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Improvement of fish length estimates for underwater visual census of reef fish biomass

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Summary

Accuracy and precision are of great importance in the assessment of reef fish biomass when conducting an underwater visual census (UVC). Quantification and subsequent correction of the bias is required in order to standardize the estimates and correct for underwater distortion. To optimize the UVC, the observer should receive length-measurement training in order to obtain *in situ*-measurements that are as accurate and precise as possible. The objective of this study was to quantify the bias of fish length measurements made by divers with and without training in order to enhance reef fish biomass estimates. Adaptation of the diver to estimate fish lengths was analysed as a part of reef fish biomass monitoring in the Karimunjawa National Park, a national marine sanctuary in the Java Sea, Indonesia. Two divers practiced estimating a variety of fish in a natural environment by using styrofoam models attached to strings and sinkers. Analyses showed that by training the diver, his/her accuracy and precision improved substantially. Proving its reliability, an underwater visual census (UVC) becomes a useful and reliable method to assess the biomass of reef fishes.

Introduction

Pioneered by Brock (1954), the underwater visual census (UVC) is the most efficient and non-destructive method to assess the abundance and biomass of reef fishes. Kadison et al. (2002) noted that many managers use the UVC as a tool to estimate length frequency and abundance of reef fish. In Indonesia, the UVC method has been used to estimate the reef fish biomass in Karimunjawa National Park, Aceh Province, Seribu Islands, North Sulawesi, Wakatobi National Park, Lombok Island, Bali, Komodo National Park, and Raja Ampat (Pet et al., 2005; Campbell and Pardede, 2006; McClanahan et al., 2006; Unsworth et al., 2007; Rudi et al., 2009; Madduppa et al., 2012; Purwanto et al., 2012; Yulianto et al., 2012).

Calculating the reef fish biomass, an important parameter for fishery management (Cochrane, 2002), requires a high accuracy of fish length estimates. These depend on the ability of observers to make accurate estimates underwater where environmental conditions create optical distortions such as visibility, colour absorption, and light (Mille and Van Tassell, 1994). Underwater objects appear larger by 4/3 angular magnification, creating a bias in size perception with a direct impact on the estimate (Ross and Nawaz, 2003). As a result of distortion, errors in size estimates are common in novice divers, but which can be solved with regular training and practice (Ross et al., 1970; Bell et al., 1985). A trained diver can thus improve his/her precision and learn to achieve an accurate size estimate (Ross, 1965).

For accurate assessments of the reef fish biomass, improvements in the UVC method are imperative. The objective of this study was to quantify the bias of fish length measurements with and without the training of divers to improve reef fish biomass estimates. The divers' ability to estimate fish lengths were analysed as a part of reef fish biomass monitoring in the Karimunjawa National Park, by quantifying the accuracy and precision of their estimates.

Materials and methods

Monitoring of the biomass of reef fish monitoring began in 2005 in the Karimunjawa National Park, Karimunjawa Islands, Central Java, Indonesia, when 43 sites were chosen inside and outside of the national park to evaluate the effectiveness of the fishery resources protection measures (Fig. 1). Before monitoring began, fish total length estimates were conducted to reduce the bias estimates of the fish and the bias of the observers (the divers). Mille and Van Tassel (1994) had suggested the training of divers in the practice of making length estimates in a survey area for adaptation to the local environmental conditions.

Two types of technically similar training programs were carried out in May and November 2004, before beginning the monitoring program: an initial 5-day extensive training for non-experienced divers; and a second 'calibration training' to test divers already skilled in estimating fish lengths underwater. For both training sessions, a total of 45 different styrofoam models were used to represent various reef fish species and nine fish sizes from small to large. Each fish model was tied to a separate string and sinker in the natural environment to simulate natural, real fish moving back and forth under the impact of currents and waves. Initial training was conducted for 5 days, and the calibration trainings were conducted for up to 5 days until the divers reached a bias of

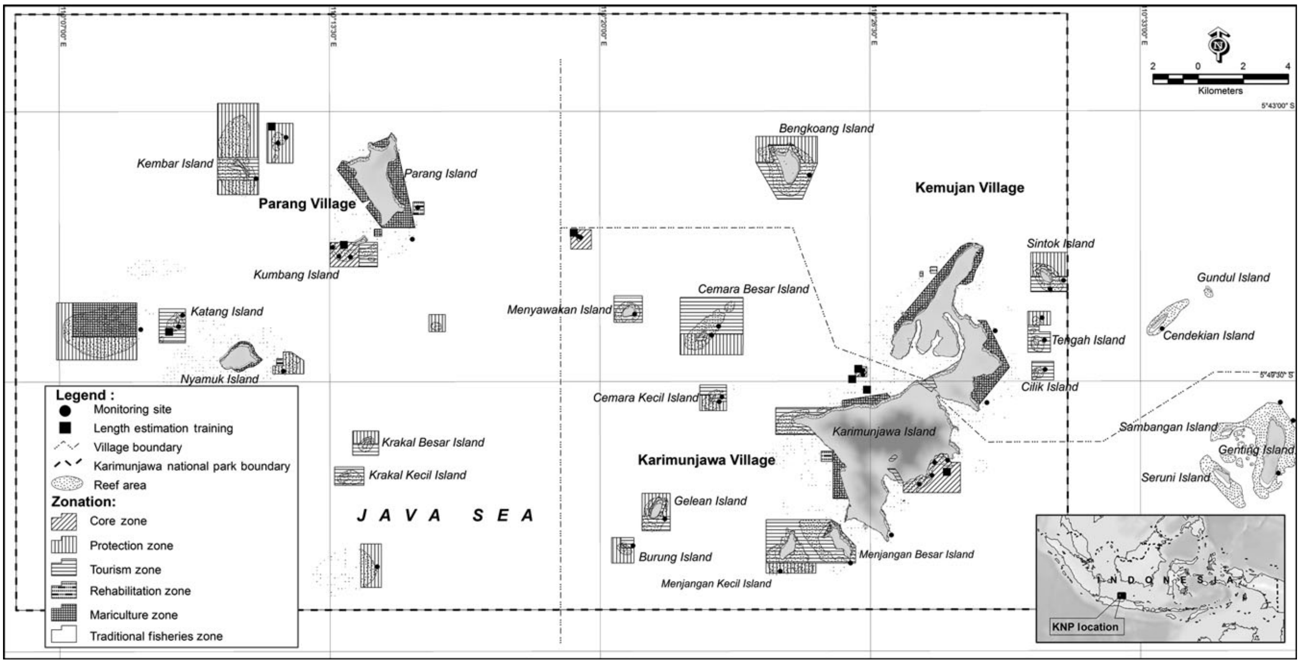

Fig. 1. The 43 reef fish monitoring sites, Karimunjawa National Park and training location for estimated total lengths of fishes

<5%. At a distance of 2.5 meters from each diver, ten fish models per day were chosen at random from the 45 models (Fig. 2), representing a maximum of five different shapes (damselfishes–Pomacentridae, butterflyfishes–Chaetodontidae, moorish idol–Zanclidae, parrotfishes–Scaridae, groupers–Epinephelidae) and sizes, similar to typical conditions in the regional reef habitat. The next day, ten models from the remaining 35 models were chosen at random. On day 5, ten fish models were also randomly chosen from the 45 fish models, a selection made to avoid a learning effect of the divers (model-induced bias). Daily discussions during the training were conducted regarding estimation errors, so that each diver was able to improve his judgement in accuracy in the days that followed.

Data from the divers' estimates were plotted, and the Mean Normalized Bias (MNB) was calculated and tested with a *t*-paired test. Plotting the data was used to compare each length estimate from a diver with the true value of the fish model. The MNB equation used to analyse the estimate bias was: $\mathrm{MNB} = 1/\mathrm{N}(\Sigma(Le - Lt/Lt) \times 100\%)$, where N is number of the estimated fish model, Le is the total length estimate of the fish model, and Lt is the true value of the fish model total length. A *t*-paired test was used to compare the length estimates between the divers.

Results

During the first experiment, two divers previously trained in reef fish taxonomy estimated the same fish models. Figure 3 gives the total length estimates from Diver 1 and Diver 2. The range of ± 5 cm from the true value of the fish model was considered to be an acceptable range of error. These divers gave satisfactory estimates almost all within the acceptable range, with most estimates close to the true value. Diver 1 overestimated the size of one fish model with a value beyond the acceptable range on the second day of training (Fig. 3).

We also grouped the data into three size-classes ($\leq$10 cm, 11–20 cm, and >21 cm) and calculated the mean and standard deviation of each class from the true value of the fish model length estimate from divers 1 and 2 (Fig. 4). The mean of the first length-class ($\leq$10 cm) from the true value of the fish model of Diver 1 estimate was 7.23 (SD = 1.88) cm, 7.45 (SD = 2.65) cm, and the estimate of Diver 2 was 7.18 (SD = 2.36) cm. The mean of the second class (11–20 cm) was 14.75 (SD = 2.21) cm, 15.88 (SD = 2.83) cm, and 14.38 (SD = 2.42) cm. The mean of the third class was 25.28 (SD = 2.02) cm, 24.90 (SD = 3.03), and 22.80 (SD = 2.35). Comparison of the mean and its standard deviation between the true value of the fish model total lengths and the total length estimates by each diver indicated that the divers had made accurate estimates.

A paired *t*-test was conducted to analyse the differences in estimates of the two divers (Table 1). On the first day of training, the length estimates by the divers were not significantly different from the true value (Diver 1, $P = 0.17$; Diver 2, $P = 0.11$), with no significant differences observed between Diver 1 and Diver 2 ($P = 0.50$). On the second day of training, the length estimates from Diver 2 were significantly different from the true value ($P < 0.05$). On the third day of training, the estimates of the divers were significantly different from the true value ($P < 0.05$), and significantly different between Diver 1 and Diver 2 ($P < 0.05$). The mean difference in estimates on the third day was the highest during training. On the fourth day, the length estimates from Diver 1 differed significantly from the true value ($P < 0.05$), with length

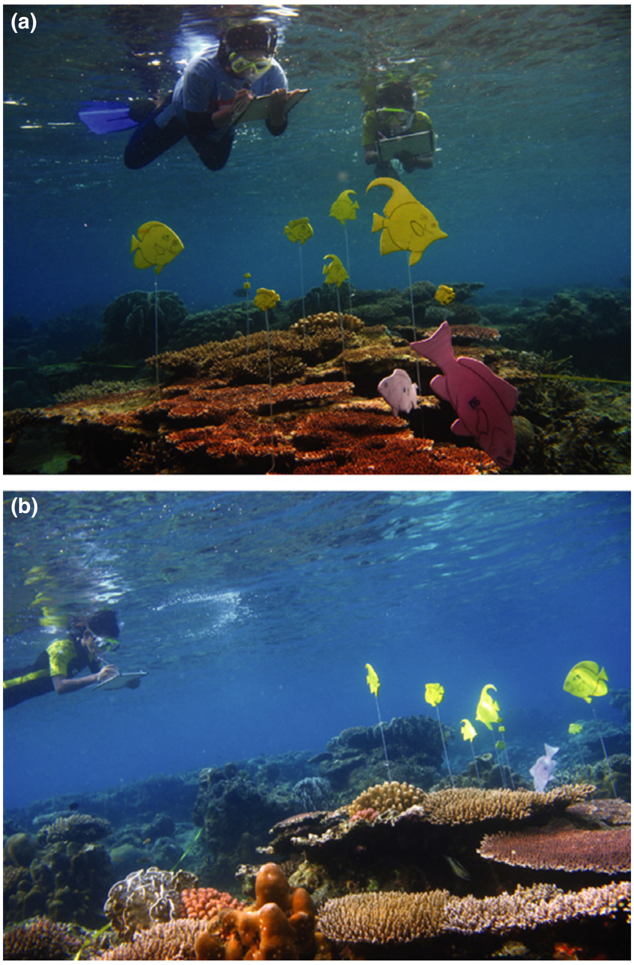

Fig. 2. a, b Two divers conducting fish length estimate training to reduce data bias and bias between divers. Distance between divers and fish model = 2.5 meters

estimates from Diver 2 not significantly different from Diver 1 (P = 0.07) and the true value (P = 0.44). On day 5, length estimates of the divers were not significantly different from the true value (Diver 1, P = 0.14; Diver 2, P = 0.12) and not significantly different between the divers (P = 0.25). Based on the MNB calculation, the accuracy of the divers increased after 5 days of training. The MNB values of both divers decreased over time. On training day 5 and based on the MNB values, the bias of both divers was <5% (Fig. 5).

After about 6 months of length estimate training, calibration training was conducted to control and calibrate the divers' skills in underwater length estimates. Figure 6 shows the results of the 3 days of calibration training. Both divers still had good estimates of the total length of the fish models. All length estimates were in the acceptable (i.e. <5% deviation) range. Although with good estimates, biases of both divers were highest on day 1 of calibration training. The MNB value reached −29.13%. Bases on the paired-*t* test, the length estimates from both divers and the true values were significantly different at 95% (Table 2). Figure 7 represents the mean of each size class of fish length, where the divers made inaccurate estimates. Diver 1 made inaccurate estimates for the 2nd length class (11–20 cm) and Diver 2 for the 1st and the 3rd classes. An inaccurate estimate contributed to the high bias on day 1 of calibration training.

Over time with practice and discussions, the accuracy of the divers increased in 3 days of calibration training to reach a MNB below or equal to 5% (Fig. 8). The length estimates were not significantly different from the true value and not significantly different between divers (Table 2). This result was reached more quickly than in the first 5-day training.

Discussion

This study demonstrates that an underwater visual census (UVC) can be tested reliably and improved, and can be of substantial help as a useful and reliable method to assess reef fish biomass. According to Kadison et al. (2002), training a new observer improved the accuracy of the diver's length-class estimates from 40% to 89% after a dozen training dives over a 6-week period. The divers tested in the present study improved their skills in making size estimates in five different fish species, attaining a bias below 5% within five (first training) and three (calibration training) days.

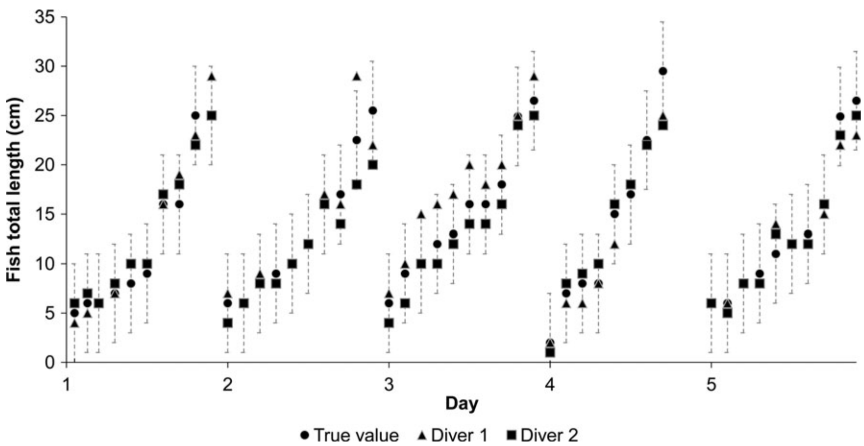

Fig. 3. Total length estimates of 10 fish models randomly chosen and placed per day in the test area during the first training, May 2004. Error bars of +/−5 cm from the true value of the fish model are within the acceptable range of estimates

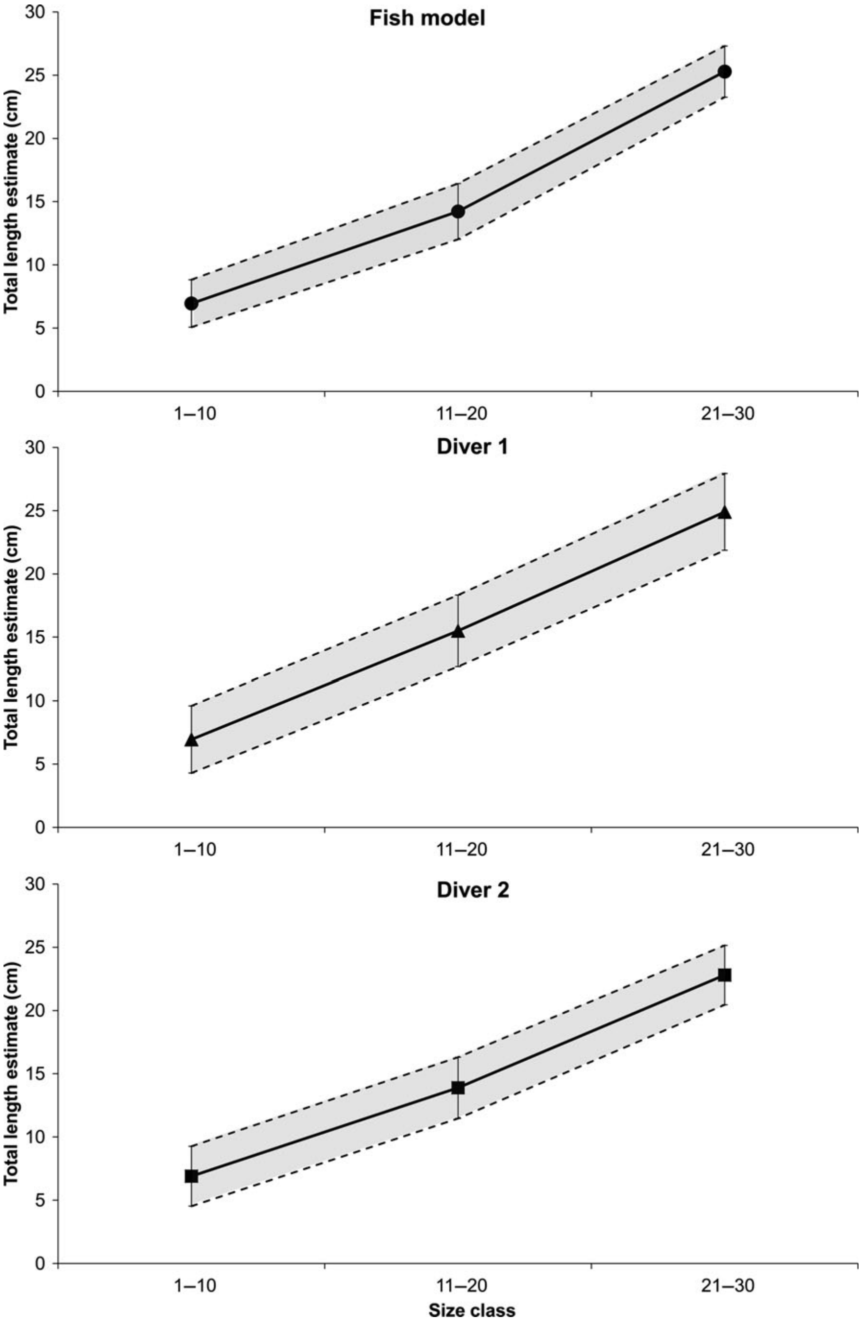

Fig. 4. Total length means with standard deviation of all fish models divided into three size classes, and estimates of the two divers during training representing their bias and precision; true values of the fish models (●); estimates of Diver 1 (▲) and Diver 2 (■)

Our experiments demonstrate to what extent corrections translated into over-compensation. It is important for a diver to reflect on his/her response to criticism and individual bias and thus for each to learn his individual learning curve. However, a good performance in training with fish models does not necessarily imply that the divers can measure live fish with the same precision and accuracy. Although it can be assumed that training and calibration will improve the competence of the divers in general, the ultimate proof in the field is still pending. Nevertheless, under the circumstances prevailing at most field stations in tropical regions and considering the practicality of dealing with live fish of known size in the field, the fish model approach as used here is a cost-efficient and robust approach for improving, quantifying and qualifying the precision of subsequent measurements in the field. This study also demonstrates that a diver can improve his estimation accuracy with training and calibration training relatively quickly, indicating the usefulness of this method. However, the estimates were made from a more-or-less predefined distance of 2.5 m whereas under natural conditions the distances will inevitably vary. It can be assumed that the

Table 1
Paired *t*-test mean differences in true value estimations from Diver 1 and Diver 2, May 2004

Day	True value vs Diver 1	True value vs Diver 2	Diver 1 vs Diver 2
Day 1	+0.60	+0.60	0.00
Day 2	+0.40	−1.60*	−2.00*
Day 3	+2.56*	−1.64*	−4.20*
Day 4	−1.25*	−0.12	+1.12
Day 5	−0.64	−0.44	+0.20

+ = overestimate; − = underestimate.
* = Significant difference at 95%.

Table 2
Paired *t*-test mean differences in true value estimations from Diver 1 and Diver 2, November 2004

Day	True value vs Diver 1	True value vs Diver 2	Diver 1 vs Diver 2
Day 1	+1.50*	−3.70*	−5.20*
Day 2	+0.80	−0.59	−1.40*
Day 3	−0.05	−0.25	−0.20

+ = overestimate; − = underestimate.
*Significant difference at 95%.

length estimates of live fish in a survey will have a lower accuracy. Edgar et al. (2004) demonstrated that UVC estimates of divers were on average 7% greater than the measured lengths of live fish. However, this result was also size-dependent, when divers possessed a clear tendency to make increasingly inaccurate size estimates when fish lengths deviated from 300 mm (175 mm underestimated by ≈20% and 400 mm overestimated by ≈10%). Our experiments show that calibration training is needed when a diver has not participated in an underwater fish length survey for least for 6 months; this result is similar to the 6-month time frame mentioned by Bell et al. (1985).

We selected five fish species of nine different sizes each, to prevent divers from easily recognizing the size of a selected fish model, which could otherwise be a training weakness. On the other hand, arbitrary species selection and a high number of size variables in each model fish species makes single model recognition difficult, especially under normal field conditions in the reef. Consequently,

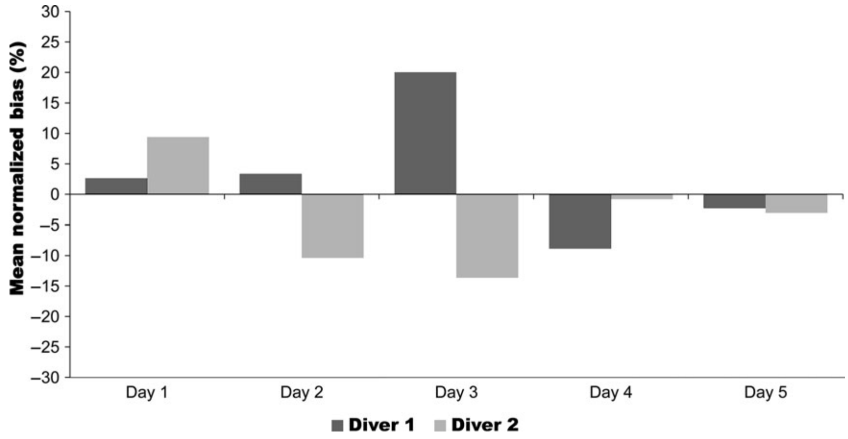

Fig. 5. Mean Normalized Bias (%) from two divers during training, May 2004; positive percentages = overestimates; negative percentages = underestimates

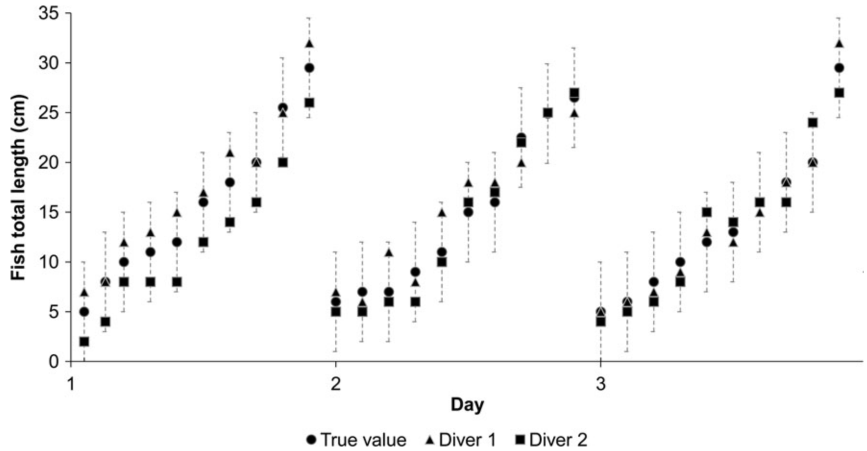

Fig. 6. Total length estimate of 10 fish models randomly chosen and placed per day in the test area during training, November 2004; Error bars of +/−5 cm from the true value of the fish model are within the acceptable range of estimates

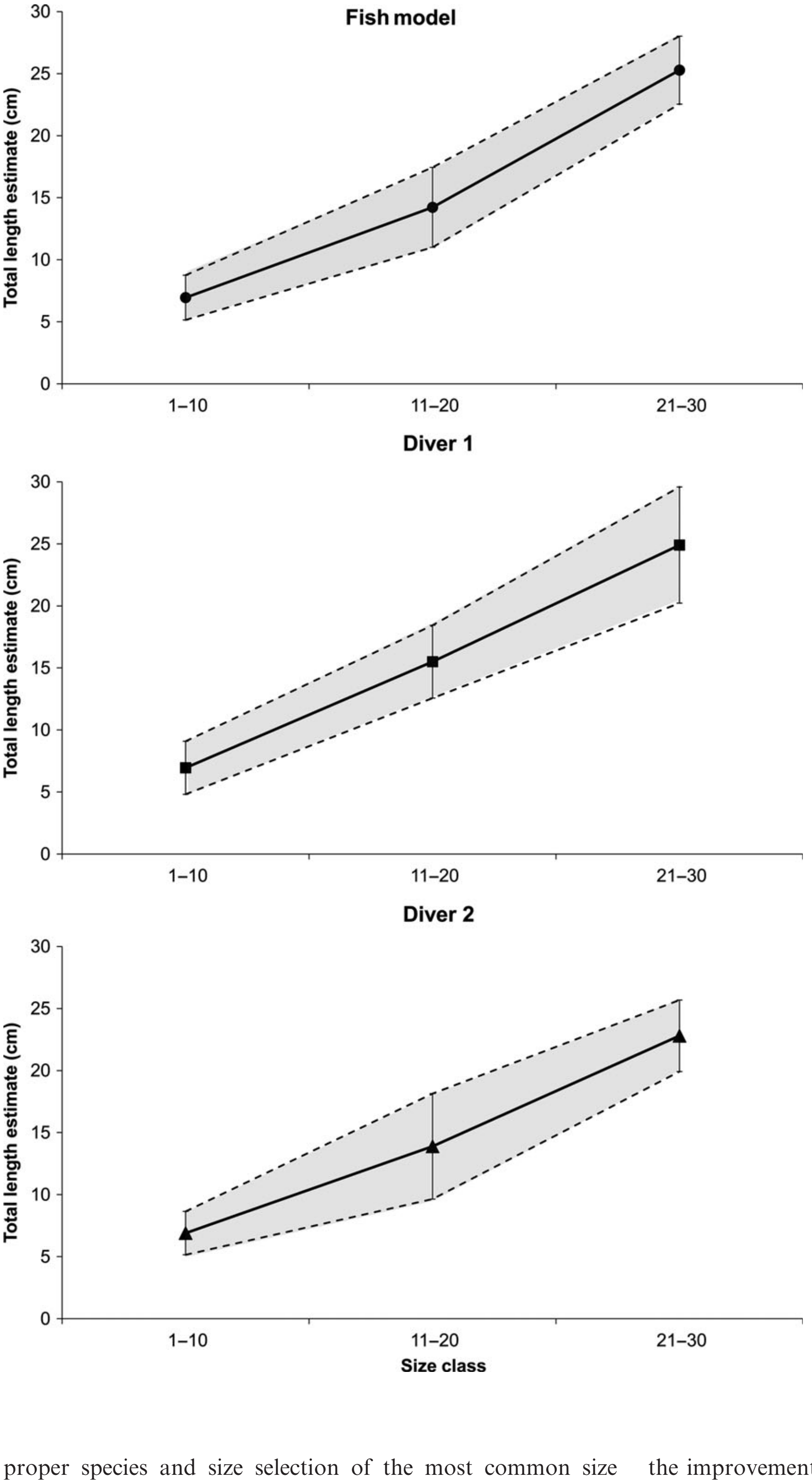

Fig. 7. Total length means with standard deviation of all fish models divided into three size classes, and estimates of the two divers during training representing their bias and precision; true values of fish models (●); estimates of Diver 1 (▲) and Diver 2 (■)

proper species and size selection of the most common size classes expected to occur in the study area are necessary for regular as well as calibration training to improve a diver's performance for the collection of scientific UVC data.

This study focuses on the total length estimate for reef fish biomass calculation and should be a significant addition to the improvement of reef fish stock assessment. A diver's lack of taxonomic knowledge also has the potential to create an additional bias in underwater visual census surveys (Thompson and Mapstone, 1997). This was not addressed in the study; however, length estimate training should be attended only by those divers who already have a good knowledge of reef fish taxonomy.

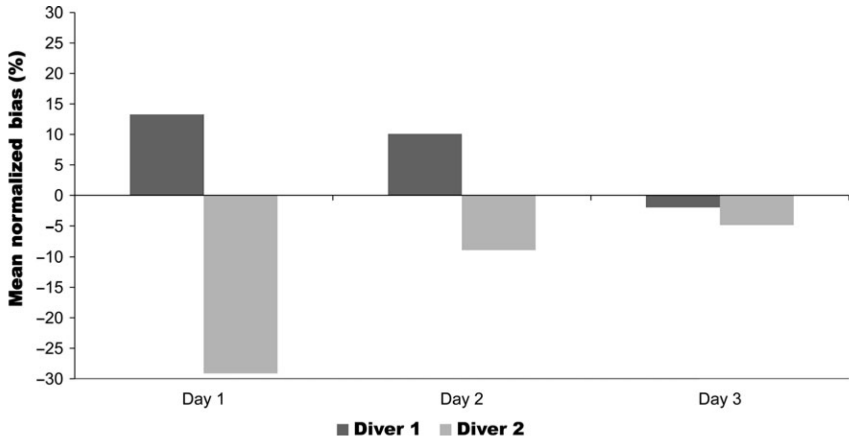

Fig. 8. Mean Normalized Bias (%) from two divers during training, November 2004; positive percentages = overestimates; negative percentages = underestimates

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