending on methodology and research goals (Beisiegel et al., 2017; Charles et al., 2022; Leonard & Clark, 1993). It is worth noting that for this study, the majority of time for the manual method is spent underwater, whereas the majority of time for the video method is spent in the lab. In areas like the Oregon coast where surge is common and diving is both seasonal and opportunistic, diveable field days come at a premium. The ability to minimize time underwater and collect replicate data that can be processed during the off-season is highly advantageous in such environments. Thus, the video method should be prioritized whenever possible to maximize efficiency in the field without compromising accuracy.

Conclusions

1) Video surveys adequately capture sea urchin densities in urchin barrens. The methodology as-is underestimates sea star densities compared to manual surveys. Conversions could be used to more accurately estimate sea star densities and decrease the disparity between video and manual density data. Video survey protocol could also be altered to better capture sea stars based on their behavior in exposed environments.

2) Observers of varying expertise can effectively quantify sea urchins from video surveys in urchin barrens.

3) More data are needed to understand how effectively the video method captures target organisms in kelp forests relative to the manual method. It may be beneficial to test the use of pelagic videos to quantify kelps. In addition, identifying a protocol for ameliorating obstruction by kelp blades may lead to more consistent macroinvertebrate density calculations between methods.

4) The difference in the average time required to complete data collection and extraction between methods is negligible (7 minutes longer for the video method). It is especially prudent to consider that the majority of time for the manual method is spent underwater, whereas the majority of time for the video method is spent in a lab. Prioritizing the field efficiency of the video method in regions where diving is seasonal and opportunistic could enable more consistent and representative ecological monitoring.

5) Based on urchin barren results and preliminary kelp forest data, I agree with Leonard & Clark in recommending the usage of video survey methodology to capture broad-scale community changes in urchin barren and kelp forest habitats (1993). Additional investigations should be made using video surveys in kelp forests, as this method could prove particularly useful in regions where scuba diving is seasonal and opportunistic. I also recommend considering the allocation of survey tasks between methods to maximize efficiency and accuracy. For example, within urchin barrens it may be wise to capture sea urchins using the video method and sea stars using the manual method. Since urchin populations tend to be dense and time-consuming to count by hand, and they can be accurately quantified using video surveys, it makes sense to favor the efficiency of this method. Since sea stars tend to hide in areas that are difficult to capture in video surveys, and the densities are generally less overwhelming, it makes sense to favor the manual method so that observers can thoroughly investigate the environment.

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