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Compensating for length biases in underwater visual census of fishes using stereo video measurements

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Abstract

Underwater visual census (UVC) is a widely used technique for estimating species richness, abundance, and lengths of reef fishes. The technique has the advantage of being non-destructive, and can therefore be used for monitoring in marine protected areas. However, acquisition of robust data using UVC is reliant on the ability of individual divers to accurately identify fish, and estimate their lengths. Both of these variables can be affected by observer bias, which may also differ among observers. This study examines a technique with the potential to quantify and correct for observer bias in individual divers. We used simultaneous diver operated stereo video and underwater visual census surveys, and compared the results to generate diver-specific correction factors. These correction factors were subsequently applied in additional estimates of fish length with measurable improvement in the accuracy of the data.

Additional keywords:
Rocky reefs, observer bias, accuracy

Introduction

Establishing reliable and accurate methods for assessing fish species richness, abundances, and lengths, is important for management of marine protected areas (marine parks) (Murphy and Jenkins 2010; Willis *et al.* 2000). Fish species richness provides a measure of biodiversity that is often used in planning marine park zoning (Curley *et al.* 2002; Malcolm *et al.* 2010), and in monitoring impacts on marine ecosystems (Edgar and Stuart-Smith 2009; Kleczkowski *et al.* 2008), while abundance and length of fishes allows the effectiveness of marine park zoning to be assessed (Babcock *et al.* 2010; Edgar *et al.* 2009).

Assessing fish species richness requires a survey technique that is capable of reliably identifying the majority of the target fish species occurring in an area. Underwater visual census (UVC) is particularly useful in this capacity because it provides one of the few non-destructive methods for obtaining quantitative data on marine communities which include highly mobile species such as fish (Brock 1982; Edgar and Stuart-Smith 2009; McCormick and Choat 1987). UVC is subject to a number of limitations, including biases in fish length estimation (Bell *et al.* 1985; Harvey *et al.* 2001), and a requirement for survey divers to be able to consistently distinguish between fish species accurately while underwater (Tessier *et al.* 2013). Recently, to overcome some of the shortcomings of UVC, diver operated stereo video (abbreviated to SV henceforth) has been used as a non-destructive method for surveying fish, primarily due to the ability to obtain accurate length information (Harasti and Malcolm 2013; Harvey *et al.* 2002; Harvey *et al.* 2004), and because SV provides the capacity for field data to be collected by divers who are not expert in fish identification (Tessier *et al.* 2013; Tessier *et al.* 2005), and allows data to be archived and re-examined (Tessier *et al.* 2013). However, using SV for surveying fish can be more costly and time consuming than UVC because it involves additional post-processing with video analysis (Holmes *et al.* 2013; Tessier *et al.* 2013), and SV typically records lower species richness than UVC (Holmes *et al.* 2013). UVC and SV both have strengths and limitations and the method chosen for a study therefore often depends on availability of experienced personnel and equipment (Holmes *et al.* 2013).

Numerous methods have been used for obtaining quantitative data on fish lengths and abundances including: UVC; baited video; traps; and various fishing methods. Increasingly, non-destructive methods are being used to gather quantitative fish data, due primarily to limitations placed on the use of destructive methods in marine parks (Brock 1982). Destructive methods may also lead to bias in subsequent monitoring surveys through removal of fishes or disturbance to habitat. To obtain quantitative length data for fish during UVC, accurate estimation of fish lengths must be achieved by survey divers underwater. Previous studies have shown that gathering UVC data with a sufficient level of accuracy to conduct reliable statistical tests can be problematic, with UVC having lower statistical power than SV to detect differences in fish length (Harvey *et al.* 2002). Bias by divers in estimation of fish lengths is unavoidable, and the level of bias differs between divers (Edgar *et al.* 2004; Thompson and Mapstone 1997). To overcome these problems, many survey programs require UVC divers to undergo extensive training in estimating fish lengths underwater (Halford and Thompson 1996; Thompson and Mapstone 1997), and this training needs to be repeated at frequent intervals to maintain required levels of accuracy (Bell *et al.* 1985).

The primary objective of this study was to develop a method that could potentially be used to improve accuracy of UVC fish survey data. Our approach was to use simultaneous UVC and SV surveys to provide diver-specific fish length correction factors to improve the accuracy of subsequent UVC surveys. The second objective was to compare the ability of UVC and SV to measure fish species richness through direct comparison of the data obtained from simultaneous surveys.

Materials and methods

Study sites

Simultaneous underwater visual census (UVC) surveys and stereo video (SV) measurements were conducted at six sites in the Port Stephens Great Lakes Marine Park (PSGLMP) in New South Wales (NSW), Australia (Table I). Sites selected for the study were located in areas primarily covered by rocky reef urchin barrens, providing views of free-swimming fish species that were unobstructed by macroalgae habitat.

Experimental design and data collection

Four replicate 25-m transects were surveyed at each site, at depths of approximately 10m, with surveys conducted as the tape was laid, to minimise any disturbance of fish assemblages caused by tape laying (Dickens *et al.* 2011). Surveys were conducted in November 2012 and repeated in May 2013 giving a total of 24 transects for each time period. Each transect involved a diver counting and sizing fishes in a 25 x 5m strip along the transect tape, to a height of 5m above the substratum, whilst a second diver, swimming parallel with the first diver, filmed each transect, using a SV system which was held so that it faced along the transect path. Transects were separated from each other by a distance of at least 20m to minimise the issue of lack of independence of sample replicates. Fish species were allocated into size-classes during the UVC surveys, by comparison of fish lengths with a scale-bar on an underwater slate carried by the first diver. Size classes used for the surveys were 25mm, 50mm, 75mm, 100mm, 125mm, 150mm, 200mm, 250mm, 300mm, 350mm, 400mm, 500mm, and classes in 125mm increments above 500mm up to 2000mm. Fish were filmed using a SeaGIS diver operated SV system (www.seagis.com.au) to obtain exact length measurements. The SV consisted of two Canon HG21 high definition video cameras in custom-made SeaGIS underwater housings. Cameras were calibrated using standard methods (Harvey and Shortis 1998), with calibration checked prior to each day's diving using a calibration scale bar with precise distances known between three marked points: precision of within 1.7mm was achieved for all surveys.

Image and data analysis

SV footage was analysed using SeaGIS EventMeasure 3.31 (www.seagis.com.au) to identify all fish species, and to measure the lengths for individuals of four target species that were observed entering the field of view from in front, or from the side of the camera. Fish entering the field of view from behind the camera were not measured, as they were not counted in the UVC. The four target fish species selected *a priori* for analysis were: blue groper *Achoerodus viridis;* red morwong *Cheilodactylus fuscus;* crimson-banded wrasse *Notolabrus gymnogenis;* and maori wrasse *Ophthalmolepis lineolatus*. These species were selected because they are large common species, not cryptic and are amenable to length measurement using both stereo video and UVC.

Paired t-tests were used to test the hypothesis that there were differences in mean lengths of target species estimated from SV and UVC methods, for transects in which target species were present in both UVC and SV data. Paired t-tests, using all 48 transects, were used to test the hypothesis that there were differences between estimates of fish species richness for UVC and SV methods.

To examine whether correction factors can be used to compensate for diver bias in UVC fish length estimates, and thereby improve the accuracy of data for subsequent UVC surveys, simultaneous UVC and SV surveys from November 2012 were used to calculate species-specific fish length correction factors ($CF_{species}$). Correction factors were calculated using the ratio of the mean length measured by SV for the species $(L_{SV})_{species}$, to the mean length estimated by UVC for the species $(L_{UVC})_{species}$ [$CF_{species} = (L_{SV})_{species}/(L_{UVC})_{species}$]. UVC fish length estimates from May 2013 surveys were then corrected by applying species correction factors to UVC lengths to give corrected UVC lengths [Corrected $(L_{UVC})_{species} = CF_{species} \times (L_{UVC})_{species}$]. Both uncorrected and corrected lengths from May 2013 surveys were compared with matching SV length measurements to determine if the application of correction factors led to improvement in the accuracy of data.

Results

Comparison of mean UVC length estimates with mean SV length measurements for November 2012 transects

Mean UVC length estimates for each transect, for the four target species, were compared with mean lengths calculated from the matching SV measurement data (Fig. 1). Paired t-tests between the matched UVC (L_{UVC}) and SV (L_{SV}) mean length data for November 2012, found no significant differences in mean fish lengths between methods for *Achoerodus viridis* and *Ophthalmolepis lineolatus*, but significant differences for *Cheilodactylus fuscus*, and *Notolabrus gymnogenis* (Table II). Mean UVC length estimates were between 1.4% and 13.8% lower than mean SV measurements (Table II). UVC length correction factors, calculated to compensate for observer bias for the target species, varied between 1.16 for *Achoerodus viridis* and *Notolabrus gymnogenis*, and 1.02 for *Ophthalmolepis lineolatus* (Table II).

Effect of length correction on accuracy of May 2013 data

Species-specific length correction factors calculated using data from November 2012 (Table II) were applied to UVC length data for surveys conducted in May 2013, and corrected and uncorrected UVC length estimates, for the four target species, were compared with matching SV measurement data (Fig. 2).

Following length correction, no significant difference was detected between UVC length data and the corresponding SV data for any of the target species (Table III).

Differences between mean UVC fish lengths, and mean SV lengths were calculated for the four target species, using both uncorrected and corrected UVC length data (Table III). The use of corrected UVC length data resulted in reductions in the differences between UVC and SV mean lengths for *Achoerodus viridis, Ophthalmolepis lineolatus*, and *Notolabrus gymnogenis* but gave an increase in the differences between mean UVC and SV lengths for *Cheilodactylus fuscus*. Overall, the use of corrected lengths reduced the maximum absolute difference between UVC and SV mean lengths across all species from 21.7% to 9.2%.

Comparison of UVC Fish Species Richness with SV

A total of 79 fish species was identified during UVC surveys, compared to 55 species from examining SV footage (Table IV). Of these species, a total of 25 identified by UVC were not identifiable from the SV footage, whereas only one species visible on the SV footage was not identified during UVC. Analysis of fish species richness from the UVC data, and from the matching SV footage, showed that significantly more species per transect were identified by UVC (mean 12.4±0.5 S.E.), than from SV footage (8.7±0.5) ($P<0.001$, $n=48$).

Discussion

Accurate size estimates are important for monitoring the size structure of exploited species, where variability in size estimates may make it difficult to determine changes in size structures over time (Harvey *et al.* 2002). It is therefore important that fish length estimates obtained during UVCs are both accurate and consistent (Edgar *et al.* 2004; Harvey *et al.* 2002). Our comparisons between mean UVC and SV lengths indicate that mean UVC length estimates were lower than SV measurements for the four species examined. Previous studies have shown that diver bias during UVC surveys can depend on fish length (Harvey *et al.* 2002), and the results of this study indicate that biases may also depend on the species of fish being observed.

The two species for which no significant length differences were found (*Achoerodus viridis* and *Ophthalmolepis lineolatus*), are both highly visible species, which maintain good separation from the bottom, and thereby allow both UVC and SV to obtain clear sighting of individuals in all size classes. For the remaining two species for which significant length differences were detected (*Cheilodactylus fuscus,* and *Notolabrus gymnogenis*), juveniles exhibit cryptic behaviour and have drab colouration (especially for *Notolabrus gymnogenis*), which may have led to increased bias in estimating their lengths using UVC.

Provided that the equipment is adequately calibrated, SV provides accurate measurement of fish lengths (Harvey *et al.* 2001; Harvey *et al.* 2002). Consequently, the use of simultaneous SV and UVC surveys provides a means of assessing the accuracy of fish length estimates from UVC, and allows individualised length correction factors to be calculated for divers. The results of this study demonstrate that applying derived correction factors to data for subsequent UVC surveys can provide improvements in the accuracy of UVC length estimates. The calculation of correction factors is reliant on there being sufficient data to provide accurate estimates of mean species length for both SV and UVC. Correction factors are therefore best applied when studying abundant highly visible species in open habitats, and are less applicable for rare species, where sufficient data will generally not be obtained.

The use of diver-specific UVC length correction factors has several advantages over training divers in underwater fish length estimation. Firstly, the method allows corrections factors to be derived for individual divers, which account for variations in bias occurring due to fish size and species. Secondly, the use of length correction factors reduces accuracy errors associated with poorly calibrated divers. Thirdly correction factors address the declining accuracy of fish length estimation which has been shown to occur in divers who survey infrequently (e.g. less than every six months) following training (Bell *et al.* 1985). Finally, correction factors can be generated over a relatively short period, and the cost associated with this process is potentially smaller than that associated with ongoing use of SV to obtain accurate data. Derivation of diver-specific correction factors, using simultaneous SV and UVC surveys, therefore potentially provides an improved approach for gaining accurate fish length data in UVC surveys.

Consistent trends in UVC size estimations, related to fish size, have been shown to occur for divers (Edgar *et al.* 2004) and species-specific correction factors could potentially be combined with these size related factors to further improve accuracy of UVC data. The utility of the method described in this paper could therefore potentially be extended by identifying trends in the accuracy of species-specific fish length estimates across multiple divers (e.g. do all divers tend to under- or over-estimate the size of some species?). Establishing these trends would require the expansion of the study to cover more species, and multiple divers, but would potentially allow generalised species-specific length correction factors to be established for UVC surveys.

The use of corrected UVC surveys also offers benefits where data on species richness and cryptic species is required in addition to accurate length estimates (e.g. in monitoring the effects of introduction of marine protected areas). Previous studies comparing the use of video and UVC for conducting fish censuses have shown that UVC typically identifies a greater number of species (Holmes *et al.* 2013; Pelletier *et al.* 2011), and is better for identifying cryptic species (Holmes *et al.* 2013; Lowry *et al.* 2012; Tessier *et al.* 2005). Our simultaneous estimates of species richness, using UVC and SV, support these conclusions, with UVC identifying significantly more species of fish than SV, and UVC proving more effective for identifying smaller and cryptic fish species. Where fish were large and highly visible, SV was able to provide precise length information; however, identification of smaller individuals was often not possible, particularly in circumstances where visibility was reduced, the camera faced into the sun, fish behaved in a cryptic manner, remained close to the bottom, or were distant from the camera. Problems with identification of small and cryptic fish species stemmed from limitations in the SV cameras used for the surveys, which were unable to distinguish colours and patterns of fish at the distances, and under the lighting conditions, experienced during the surveys. Previous studies have also identified that video transects have limitations in detecting cryptic species (Holmes *et al.* 2013; Tessier *et al.* 2013; Tessier *et al.* 2005; Watson *et al.* 2005). The results of this study indicate that UVC has the potential to supplement data gathered using SV, for studies where both highly accurate length data, and data on species richness, are of importance. The choice of methodology to be used depends on the species to be examined, the type of data required, and the availability of resources.

In conclusion, this study demonstrates that biases in UVC can be measurably reduced using correction factors calculated from prior simultaneous SV and UVC survey data. The methods detailed in this study therefore provide a potential approach for improving the accuracy of fish length estimates from UVC surveys. This study also found that, during simultaneously conducted surveys, UVC identified significantly more species of fish than SV, suggesting that UVC is a better method to use in studies assessing fish species richness.

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Table I: Survey site names and coordinates

Site name	Latitude	Longitude
North Rock	-32.600	152.324
Little Broughton Island	-32.619	152.334
Cabbage Tree Island	-32.685	152.228
Boondelbah Island	-32.708	152.225
Fingal Island	-32.750	152.194
Boulder Bay	-32.760	152.172

Table II: Analysis of UVC (L_{UVC}) and SV (L_{SV}) mean fish lengths, differences in mean fish length between UVC and SV, and UVC length correction factors (CF) for November 2012 transects. Significant values in bold font.

Species	Paired t-test L_{UVC} vs. L_{SV} (*P*)	Difference in mean length $(L_{UVC}-L_{SV})/L_{SV}$	UVC length correction factor $(CF=L_{SV}/L_{UVC})$	Mean abundance (UVC)	Mean abundance (SV)
A. viridis (n=11)	0.071	-13.8%	1.16	1.5±0.1	1.5±0.3
C. fuscus (n=14)	**0.007**	-11.9%	1.13	6.1±2.0	4.3±1.4
O. lineolatus (n=20)	0.818	-1.4%	1.02	5.9±1.0	5.1±1.1
N. gymnogenis (n=16)	**0.044**	-13.7%	1.16	3.7±0.4	2.7±0.5

Table III: Analysis of Corrected UVC (Corrected L_{UVC}) and SV (L_{SV}) mean fish lengths for May 2013 transects, and differences in mean fish length between UVC and SV for May 2013 transects using uncorrected and corrected UVC length data

Species	Paired t-test Corrected L_{UVC} vs. L_{SV} (*P*)	Uncorrected difference in mean length $(L_{UVC}-L_{SV})/L_{SV}$	Corrected difference in mean length (Corrected $L_{UVC}-L_{SV})/L_{SV}$
A. viridis (n=9)	0.944	-12.8%	1.1%
C. fuscus (n=12)	0.106	-3.9%	8.6%
O. lineolatus (n=19)	0.509	-6.6%	-4.8%
N. gymnogenis (n=17)	0.284	-21.7%	-9.2%

Table IV: Number of transects where fish species were recorded during simultaneous underwater visual census (UVC) and stereo video (SV) surveys

Species	UVC transects with species	SV transects with species	Species	UVC transects with species	SV transects with species
Ophthalmolepis lineolata	43	44	*Parma unifasciata*	42	40
Notolabrus gymnogenis	43	39	*Cheilodactylus fuscus*	33	27
Atypichthys strigatus	28	24	*Achoerodus viridis*	24	21
Parma microlepis	27	18	*Acanthapagrus australis*	18	18
Chromis hypsilepis	20	17	*Trachurus novaezelandiae*	18	15
Trachinops taeniatus	34	13	*Scorpis lineolata*	10	11
Coris picta	14	10	*Olisthops cyanomelas*	10	8
Hypoplectrodes maccullochi	24	7	*Chironemus marmoratus*	11	7
Prionurus microlepidotus	6	7	*Parupeneus spilurus*	13	6
Girella tricuspidata	7	6	*Meuschenia freycineti*	5	5
Coris dorsomacula	4	5	*Plagiotremus tapeinosoma*	10	4
Halichoeres nebulosus	7	4	*Thalassoma lunare*	6	4
Pempheris compressa	5	4	*Monodactylus argenteus*	4	4
Dinolestes lewini	7	3	*Meuschenia trachylepis*	6	3
Pagrus auratus	6	3	*Anampses caeruleopunctatus*	4	3
Anampses elegans	3	3	*Aplodactylus lophodon*	2	3
Mecaenichthys immaculatus	14	2	*Enoplosus armatus*	7	2
Pseudolabrus luculentus	7	2	*Orectolobus maculatus*	4	2
Pempheris affinis	3	2	*Kyphosus sydneyanus*	2	2
Pomacentrus coelestis	2	2	*Stethojulis interrupta*	7	1
Cheilodactylus vestitus	3	1	*Pictilabrus laticlavius*	3	1
Microcanthus strigatus	2	1	*Siganus fuscescens*	2	1
Aulopus purpurissatus	1	1	*Chrysiptera notialis*	1	1
Dicotylichthys punctulatus	1	1	*Eubalichthys bucephalus*	1	1
Myliobatis australis	1	1	*Schuettea scalaripinnis*	1	1
Seriola dumerili	1	1	*Seriola lalandi*	1	1
Stegastes gascoynei	1	1	*Sarda australis*	0	1
Labroides dimidiatus	4	0	*Gymnothorax prasinus*	3	0
Pseudocaranx georgianus	3	0	*Suezichthys arquatus*	3	0
Acanthistius ocellatus	2	0	*Eupetrichthys angustipes*	2	0
Nemadactylus douglasii	2	0	*Plagiotremus rhinorhynchos*	2	0
Pseudolabrus guentheri	2	0	*Rhabdosargus sarba*	2	0
Upeneichthys lineatus	2	0	*Anoplocapros inermis*	1	0
Austrolabrus maculatus	1	0	*Chaetodon guentheri*	1	0
Chelonia mydas	1	0	*Coris sandageri*	1	0
Eubalichthys mosaicus	1	0	*Limnichthys fasciatus*	1	0
Lotella rhacina	1	0	*Macropharyngodon meleagris*	1	0
Macropharyngodon negrosensis	1	0	*Platycephalus fuscus*	1	0
Scorpaena jacksoniensis	1	0	*Thalassoma lutescens*	1	0
Zanclus cornutus	1	0			
			Total Species	79	55

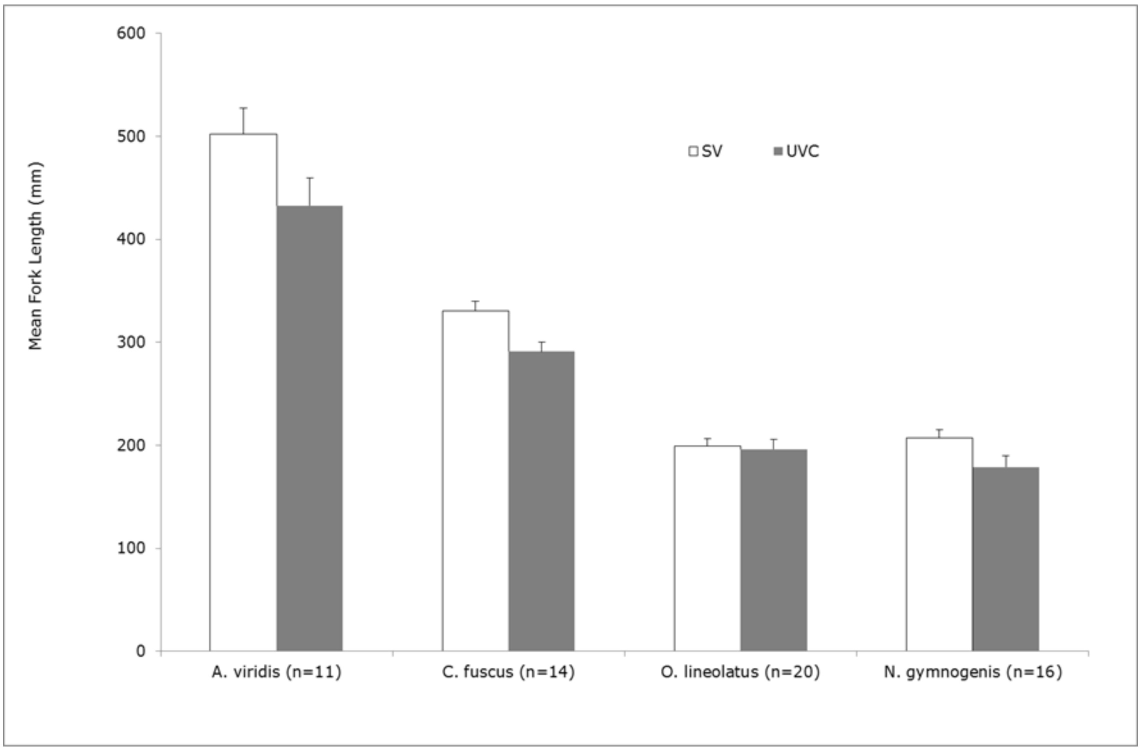

Fig. 1. Mean lengths of target fish species for November 2012 transects, from simultaneous underwater visual census (UVC) and stereo video (SV) data

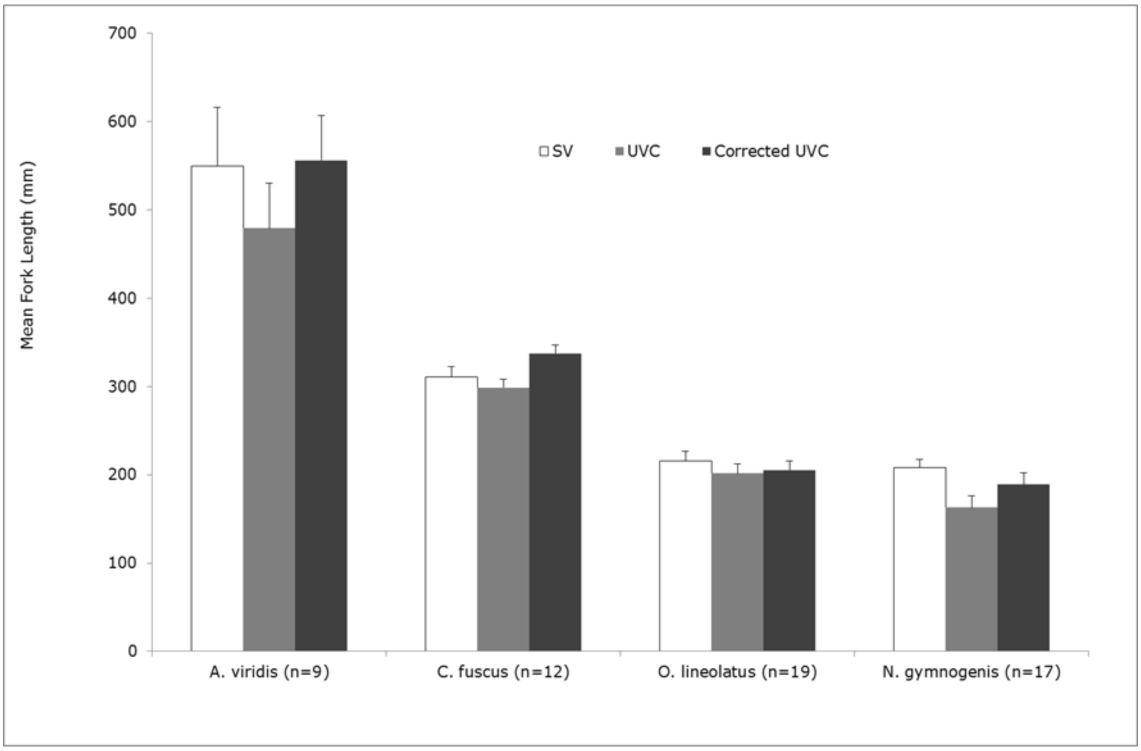

Fig. 2. Mean lengths of target fish species for May 2013 transects, from simultaneous underwater visual census (UVC) and stereo video (SV), including UVC data corrected for observer bias (Corrected UVC).