Precision and accuracy of fish length measurements obtained with two visual underwater methods

Marie-Joëlle Rochet
Laboratoire MAERHA, IFREMER
Rue de l'Ile d'Yeu, B.P. 21105
44311 Nantes, Cedex 03, France
E-mail address: mjrochet@ifremer.fr

Jean-François Cadiou
IFREMER (DNIS/SM/IM)—Centre Méditerranée
B.P. 330
83507 La Seyne, France

Verena M. Trenkel
Laboratoire MAERHA, IFREMER
Rue de l'Ile d'Yeu, B.P. 21105
44311 Nantes, Cedex 03, France

Abstract—During the *VITAL* cruise in the Bay of Biscay in summer 2002, two devices for measuring the length of swimming fish were tested: 1) a mechanical crown that emitted a pair of parallel laser beams and that was mounted on the main camera and 2) an underwater auto-focus video camera. The precision and accuracy of these devices were compared and the various sources of measurement errors were estimated by repeatedly measuring fixed and mobile objects and live fish. It was found that fish mobility is the main source of error for these devices because they require that the objects to be measured are perpendicular to the field of vision. The best performance was obtained with the laser method where a video-replay of laser spots (projected on fish bodies) carrying real-time size information was used. The auto-focus system performed poorly because of a delay in obtaining focus and because of some technical problems.

Manuscript submitted 22 July 2003
to the Scientific Editor's Office.

Manuscript approved for publication
20 April 2005 by the Scientific Editor.

Fish. Bull. 104:1–9 (2006).

Visual sampling of marine systems by SCUBA divers and underwater vehicles is increasingly used to estimate animal abundances, to observe natural behavior and response behavior to fishing gear *in situ*, and to assess community interactions (e.g., Bublitz, 1996; Auster et al., 1997; Davis et al., 1997; Uiblein et al., 2002; Trenkel et al., 2004). Visual methods also allow estimates of population-size structures without the bias caused by the size selectivity of fishing gear. Visual techniques have been used in the wild for measuring the length of animals by SCUBA divers (e.g., Yoshihara, 1997; Pfister and Goulet, 1999; Harvey et al., 2002a) or by submersibles (Love et al., 2000; Yoklavich et al., 2000). They have also been employed for estimating the length frequency of the catch of live tuna to be fattened after capture (Harvey et al., 2003), and in aquaculture to estimate the size range of fish (Petrell et al., 1997). Until now these techniques were mainly used in shallow waters or tanks. Because of the optical characteristics of sea water—its turbidity, the variations in light intensity with depth and water movements and fish movements, these methods are subject to measurement errors. Estimating the order of magnitude of this measurement error has been the focus of many studies (van Rooij and Videler, 1996; Yoshihara, 1997; Harvey et al., 2001, 2002a, 2002b, 2003).

Efficient methods for measuring fish length *in situ* can also be used in deeper waters not accessible to divers. Parallel laser projected from a video camera onto the seafloor or fish bodies permit accurate measurements (Love et al., 2000; Yoklavich et al., 2000). Albert et al. (2003) measured fish lengths on a video screen and then transformed these measurements into real length knowing the distance of the camera from the ground, its tilt angle, and the horizontal opening angle of the camera. If fish are not on or close to the bottom, it is necessary to know their distance off the bottom to apply this method. Auster et al. (1997) and Norcross and Mueter (1999) measured fish size on a video screen when the fish appeared between the skids of their ROV. The screen measurement is then related to the known distance of the skids. This method relies on the fish and skids being in the same horizontal plane and on the fish being perpendicular to the axis of the camera. Krieger (1992) used a submersible to estimate the size of rockfish.

Two methods were tested during the *VITAL* cruise in the Bay of Biscay, in late August and early Septem-

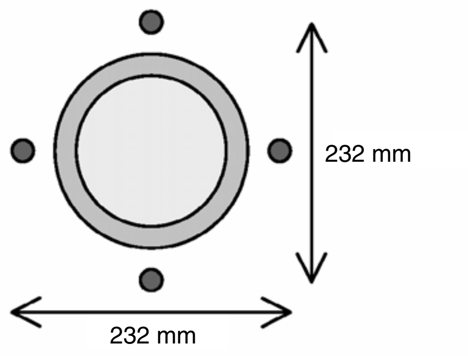

Figure 1
The four laser pointers mounted on a crown around the main camera in front of the ROV *Victor 6000*. The inner circle is the camera lens.

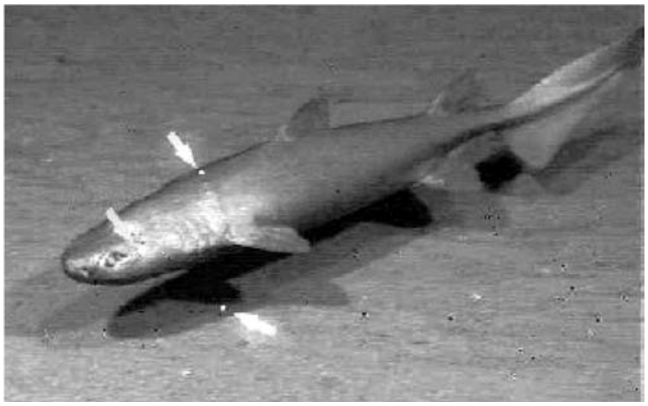

Figure 2
Laser spots (indicated by arrows) visible on and under a fish. These laser spots documented on videotape provided size information both in real time and during video replay.

ber 2002.[1] *Victor 6000*, a remotely operated vehicle (ROV) equipped with several video cameras and recorders, was operated at depths ranging from 1100 to 1500 m. Fish size was measured both by using a pair of parallel laser beams, and an auto-focus video camera linked to software for estimating object size based on the focal distance of the object in focus. In this study three sources of measurement variability were investigated: 1) systematic errors inherent to each method; 2) variability due to observer differences; 3) variability due to continuous fish movements and horizontal body orientation. To estimate these error components separately, rigid and articulated artificial objects ("artificial fish") of known size were measured repeatedly by several independent observers. Individuals belonging to several deep-sea fish species were also repeatedly measured. Mixed-effects models and heteroscedastic error models were fitted to the resulting measurements to compare the magnitude of errors due to different sources.

Materials and methods

Measurement devices

Both measurement devices were installed close to each other on the ROV *Victor*. The laser-beam crown was mounted on the main camera, which was itself attached to the pan and tilt unit. The METRAU© (SONY, model FCB-1X 47P) autofocus camera was mounted on the same pan and tilt unit.

Laser-beam pointers Four red laser pointers (10 mW, 635 nanometers [nm]) were mounted around the main camera housing (Fig. 1). The distance between each two opposite lasers was 232 mm. Red light is strongly attenuated by water but because of the relatively high power of the laser light-emitting diode (LED), a range of up to 7 m is reachable in clear waters.

To measure the fish and objects, the laser beams were projected on the target (Fig. 2). The laser spots, visible on the video, give size information both in real time and during video replay. The principle is simple, but several limitations exist. First, the measurement is correct only for an object located in a plane perpendicular to the laser axis. Second, the target should be large enough to be reached by at least two laser beams; the more laser impacts that are seen on the object to be measured, the easier the measurement.

For the measurement to be accurate, there must be a strict parallelism between the laser beams. This is complicated by the fact that the laser component itself (the diode with its optic lens) does not necessarily have a beam parallel to the axis of the component package. Further, designing an accurate alignment mechanism that is compatible with offshore and deep underwater operating conditions is difficult. The residual error after alignment is about 0.15°, which entails an error of 10 mm for the distance between two opposite spots at a distance of 4 meters (i.e., 4% of size).

METRAU camera The METRAU system is based on the autofocus video camera. The imaging device is an original equipment manufacturer (OEM) camera module similar to those used in off-the-shelf camcorders. The

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[1] Trenkel, V. M., N. Bailly, O. Berthelé, O. Brosseau, R. Causse, F. de Corbière, O. Dugornay, A. Ferrant, J. D. M. ordon, D. Latrouite, D. Le Piver, B. Kergoat, P. Lorance, S. Mahévas, B. Mesnil, J.-C. Poulard, M.-J. Rochet, D. Tracey, J.-P. Vacherot, G. Veron, and H. Zibrowius. 2002. First results of a quantitative study of deep-sea fish on the continental slope of the Bay of Biscay: visual observations and trawling. ICES CM 2002/L:18, 2002, 15 p.

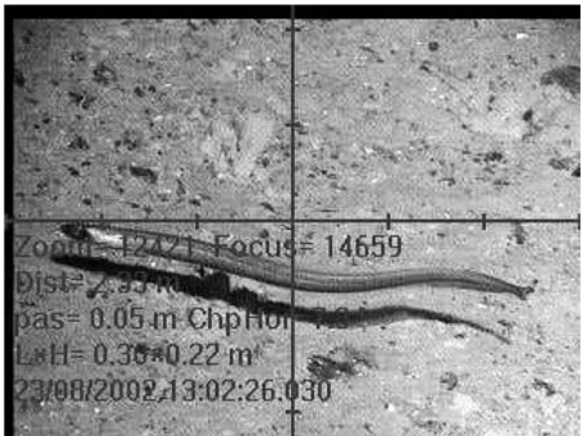

Figure 3

A METRAU video camera image with overlaid grid.

camera has a built-in automatic focus unit which adjusts lens settings to provide a sharp image. The camera is remotely controlled by a RS323 digital link and sends data back over this link, including zoom position and focal value (see details in Cadiou et al., 2004). A previous calibration in air and in a test tank provided correlation rules between raw data and field angle or focal distance.

When the system is operated, the data received by the computer are processed in real time. The object distance and the field angle are computed and a scale is overlaid on the video image (Fig. 3).

According to optical laws, the depth of focus decreases as the focal length increases. This means that in order to obtain an accurate measure of focal distance, a narrow field angle is required. In addition, the depth of focus increases when the focal distance moves towards infinity. Consequently, a domain of validity of the measurement can be defined. With the METRAU camera, there must be a target distance under three meters and a field angle of less than 6°. These constraints have to be combined with the following conditions: a steady image that would allow the automatic focal servo to stabilize; and avoidance of scenes with several image planes. In turbid waters, particles can create disturbing focal planes and affect the measurement process.

Measurement experiments

Artificial objects and live fish Objects of known size were used to estimate the potential bias in the length measurements obtained with the two devices. Three rigid objects—a can, a bottle, and a plastic tube measuring respectively 13, 30, and 66 cm—were repeatedly measured to evaluate device performance and observer-induced variability in the absence of errors induced by fish movement and variations in horizontal observation angles.

Fish movement makes the horizontal observation angle vary continuously. As a result, it is difficult to judge if and when an individual fish is perpendicular to the measurement axis. Further, fish seldom lie in a straight plane. Some species continuously flex their tail, others bend their whole body. To mimic the mobility of a real fish, a mobile object was built consisting of several pieces of Ertalyte (Quadrant Engineering Plastic Products, Bridgeport, CT) plates linked together with rope rings. This artificial fish was designed to be neutrally buoyant so that it could be moved by water currents and undulate like a real swimming fish. The "artificial fish" had three distinctively colored parts. Thus depending on how many parts were measured, a small (13 cm), medium (17 cm), or large (41 cm) "artificial fish" was the result. The real size of rigid objects and of the artificial fish was unknown to the observers throughout the measurement experiment.

In addition to measuring each of the rigid objects and the artificial fish, 351 individuals belonging to 21 deep-sea fish species were measured with both methods. The body sizes of these species ranged from 5 to 110 cm. Each individual fish was measured up to nine times. Altogether 2373 measurements were carried out.

Real time and postoperation measurements While the ROV was in operation, four to five observers were able to watch the video images. Real time measurements were performed by estimating sizes directly from the screen, without using any measuring instrument. Each observer was asked to write down his or her length estimate without announcing it, so that independent measurements were obtained. All artificial objects were measured by both trained and novice observers; real fish were measured only by trained observers, namely scientists and ROV pilots. All objects and fish were measured at distances of 2 to 5 meters.

Postoperation measurements were also performed on registered videos and digital images. For the laser method, the video tape was replayed. The tape was stopped when the image with an object or fish seemed to be in the best possible position. The fish or object was then measured with a ruler on the still video image. Postoperation measurements made with a ruler were also performed on digital snapshots taken from the videos in real time for both the laser and the METRAU method. A ruler was used rather than computer image analysis because it was easy and cost-efficient and it was felt appropriate for this trial appraisal of measurement methods. The bias introduced by this method was assumed to be negligible compared to observer-induced and fish-movement-induced errors.

Operational constraints prevented a full factorial design where all observers could use all methods and measure all objects.

Data analysis

Variance components for observers and fish movements The measurement variability due to observer differences and fish movements was estimated from the measurements of the artificial objects, for which the true size was known. Because the measurement variance was expected to be larger for the mobile artificial fish than for the rigid objects, an extended linear mixed-effects model (Pinheiro and Bates, 2000) was used to account for this expected heteroscedasticity. The model included true length as a fixed effect and observer as a random effect. Fixed objects and mobile objects (artificial fish) were allowed separate variances. The resulting model was

$$L_{i,f} = \mu + \beta L^* + o_i + f_j + \varepsilon_{ij}, \tag{1}$$

where $L_{i,j}$ = length measured by observer i of an object of class j={fixed, mobile} and of true size L^*;
$\mathrm{o}_i \sim N(0,\sigma(o))$; and
$\varepsilon_{ij} \sim \mathrm{N}(0,\sigma)$, whereas $f_j \sim \mathrm{N}(0, \sigma_j(f_i))$.

The model was fitted to the data from the eight observers who had measured all objects with the laser method.

Accuracy and precision for artificial objects An extended linear model including heteroscedastic variance terms was used to compare the precision and accuracy of the two methods. The model included fixed effects for true length and the measurement method. The estimated fixed effects allow assessment of the potential measurement bias of each method. The measurement errors for fixed and mobile artificial objects were modeled separately for each method. This allowed us to compare the precision of the methods. Thus, the fitted model was

$$L_{j,k} = \mu_k + \beta L^* + f_{jk} + \varepsilon_{jk}, \tag{2}$$

where k = the measurement method and j the object class as before. As in model 1, $\varepsilon_{jk} \sim N(0, \sigma)$. In contrast, $f_{jk} \sim N(0, \sigma_{jk}(f_{jk}))$ allowed for separate variances for each object-type and method pair. Only two trained observers used both measurement methods for all objects. Because there was no significant difference between their measurements, and in order to reduce the number of parameters to be estimated, no observer effect was included in this model.

Precision of fish measurements The precision of fish-length estimates was compared for two species, *Bathypterois dubius* and *Lepidion eques*. These species were selected for this analysis because they are abundant and relatively easy to measure, compared to other species that move faster or flex their body more often. Twenty-four individuals belonging to these two species were measured repeatedly by up to five observers using the real-time laser measurement method.

Because true fish size was unknown, measurement accuracy could not be estimated. For estimating the precision of fish measurements, an extended linear model with heteroscedastic errors was fitted to the fish length measurements. The model included a fixed individual fish effect (each fish had a different, unknown size) and a random observer effect; and fish species were allowed heteroscedastic variances to account for species behavior differences (*Lepidion* versus *Bathypterois*). The stationary species, *B. dubius,* is easier to measure compared to the more lively *L. eques*. The model was

$$L_{n,i,l} = \mu_n + o_i + s_l + \varepsilon_{nil}, \tag{3}$$

where $L_{n,i,l}$ = the length measurement obtained by observer i for individual fish n belonging to species l;
$o_i \sim N(0, \sigma(o))$; and
$\varepsilon_{nil} \sim N(0, \sigma)$, whereas $s_l \sim N(\mathrm{o}, \sigma_l\,(s_l))$.

Unfortunately, it was not possible to carry out a direct comparison between the precision of size estimates of fish and artificial objects because the latter were measured seven to 11 times, whereas the former were measured only two to seven times. Random subsamples could be carried out to obtain comparable sample size; unfortunately, subsamples from large samples would still have a larger variance than small samples.

All models were fitted by using Splus 6.0 for Unix (MathSoft, Seattle, WA). For heteroscedastic models, because of identifiability constraints, the fitting algorithm provided estimates of the ratio between the standard deviations of each class in relation to the standard deviation of a specified class instead of the full set of standard deviations.

Results

Precision and accuracy of measurements varied among objects and methods (Table 1). The best precision was obtained with the video-replays of laser measurements, whereas METRAU generally did not perform very well, especially on snapshots. The precision was generally much lower for mobile objects than for rigid objects. Measurement bias was generally low for the laser method, whereas the METRAU method systematically underestimated the size of objects. A variety of fish species with various sizes were measured. CVs for individual fish measurements varied from 3% to 23% (Table 2). Species were grouped according to their motion behavior (1=sitting on bottom motionless, 2=station holding or drifting, 3=slow swimming, 4=fast swimming [Lorance and Trenkel[2]]). CVs were found to differ between groups, increasing with mobility (mean CV in group 1: 8.9%; group 2: 9.7%; group 3: 12.9%; group 4 was excluded because there was only one individual, $P<10^{-5}$).

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[2] Lorance, P., and V. Trenkel. In preparation. Natural behaviour and reaction to an approaching ROV of large mid-slope species. IFREMER, Centre do Brest, B.P. 70, 29280 Plouzané, France.

Table 1

Summary of length measurements for artificial objects by five visual methods. Lengths (in cm) are given along with their coefficient of variation (%) and number of observations in parentheses. a.f. = artificial fish. The laser method entailed viewing laser points (that permit accurate length data) projected on fish. The METRAU method is based on an autofocus video camera.

Object	True size	Laser	Laser + video	Laser + snapshot	METRAU	METRAU + snapshot
Can	13	14.31 (13%, 26)	13.76 (3%, 5)	13.55 (4%, 5)	11.25 (7%, 10)	10.96 (7%, 5)
Bottle	30	30.87 (7%, 26)	31.90 (2%, 5)	31.47 (2%, 5)	26.90 (18%, 10)	32.05 (41%, 5)
Tube	66	65.62 (9%, 26)	66.40 (2%, 5)	66.66 (1%, 5)	44.25 (14%, 8)	40.75 (25%, 4)
Short a.f.	13	13.30 (13%, 21)	13.32 (6%, 3)	22.10 (23%, 2)	11.50 (6%, 2)	7.55 (33%, 6)
Medium a.f.	17	16.49 (14%, 21)	17.11 (5%, 3)	24.86 (25%, 2)	11.50 (18%, 2)	9.25 (32%, 6)
Large a.f.	41	40.80 (17%, 21)	44.87 (14%, 3)	63.23 (25%, 2)	30.00 (14%, 4)	23.21 (31%, 6)

Table 2

Summary of fish length measurements. n = number of individual fish measured for each species. m = total number of measurements. m/n = mean number of observations per individual. Mean length = average individual fish length (cm) per species. Mean CV = average individual coefficient of variation per species. Group = behavioral group of the species (1=sitting on bottom motionless, 2=station holding or drifting, 3=slow swimming, 4=fast swimming).

Species	n	m	m/n	Mean length	Mean CV	Group
Alepocephalus bairdi	2	4	2.0	48.4	8.2%	2
Bathypterois	87	586	6.7	19.2	8.9%	1
Breviraja caerulea	3	13	4.3	29.6	4.8%	2
Caelorinchus labiatus	15	73	4.9	28.7	10.2%	2
Cataetyx latyceps	1	5	5.0	24.1	12.4%	2
Chimaera monstrosa	6	23	3.8	91.4	9.2%	3
Coelorhyncus labiatus	2	8	4.0	25.4	14.9%	2
Coryphaenoides rupestris	21	77	3.7	45.4	12.1%	2
Cottunculus thomsoni	2	17	8.5	29.1	16.1%	1
Galeus melastomus	1	4	4.0	30.7	2.8%	4
Hoplostethus atlanticus	6	27	4.5	32.6	9.4%	2
Hydrolagus affinis	1	6	6.0	74.9	23.3%	3
Hydrolagus mirabilis	3	6	2.0	78.4	11.9%	3
Lepidion eques	161	814	5.1	26.6	9.6%	2
Mora moro	3	8	2.7	60.0	7.9%	2
Nezumia aequalis	10	22	2.2	32.8	8.9%	2
Notacanthus	2	5	2.5	44.6	10.6%	2
Phycis blenoides	1	4	4.0	44.8	15.3%	2
Syphobranchus kaupii	7	23	3.3	27.2	16.2%	3
Trachyrincus murrayi	4	7	1.8	38.9	3.5%	2
Trachyscorpia cristulata echinata	14	67	4.8	40.7	8.1%	1

Measurement variance for observers and fish movements

The standard deviation of the observer random effect, $\sigma(o)$, amounted to approximately 20% of the residual standard deviation. The standard deviation of the random effect for mobile objects, $\sigma_{mobile}(f_{mobile})$, was 40% higher than that for rigid objects, indicating that the measurement variability was lower for fixed than for mobile objects, as expected. The slope and intercept of the fixed effects did not significantly differ from 1 and 0, respectively. Thus the laser method is unbiased and performs equally well for all sizes in the range tested (Table 3).

Accuracy and precision of measurements for artificial objects

Size measurements carried out using the laser beams in real time or on registered videos were found to be

Table 3

Estimated fixed-effect coefficients and standard deviations for model 1 for the measurements of rigid and mobile objects by eight independent observers using the laser method. SE = standard error; CL =confidence limit.

Coefficient	Estimate	SE	P-value
μ	1.53	0.97	0.12
β	0.976	0.023	<0.0001

Standard deviation	Lower CL	Estimated	Upper CL
$\sigma(o)$	0.296	1.126	4.435
σ	4.369	5.535	7.014
$\sigma_{rigid}(f_{rigid})/\sigma_{mobile}(f_{mobile})$[1]	0.523	0.710	0.964

[1] Standard deviations were estimated in relation to the standard deviation for mobile objects.

Table 4

Estimated coefficients for model 2 for measurements of rigid and mobile objects by five variants of the two methods.

Coefficient	Estimate	SE	P-value
μ_{laser}	0.106	0.934	0.91
μ_{METRAU}	–7.198	1.621	<0.0001
$\mu_{laser+video}$	1.466	0.937	0.15
$\mu_{laser+snapshot}$	1.348	0.932	0.19
$\mu_{METRAU+snapshot}$	–9.516	1.806	<0.0001
β	0.976	0.023	<0.0001
σ	4.592		

Table 5

Estimates of the standard deviations of length measurements for rigid and mobile objects obtained by five variants of the two methods, from model 2. Number of measurements are given in parentheses. Estimates significantly different from 1 are in bold font.

Method	Rigid objects	Mobile objects
Laser	1.12 (21)	1.00[1] (9)
Laser + video	**0.21** (15)	1.03 (9)
Laser + snapshot	**0.19** (15)	3.43 (6)
METRAU	2.11 (20)	1.06 (8)
METRAU + snapshot	3.16 (14)	1.58 (18)

[1] All standard deviations are relative to the standard deviation for laser measurements of mobile objects.

unbiased, whereas the METRAU-based measurements underestimated the true length of objects by as much as 7 cm for real-time measurements and 10 cm for time-delayed measurements (Table 4, Fig. 4). In addition, the variance of METRAU measurements was systematically larger than the corresponding laser measurements (Table 5: ratios larger than 1). For rigid objects, laser-based video-replays had a lower variance than real time measurements. This lower variance for postoperational measurements was due to the allowance of videos to be replayed as many times as necessary in order to select the best image where an object was perpendicular to the optical axis. Use of a ruler also improves the measurement. The high estimation variance obtained for mobile objects measured with the laser method on digital snapshots was partially due to one outlier (Fig. 4B). The object was measured at a relatively great distance in somewhat turbid water. The outlier was not removed because these kinds of errors are to be expected under common measurement conditions in the field. Generally the most precise results were obtained for video-replays with the laser beam method.

Precision of fish measurements

The variance of the random effect for *B. dubius* was about 66% of the variance estimated for *L. eques*. For live fish, the standard deviation of the observer random effect was approximately 16% of the residual standard deviation (Table 6). This standard deviation is lower than that obtained for objects of known size because the residual variance was larger owing to the small number of repeated measurements obtained for each fish. It was not easy to repeatedly measure fish because of escapement behavior. In addition, only trained observers took part in this experiment, which reduced observer variability.

Discussion

The potential sources of errors and variability in visual fish length measurements are 1) the design and calibra-

Table 6

Estimates and 95% confidence limits for the standard deviations of the components of model 3 for fish size measurements obtained for two species by five independent observers using the laser method.

Standard deviation	Lower	Estimate	Upper
$\sigma(o)$	0.068	0.278	1.130
σ	1.096	1.702	2.642
$\sigma_{B.dubius}(S_{B.dubius})/\sigma_{L.eques}(S_{L.eques})$[1]	0.41	0.66	1.06

[1] Standard deviations provided in relation to the standard deviation for *Lepidion* measurements.

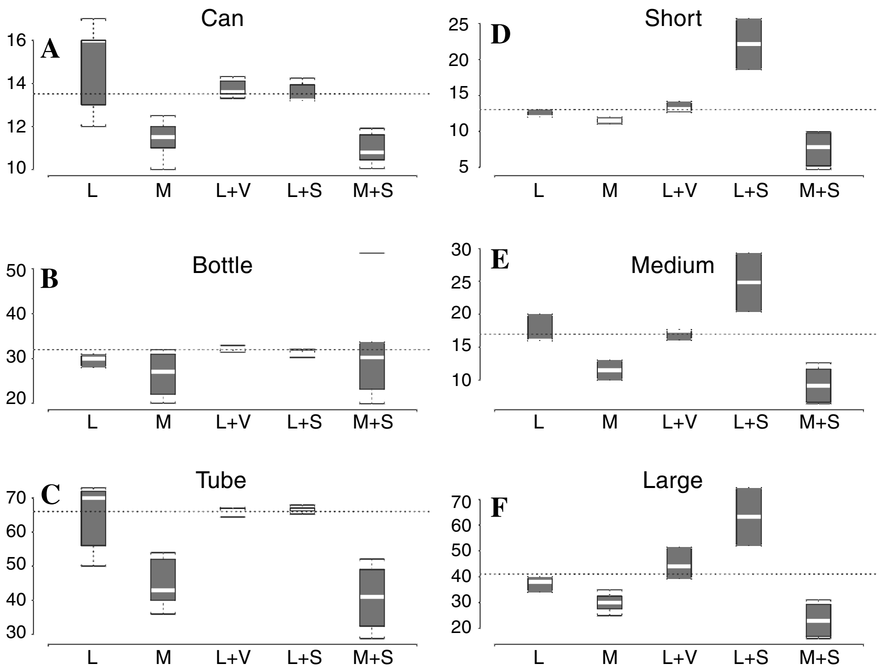

Figure 4

Boxplots for the distributions of length measurements (cm) obtained by five measurement methods for each of three fixed (left) and three mobile (right) objects. Boxes = interquartile range, white line = median, whiskers = extremes (excluding outliers). Dotted line is the true size of the object. L = laser method; M = METRAU method; L+V = laser video-replay; L+S = laser snapshot measurement; M+S = METRAU snapshot measurement.

tion of the measurement devices, 2) differences among observers, 3) orientation and position of fish in relation to the camera, and 4) swimming motion. We investigated each of these featuress.

Among the two methods tested during this study, the METRAU method performed poorly. It has several disadvantages. First, METRAU system needs the fish brought into focus when it is perpendicular to the field of vision. This may take time during which the fish can escape. Second, the registered video images do not include the superimposed calculated scales. Thus, unlike the laser method, it is not possible to replay the video to identify the best image. Postoperational measurements can be performed only by using the digital snapshots registered in real time. Third, this method had a higher variance than the laser method, probably because of the technical constraints just mentioned. Fourth, during the *VITAL* cruise the estimates were systematically biased downwards. Measurements carried out after the cruise in a laboratory pool confirmed this systematic underestimation to be ~20% of the real sizes. This result may be due to errors in the software which processes the output of the camera. Although the errors could probably be fixed, and the hardware improved to generate a video signal with the overlaid scale for recording, the other disadvantages are more difficult to eliminate, because of the intrinsic limitations of the system. Hence the method is not promising for estimating the size of fish in the wild.

By contrast, the laser beam method performed rather well, at least for rigid objects. We obtained CVs of 7–13% for rigid objects in real time and 1–4% with image postprocessing (Table 1), both of which compare well with CVs for silhouette measurements obtained with a single camera placed in a laboratory pool (with scale bars placed on the bottom of the pool) and with computer image processing (1%, Harvey et al., 2002b), or even with stereo-video measurements of silhouettes (0.6–7.5%, Harvey and Shortis, 1996). Length measurements were always unbiased and postoperational measurements on video images reached a high precision for rigid objects and for small- to medium-size mobile objects. Thus the method seems suited for measuring the size of animals of low mobility, like invertebrates, along visual observation transects.

The variance due to differences between observers was about 20% of the residual variance. This variance was reduced to 16% when measurements were performed by trained observers. This is true for real-time measurements. For video-replays of the laser-beam data, the variance due to observers was very small because of the use of a ruler instead of subjective extrapolation of the known laser distance. The use of automated analysis of video images may further reduce the observer error source.

The major difficulty in measuring fish length *in situ* is caused by fish mobility, which causes them to be in variable orientations and positions in relation to the camera, and also to be flexed. We addressed both variance components together by comparing measurements of mobile objects ("artificial fish") and rigid objects. With the laser beam method, the measurement standard deviation of rigid objects was estimated to be 20% of the standard deviation of mobile objects (95% confidence limits: 6–75%). These components may be of the same order of magnitude as those for fish measurements, although fish measurements could not be estimated in our study because the true size of the fish was unknown. An attempt to disentangle both components is provided by estimating the difference between the precision obtained for species with contrasting behaviors. *Bathypterois dubius* individuals lie motionless on the bottom and seldom move, but because they stand on their fins they are never exactly perpendicular to the camera. By contrast, *L. eques* swims close to the bottom and tends to escape when the ROV is approaching too closely. This species continuously moves its tail; therefore it is very difficult to obtain an image with the whole body properly orientated and straight. The standard deviation of *B. dubius* length measurements was estimated to be 66% of that of *L. eques*. This difference is smaller than the difference between rigid and mobile objects above; therefore we conclude that the major part of variance is due to the orientation of the fish in relation to the camera. Similarly, the estimated CVs of 21 species grouped by motion behavior differed only slightly. This is consistent with previous studies which have shown that relative errors of single-camera or stereo-video measurements of silhouettes or frozen fish could reach 10% to 30%, depending on the distance to the camera, when the angle to the camera was increased from 0° to 60°, whereas the measurement CVs increased fourfold (Harvey and Shortis, 1996; Petrell et al., 1997; Harvey et al., 2002b). By contrast, error due to tail flexion and muscle contractions during swimming motions was estimated at ~5% in a comparison of "linear" to "sinusoidal" length of dorsally photographed sharks (Klimley and Brown, 1983) and at 0.5% for repeated stereo-video measurements of swimming tunas (Harvey et al., 2003).

In conclusion, the major source of measurement error for live fish may be their orientation and position in relation to the camera. For animals that are sessile or lying immobile on the ocean floor, this would be much reduced if the camera and laser beams were mounted vertically instead of obliquely. Thus the laser-beam method may be potentially useful for measuring benthic animals. For mobile animals, however, stereo-video methods (Harvey et al., 2001; Harvey et al., 2002a; van Rooij and Videler, 1996) may be more promising, and are continuously improving (Harvey et al., 2003).

Acknowledgments

We thank all observers for taking part in the experiment, and the ROV pilots for their willingness and skill at pursuing fish and in obtaining positions suitable for being measured. An anonymous referee gave very helpful comments on a previous version of this manuscript.

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