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ESTIMATING FISH LENGTH FROM VERTICAL MORPHOMETRIC PARAMETERS

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ABSTRACT

Fish lengths are important for resource assessment and management, particularly when methods to obtain age or weight are impractical or harmful to the resource. Underwater videos are commonly used to monitor fisheries because they are less invasive than other sampling methods. However, because of a fish's continuous lateral flexion while swimming and angle to the viewer, its length is often difficult to estimate from videos. In many cases, vertical morphometric parameters may be measured more accurately than horizontal parameters. To evaluate vertical parameters as predictors of length, regression equations were developed for species observed in underwater videos along the California coast, including kelp greenling, *Hexagrammos decagrammus*, lingcod, *Ophiodon elongatus*, black rockfish, *Sebastes melanops*, and blue rockfish, *S. mystinus*. A separate regression was calculated for combined rockfish, *Sebastes* spp., to serve as a monitoring tool until sufficient samples are collected for more specific regressions. Species combined were gopher rockfish, *S. carnatus*, copper rockfish, *S. caurinus*, black and yellow rockfish, *S. chrysomelas*, yellowtail rockfish, *S. flavidus*, quillback rockfish, *S. maliger*, black rockfish, *S. melanops*, vermilion rockfish, *S. miniatus,* blue rockfish, *S. mystinus*, China rockfish, *S. nebulosus*, canary rockfish, *S. pinniger*, and olive rockfish, *S. serranoides*. Vertical parameters were depth at mid-orbit, depth at pelvic fin origin, depth at anal fin origin, and least depth at caudal peduncle. Relationships between each vertical parameter and fork length were strongly correlated for individual species ($r \geq 0.973$) and combined rockfish species ($r \geq 0.947$).

INTRODUCTION

Fish length measurements are important for resource assessment and management (Petrell et al. 1997; Harvey et al. 2001a, 2002b; Cadiou et al. 2004), including evaluation of population age structure and biomass for harvest regulations and habitat protection. Fish lengths are particularly useful when methods to obtain age or weight are impractical as part of a sampling program (Karpov et al. 1995). Less invasive monitoring tools have been identified as priorities for collecting length or age data (Naiberg et al. 1993; Robins et al. 2000; Harvey et al. 2003). Researchers have used various techniques, including underwater video and still images (Klimley and Brown 1983; Naiberg et al. 1993; Harvey and Shortis 1996; Petrell et al. 1997; Love et al. 2000, 2006; Yoklavich et al. 2000, 2002; Harvey et al. 2001a, b, 2002a, b, 2003; Cadiou et al. 2004; Rochet et al. 2006). However, length is often difficult to estimate from videos because of continuous lateral flexion and variable orientation of swimming fishes toward the camera (Klimley and Brown 1983; Naiberg et al. 1993; Harvey et al. 2002a, 2003; Rochet et al. 2006).

Measurements of live fish (Naiberg et al. 1993; Harvey et al. 2002b, 2003), artificial models (Harvey et al. 2002b; Rochet et al. 2006), dorsal views of swimming fish (Klimley and Brown 1983), and allometric relationships of squid (Zeidberg 2004), dolphins (Bräger and Chong 1999), and whales (Ratnaswamy and Winn 1993; Dawson et al. 1995) have been evaluated for length estimation in photographs or videos. Accuracy and precision of length measurements decline substantially when fish models are oriented 60 degrees or more away from the camera (Harvey et al. 2002b). Techniques that provide depth perception such as visual estimates by divers and stereoscopic cameras (e.g., Harvey et al. 2002a, b; Yoklavich et al. 2000, 2002) still do not correct for angle of incidence. Current methods are also limited to simultaneous views of the head and tail (Harvey et al. 2002b), suggesting the need to evaluate whether vertical morphometric parameters at various points along the lateral axis may be used to estimate length.

The vertical axis of a fish is typically oriented perpendicular to the bottom either because of swim bladder position (e.g., scorpaenids) or behavioral orientation to the substrate (e.g., hexagrammids). Assuming perpendicular orientation, and given the camera angle relative to the bottom and distance to a fish, actual height can be measured with a trigonometric function. If equations can be developed from vertical parameters to predict length, then these parameters may be used as surrogates for length in video analysis. In any given video image, the clearest view of a fish may include only the anterior, middle, or posterior body region. Therefore, vertical parameters should be evaluated at various locations along the lateral axis. Given improvements in video and photographic quality, even relatively small features such as caudal peduncle depth may become a practical proxy for body length. The impetus for this research was the need to estimate biomass by species in addition to fish counts obtained from underwater video surveys. The objective of this study was to publish fish lengths and vertical parameters for a subset of nearshore species observed in video surveys along the coasts of California and Oregon. Reported here are results for kelp greenling, *Hexagrammos decagrammus*, lingcod, *Ophiodon elongatus*, black rockfish, *Sebastes melanops*, and blue rockfish, *S. mystinus*. Results are also reported for 11 combined rockfish, *Sebastes* spp., to serve as a monitoring tool until sufficient samples are collected for more specific regressions. Combined species include gopher rockfish, *S. carnatus*, copper rockfish, *S. caurinus*, black and yellow rockfish, *S. chrysomelas*, yellowtail rockfish, *S. flavidus*, quillback rockfish, *S. maliger*, black rockfish, *S. melanops*, vermilion rockfish, *S. miniatus*, blue rockfish, *S. mystinus*, China rockfish, *S. nebulosus*, canary rockfish, *S. pinniger*, and olive rockfish, *S. serranoides*. These results, once published, will then be applied *in situ* to further evaluate their utility in estimating length.

METHODS

Measurements

All parameters were measured to the nearest millimeter with calipers for vertical parameters and measuring boards for length. Vertical parameters were measured at four locations: depth at mid-orbit; depth at pelvic fin origin; depth at anal fin origin; and least depth at caudal peduncle (Fig. 1). Fork length was measured from the most anterior part of the closed mouth to the center of the fork (e.g., Holt 1959; Laevastu 1965; Miller and Lea 1972; Anderson and Gutreuter 1983), or to the median caudal rays for fish without forked tails.

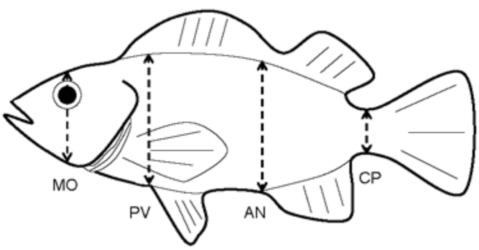


Figure 1. Vertical parameters measured on fish species observed in underwater videos along the California coast. (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)

Samples

Attempts were made to cover a wide range of sizes greater than or equal to 110 mm (Chen 1971). Fresh and preserved samples and sexes were combined (Chen 1971; Karpov and Kwiecien[1] 1988a). Preserved specimens were measured from the California Academy of Sciences collection on 23 and 24 June 2008. Fresh specimens were measured from sport and commercial catch in Crescent City (29 May 2008), Eureka (11 Jun 2008), Santa Cruz (28 Jun 2008), and Fort Bragg (10 Aug 2008), California.

Analyses

Following database entry and verification by two individuals, original measurements were plotted for exploratory analysis and detection of possible errors. Dependent and independent variables, fork length and vertical measurements, respectively, were transformed

[1]Karpov, K. and G. Kwiecien. 1988a. Conversions between total, fork, and standard lengths for 41 species in 15 families of fish from California using fresh and preserved specimens. California Department of Fish and Game, Marine Resources Administrative Report No. 88-9. 14 pp.

using natural logarithms to reduce heteroskedasticity of variance around the dependent variable (Snedecor and Cochran 1989, p. 290). For each species, four regressions were calculated, one for each vertical variable against fork length.

RESULTS

Initial plots (Figs. 2-6) indicated no outliers in our data. For single species, each vertical parameter correlated highly with fork length (Table 1; $r \geq 0.973$). The lowest correlation with fork length was depth at mid-orbit for black rockfish, and the highest was depth at pelvic fin origin for lingcod (Table 1; $r = 0.997$). Vertical parameters and fork length were also highly correlated for combined rockfish (Table 1; $r \geq 0.946$), with depth at mid-orbit having the lowest correlation and depth at anal fin origin having the highest (Table 1; $r = 0.975$).

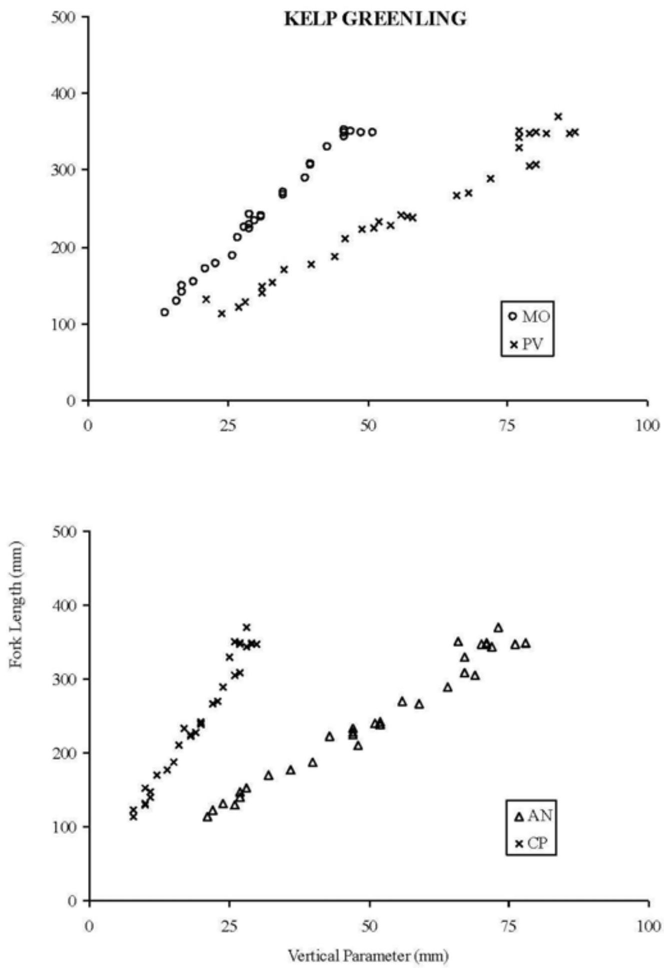


Figure 2. Scatter plots of non-transformed fork lengths and vertical parameters for kelp greenling. (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)

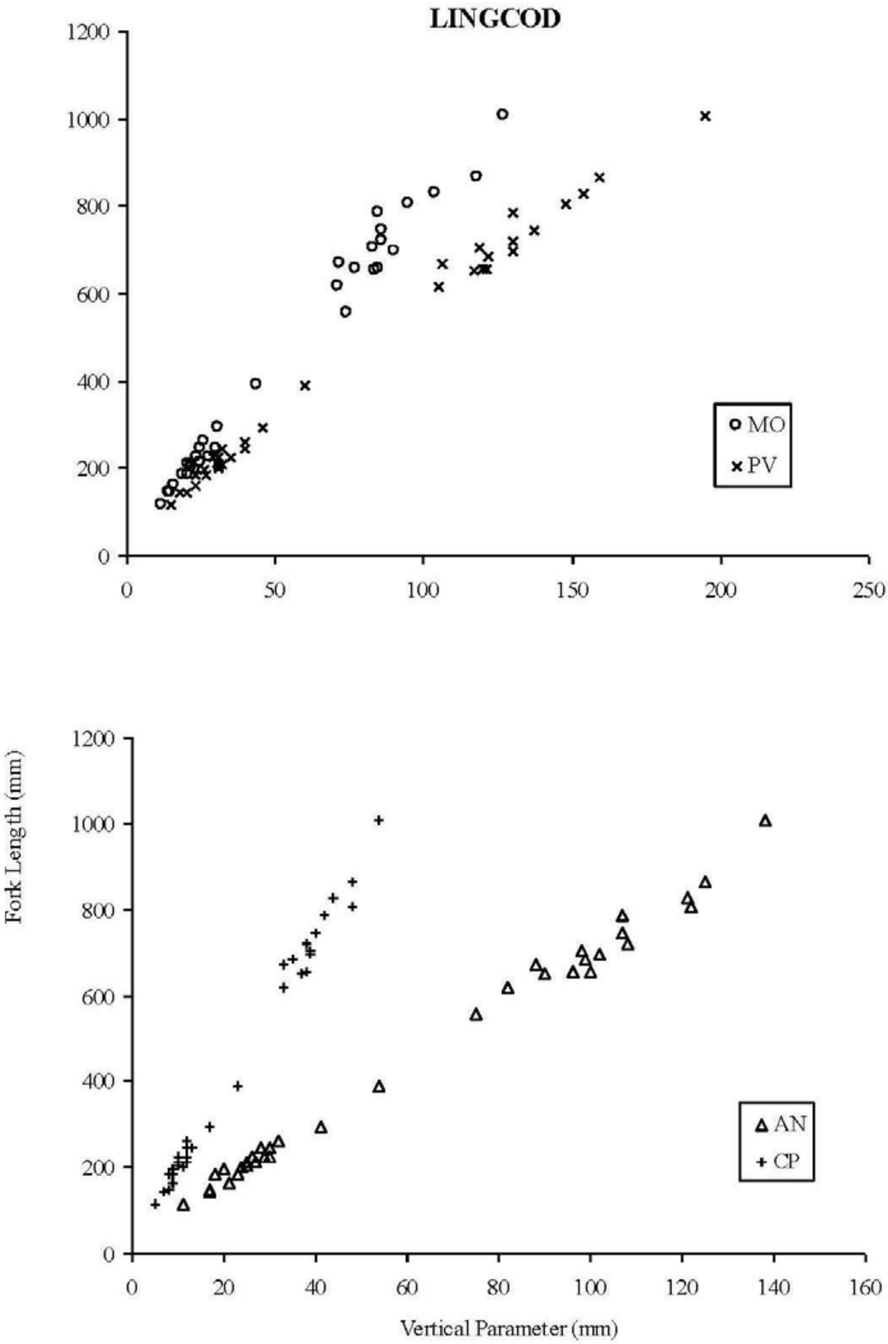
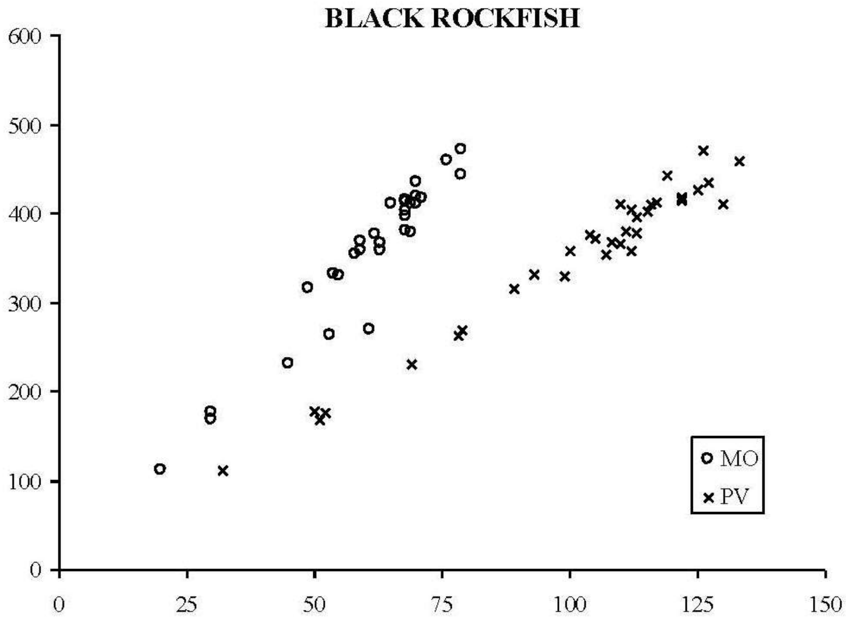


Figure 3. Scatter plots of non-transformed fork lengths and vertical parameters for lingcod. (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)



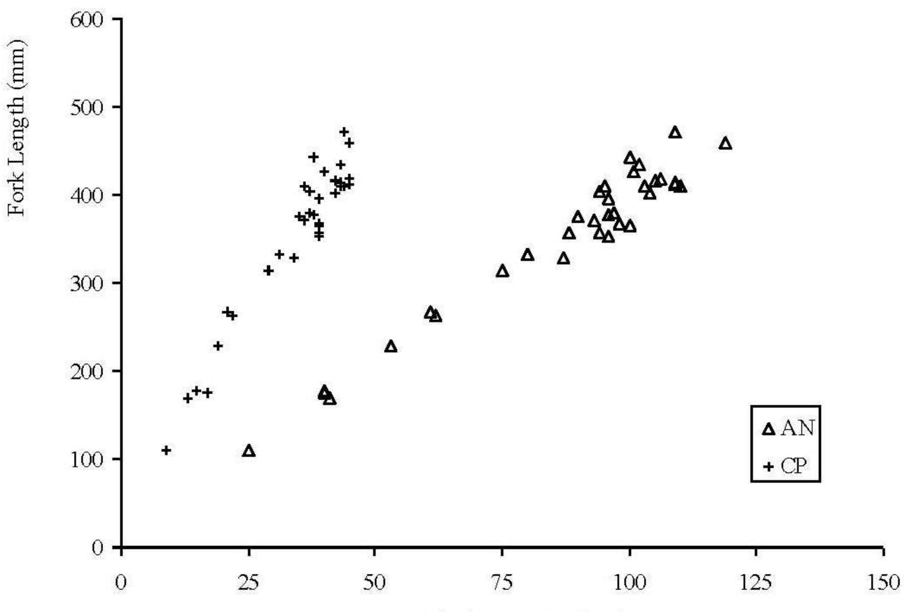


Figure 4. Scatter plots of non-transformed fork lengths and vertical parameters for black rockfish. (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)

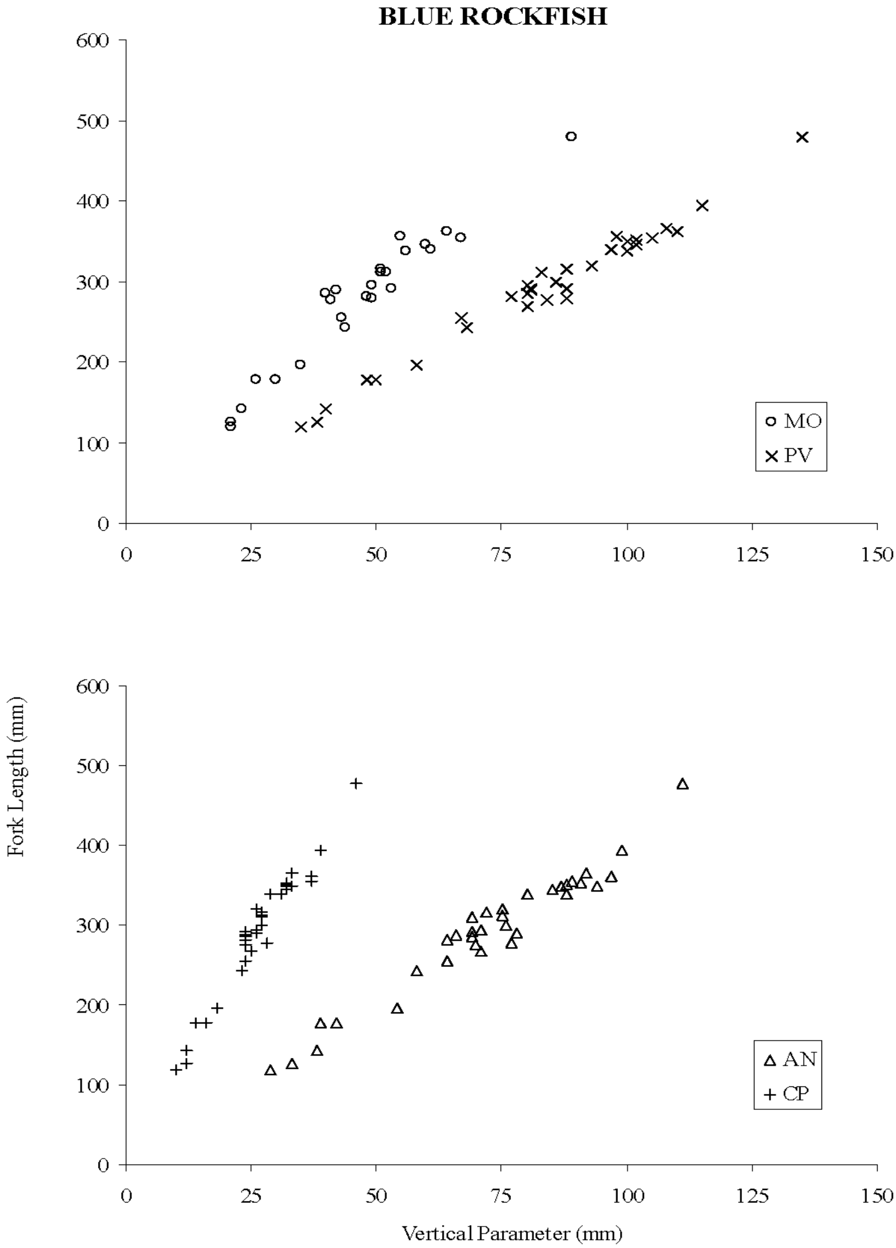
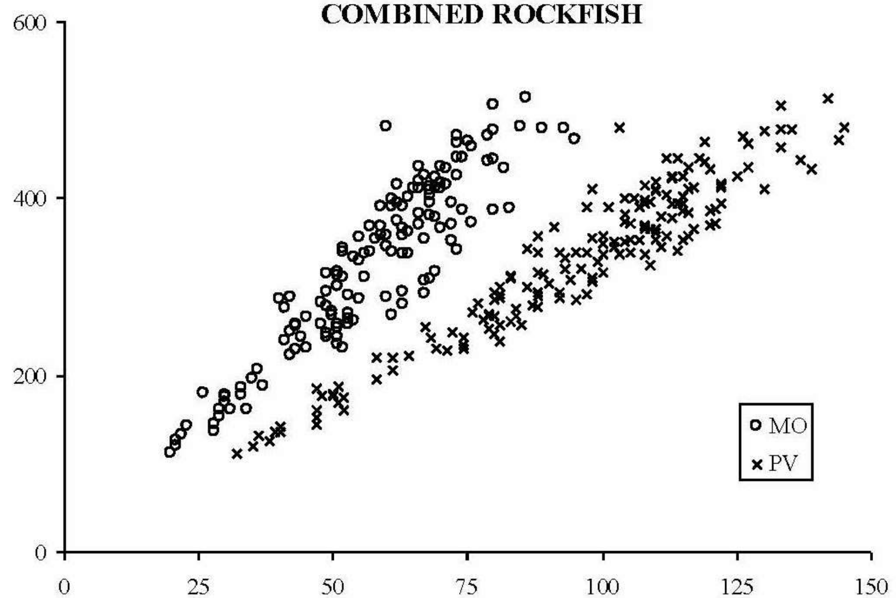


Figure 5. Scatter plots of non-transformed fork lengths and vertical parameters for blue rockfish. (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)



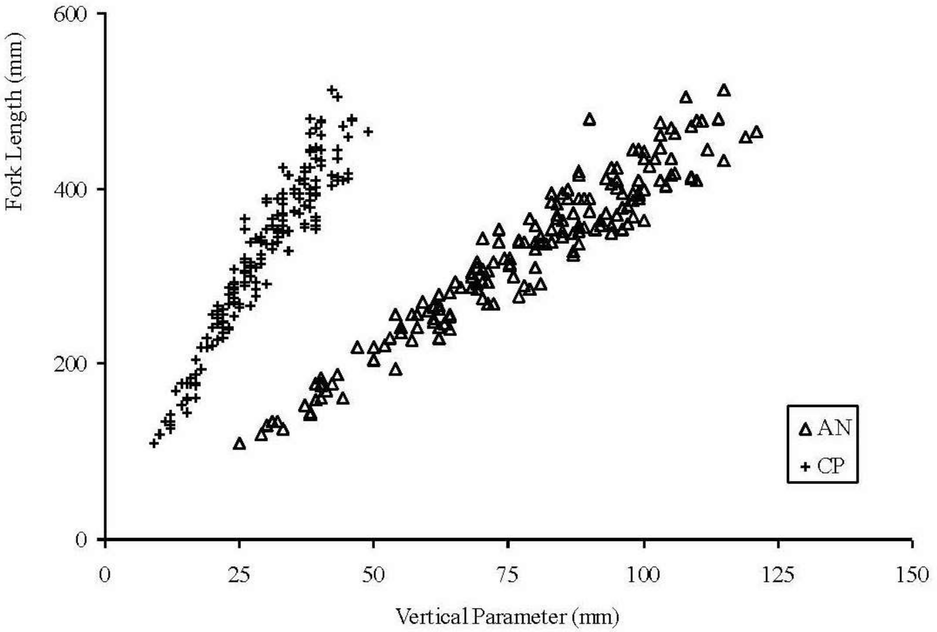


Figure 6. Scatter plots of non-transformed fork lengths and vertical parameters for combined rockfish (gopher rockfish, copper rockfish, black and yellow rockfish, yellowtail rockfish, quillback rockfish, black rockfish, vermilion rockfish, blue rockfish, China rockfish, canary rockfish, and olive rockfish). (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)

Table 1. Sample number, vertical size range, and regression equation values for predicting fork length from vertical parameters of kelp greenling, lingcod, black rockfish, blue rockfish, and combined rockfish (gopher rockfish, copper rockfish, black and yellow rockfish, yellowtail rockfish, quillback rockfish, black rockfish, vermilion rockfish, blue rockfish, China rockfish, canary rockfish, and olive rockfish). (MO = depth at mid-orbit; PV = depth at pelvic fin origin; AN = depth at anal fin origin; CP = least depth at caudal peduncle)

Regression: $Y=\exp(a)*X^b$, Y=Fork Length (mm), X=Vertical Parameter (mm)

Vertical Parameters/ Species	n*	r	Vertical Parameter (mm)** min	max	Regression Values*** $\exp(a)$	b	S_{y*x}
MO							
kelp greenling	28	0.995	14	51	10.960	0.898	3.368
lingcod	34	0.996	12	127	12.645	0.903	16.142
black rockfish	30	0.973	20	79	4.828	1.045	2.867
blue rockfish	25	0.977	21	89	7.937	0.925	3.023
rockfish spp.	143	0.946	20	95	5.880	0.990	15.347
PV							
kelp greenling	32	0.986	21	87	7.977	0.850	4.791
lingcod	35	0.997	15	195	12.026	0.842	17.991
black rockfish	34	0.993	32	133	3.276	1.011	3.582
blue rockfish	34	0.991	35	135	3.750	0.984	3.383
rockfish spp.	173	0.973	32	145	3.399	1.003	17.913
AN							
kelp greenling	32	0.990	21	78	7.652	0.885	4.640
lingcod	36	0.996	11	138	13.042	0.865	17.696
black rockfish	34	0.989	25	119	6.161	0.906	3.967
blue rockfish	34	0.981	29	111	4.427	0.978	3.336
rockfish spp.	175	0.975	25	121	4.609	0.978	18.536
CP							
kelp greenling	32	0.989	8	30	18.152	0.878	4.662
lingcod	35	0.994	5	54	24.138	0.922	16.343
black rockfish	34	0.979	9	45	20.170	0.809	4.350
blue rockfish	34	0.983	10	46	14.869	0.910	3.602
rockfish spp.	175	0.969	9	49	14.968	0.911	19.656

* Sample numbers were smaller for depth at mid-orbit because of flared branchiostegal rays obstructing measurement. Samples were also missing from some vertical parameters when fish escaped to water before all measurements were taken.

** Miniumum and maximum vertical parameters for combined rockfish (rockfish spp.) varied by species. Vertical measurements for combined rockfish are the minimum and maximum overall. The combined regression will be used for similarly shaped species until more specific regressions are available.

*** For nineteen samples, total length was measured instead of fork length. To include these samples in the regressions, fork lengths were converted from total length for eight black rockfish, four china rockfish, one copper rockfish, one gopher rockfish, and five quillback rockfish with equations provided by Echeverria and Lenarz (1984). Fork lengths for two lingcod were converted from total length with equations provided by Karpov and Kwiecien[1] (1988a).

DISCUSSION

We selected four vertical parameters based on their previous use by researchers, feasibility of obtaining precise measurements, and practicality of measuring these parameters from video data in the future. For example, in sample videos of live fish in their natural habitat, pelvic fin origin was easier to determine than was the posterior gill margin or the dorsal fin origin. Morphometrics widely used for a variety of taxa are depth at pelvic fin origin (e.g., Phillips 1957; Miller 1988; Chen and Shao 1996), depth at anal fin origin (e.g., Phillips 1957; Holt 1959; Laevastu 1965; Miller 1988; Chen and Shao 1996), and least depth at caudal peduncle (e.g., Phillips 1957; Holt 1959; Laevastu 1965; Miller 1988; Kottelat 1990; Chen and Shao 1996; Compagno 2001; Coelho and Erzini 2008). Systematists have measured body depth at the anterior margin of the orbit (Kottelat 1990) and from the orbital crest down through the center of the pupil (Holt 1959; Laevastu 1965); however, mid-orbit depth from the top of the head (North et al. 2002) was seen more easily in sample videos. Depth at mid-orbit was not measured when branchiostegal rays were locked in a flared position, obstructing measurement. We therefore had the fewest samples for this parameter (Table 1). This factor may also limit the utility of depth at mid-orbit as a predictor of length from videos of the anterior body region. Depth at mid-orbit and least depth at caudal peduncle lack defined reference marks, which may also increase the likelihood of error in measurements (Harvey et al. 2003). Another possible limitation is that these measurements are small relative to length. Nevertheless, the two parameters were observed in videos of the anterior and posterior body regions and were measured in anticipation of technological advancements improving video resolution or for applications using still photography.

We chose fork length because it is consistent with other protocols for monitoring marine fish species (e.g., Holliday et al.[2] 1987) and is practical for visual data. Extreme or maximum total length, measured to the end of the pinched tail (Holt 1959; Laevastu 1965; Anderson and Gutreuter 1983), has also been used as a standard (e.g., Holt 1959; Hubbs and Lagler 1959; Miller and Lea 1972; Karpov and Kwiecien[3] 1988b; Karpov et al. 1995) but was not practical for our study which included preserved specimens. Measurements for species in our study can be compared to standard length or extreme total length with conversion equations provided by Echeverria and Lenarz (1984) and Karpov and Kwiecien[1] (1988a). Natural total length is a useful alternative to fork length for video analysis. Conversions between standard length, fork length, and natural total length are available for many marine and fresh water fish species (Gaygusuz et al. 2006), but not for species reported here. The conversions are important for estimates of biomass because weight-length relationships for various species have been developed from different body length measurements. However, because many species in this study have lobed or squared tails, natural total length and fork length are identical. For species with variably forked tails, differences between fork length and natural or extreme total length may be negligible concerning the level of accuracy for biomass estimates. Lengths estimated using visual

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[2]Holliday, M., Deuel, D., and W. Scogen. 1987. Marine Recreational Fisheries Statistics Survey, Pacific Coast 1986. U.S. Department of Commerce, NOAA/NMFS Current Fisheries Statistics. No. 8393. 114 pp.

[3]Karpov, K. and G. Kwiecien. 1988b. Marine Recreational Fisheries Statistics Survey for Northern and Central California. Quarterly Report No. 19, January-March 1984. California Department of Fish and Game, Marine Resources Administrative Report No. 88-19. 281 pp.

survey by divers and submersible (Yoklavich et al. 2000, 2002; Love et al. 2000, 2006) most closely approximate fork length or natural total length but not extreme total length. Depending on the study comparison, fork lengths estimated using our methods can be converted to either standard length or extreme total length (Echeverria and Lenarz 1984; Karpov and Kwiecien[1] 1988a) or used as a proxy for natural total length.

Error terms of fork lengths tend to be proportional to the fork length. For this reason we used natural logarithm transformations (Snedecor and Cochran 1989). Variances in the transformed space are homogeneous, thereby meeting a basic assumption for linear regression. However, it should be noted that when anti-logged, transformations can result in a slightly negative bias in predicted values (fork lengths). Our lower size limit was likely to have avoided ranges exhibiting departure from linearity, which has been observed for some morphometrics in rockfish smaller than 110 mm in length (Chen 1971). If allometry existed, the data transformations also allowed for description of those relationships in linear terms (Huxley 1932; Martin 1949; Chen 1971; Ratnaswamy and Winn 1993; Bräger and Chong 1999; Zeidberg 2004). The variation we observed may be explained by geography, season, sex, measuring precision, or preservation method—factors that were assumed to have little or no effect on the regressions. Preservation can shrink fish variably depending on the solution, duration in solution, and morphometric parameter (Holt 1959). In a study on mackerel, body depth shrank more than body length in some solutions (Holt 1959). If preservation affected morphometric parameters similarly in our study, the predicted value (fork length) would be positively biased. Ideally, the regressions should be calculated from fresh fish only. However, we were unable to collect sufficient sample numbers and sizes from recreational and commercial catch alone, requiring an additional 45% preserved specimens. Fresh and preserved specimens have been combined for other morphometric analyses of rockfish (Chen 1971). The high correlations (Table 1) we observed indicate that any biases were minimal.

We had sufficient samples to analyze kelp greenling, lingcod, black rockfish, and blue rockfish (Table 1). For other species, either our sample number or the length range was inadequate to calculate regressions. However, for our work, lengths by species are still needed to estimate biomass from videos. We therefore combined data from several rockfish species to calculate relationships to be used until more specific regressions are available. Although the combined regressions include variable rockfish body shapes, from fusiform (e.g., olive rockfish) to more deep-bodied species (e.g., gopher rockfish), they are useful for estimation of overall biomass in our study areas. Biomass estimates may then be updated by species as more regressions are calculated.

Use of these regressions for estimating length and weight is supported by high correlations (Table 1). When possible, predicted fork lengths may also be averaged from more than one vertical parameter regression. While absolute accuracy may decrease with larger fish, the level of discrimination should be appropriate for age structure and biomass estimates from videos when lengths are corrected for camera distance and tilt angle (Figure 7). These regressions may also be used to update existing analyses of underwater videos, in which the most ideal views may be of anterior, middle, or posterior body regions.

Future research should evaluate accuracy and precision of the regressions for estimating lengths from videos of live, swimming fish with known body measurements. Evaluations should also include estimates by experienced divers trained to estimate size by eye, a technique widely used for visual sampling (e.g., Harvey et al. 2002a, b; Yoklavich et al. 2000, 2002). True mean length is likely to be underestimated in such surveys because of sinusoidal

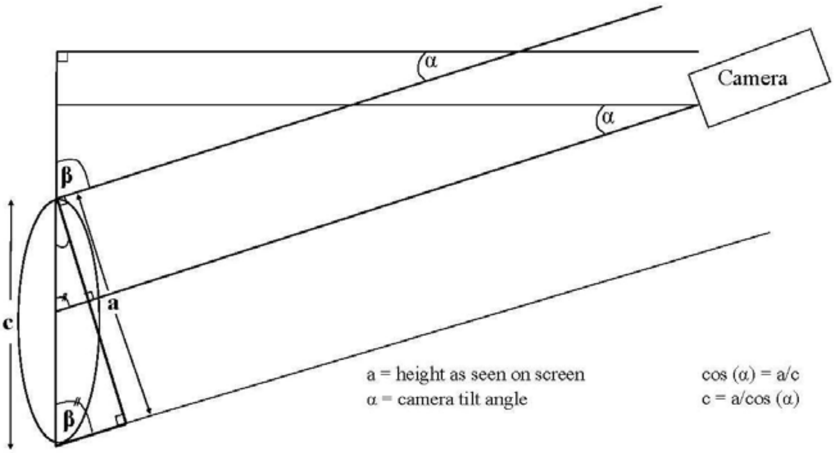

Figure 7. Geometry and mathematical proofs for estimating vertical parameters of fish observed in underwater videos along the California coast. (a = height of fish as observed in camera = side of triangle adjacent to angle alpha); c = actual height of fish = hypotenuse of right triangle)

fish movement (Naiberg et al. 1993; Harvey et al. 2002a, 2003; Rochet et al. 2006) and the unknown angle relative to the viewer (Naiberg et al. 1993). However, accuracy of vertical parameters depends on video clarity, regression error, and accurate estimation of camera angle.

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LITERATURE CITED

Anderson, R.O., and S.J. Gutreuter. 1983. Length, weight, and associated indices. Pages 283-324 *in* Fisheries Techniques, Nielsen, L.A. and D.L. Johnson, eds. American Fisheries Society, Bethesda, Maryland.

Bräger, S. and A.K. Chong. 1999. An application of close range photogrammetry in dolphin studies. Photogrammetric Record 16:503-517.

Cadiou, J., V. Trenkel, and M. Rochet. 2004. Comparison of several methods for *in situ* size measurements of moving animals. Pages 438-444 *in* Proceedings of The Fourteenth International and Polar Engineering Conference, Toulon, France, May 23-28, 2004.

Chen, L-C. 1971. Systematics, variation, distribution, and biology of rockfishes of the subgenus Sebastomus (Pisces, Scorpaenidae, Sebastes). Bulletin of the Scripps Institute of Oceanography, University of California Press 18:1-104.

Chen, I-S., and K-T. Shao. 1996. A taxonomic review of the gobiid fish genus *Rhinogobius* Gill, 1859 from Taiwan, with descriptions of three new species. Zoological Studies 35:200-213.

Coelho, R. and K. Erzini. 2008. Identification of deep water lantern sharks (Chondrichthyes: Etmopteridae) using morphometric data and multivariate analysis. Journal of the Marine Biological Association of the United Kingdom 88:199-204.

Compagno, L. 2001. Sharks of the World: An annotated and illustrated catalogue of shark species known to date. Volume 2: Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes. 269 pp.

Dawson, S.M., Chessum, C.J., Hunt, P.J. and E. Slooten. 1995. An inexpensive, stereo-photographic technique to measure sperm whales from small boats. Report of the International Whaling Commission 45:431-436.

Echeverria, T. and W.H. Lenarz. 1984. Conversions between total, fork, and standard lengths in 35 species of *Sebastes* in California. Fishery Bulletin 82:249-251.

Gaygusuz, O., Gursoy, C., Ozolug, M., Tarkan, A.S., Acipinar, H., Bilge G., and Filiz, H. 2006. Conversions of total, fork and standard length measurements based on 42 marine and freshwater species from Turkish waters. Turkish Journal of Fisheries and Aquatic Sciences 6:79-84.

Harvey, E. and M. Shortis. 1996. A system for stereo-video measurement of subtidal organisms. Marine Technical Society Journal 29:10-22.

Harvey, E., Fletcher, D., and M. Shortis. 2001a. A comparison of the precision and accuracy of estimates of reef-fish lengths made by divers and a stereo-video system. Fishery Bulletin 99:63-71.

Harvey, E., Fletcher, D., and M. Shortis. 2001b. Improving the statistical power of visual length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. Fishery Bulletin 99:72-80.

Harvey, E., Fletcher, D., and M. Shortis. 2002a. Estimation of reef fish length by divers and by stereo-video. A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fisheries Research 57:257-267.

Harvey, E., Shortis, M., Stadler, M., and M. Cappo. 2002b. A comparison of the accuracy and precision of measurements from single and stereo-video systems. Marine Technical Society Journal 36:38-49.

Harvey, E., Cappo, M., Shortis, M., Robson, S., Buchanan, J., and P. Speare. 2003. The accuracy and precision of underwater measurements of length and maximum body depth of southern bluefin tuna (*Thunnus maccoyii*) with a stereo-video camera system. Fisheries Research 63:315-326.

Holt, S.J. 1959. Report of the international training center on the methodology and techniques of research on mackerel (*Rastrelliger*). Food and Agriculture Organization of the United Nations ETAP Report 1095. 195 pp.

Hubbs, C.L. and K.F. Lagler. 1958. Fishes of the Great Lakes Region. Cranbrook Institute of Science Bulletin 26, Bloomfield Hills, Michigan. 213 pp.

Huxley, J.S. 1932. Problems of relative growth. Methuen, London. 276 pp.

Karpov, K.A., D.P. Albin, and W.H. Van Buskirk. 1995. The marine and recreational fishery in northern and central California: A historical comparison (1958-1986), status of stocks (1980-1986), and effects of changes in the California current. California Department of Fish and Game, Fish Bulletin 176. 192 pp.

Klimley, A. and S. Brown. 1983. Stereophotography for the field biologist: measurement of lengths and three-dimensional positions of free-swimming sharks. Marine Biology 74:175-185.

Kottelat, M. 1990. Indochines nemacheilines: A revision of nemacheiline loaches (Pisces: Cypriniformes) of Thailand, Burma, Laos, Cambodia, and southern Viet Nam. Verlig Dr. Friedrich Pfiel, Munchen, F.R. Germany. 262 pp.

Laevastu, T. 1965. Manual of methods in fisheries biology. Food and Agriculture Organization of the United Nations, Rome, Italy. Manual in Fishery Science 9:1-51.

Love, M., Caselle, J., and L. Snook. 2000. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. Fishery Bulletin 98:96-117.

Love, M., Schroeder, D., Lenarz, B., and G. Cochrane. 2006. Gimme Shelter: The importance of crevices to some fish species inhabiting a deeper-water rocky outcrop in southern California. California Cooperative Oceanic Fisheries Investigations Reports 47:119-126.

Martin, W.R. 1949. The mechanics of environmental control of body form in fishes. University of Toronto Studies, Biological Series 58. University of Toronto Press, Canada. 81 pp.

Miller, P. 1988. New species of *Coryrogobius*, *Thorogobius*, and *Wheelerigobius* from West Africa (Teleosti: Gobiidae). Journal of Natural History 22:1245-1262.

Miller, D. and R. Lea. 1972. Guide to the Coastal Marine Fishes of California. California Fish Bulletin 157:249 pp.

Naiberg, A. Petrell, R., Savage, C., and T. Neufeld. 1993. Non-invasive fish size assessment method for tanks and sea cages using stereo-video. Pages 372-381 *in* Techniques for Modern Aquaculture,Wang, J.K., ed. American Society for Agricultural Engineering.

North, J.A., Farr, R.A., and P. Vescei. 2002. A comparison of meristic and morphometric characters of green sturgeon *Acipenser medirostris*. Journal of Applied Ichthyology 18:234-239.

Petrell, R., Shi, X., Ward, R., Naiberg, A., and C. Savage. 1997. Determining fish size and swimming speed in cages and tanks using simple video techniques. Aquacultural Engineering 16:63-84.

Phillips, J. 1957. A Review of the Rockfishes of California (Family Scorpaenidae). California Fish Bulletin 104:158 pp.

Ratnaswamy, M. and H.E. Winn. 1993. Photogrammetric estimates of allometry and calf production in fin whales, *Balaenoptera physalus*. Journal of Mammalogy 74:323-330.

Robins, C., Polacheck, T., Preece, A., and Caton, A. 2000. Southern bluefin tuna fishery. Pages 159-168 *in* A. Caton and K. McLoughlin, editors, Fishery Status Reports 1999: Resource Assessments of Australian Commonwealth Fisheries. Bureau of Rural Sciences, Canverra, Australia.

Rochet, M., J. Cadiou, and V.M. Trenkel. 2006. Precision and accuracy of fish length measurements obtained with two visual underwater methods. Fishery Bulletin 104:1-9.

Snedecor, G. W. and W. G. Cochran, 1989. Statistical Methods, 8th edition. Iowa State University Press, Ames, Iowa.

Yoklavich, M., Greene, H., Cailliet, G., Sullivan, D., Lea, R., and M. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery Bulletin 98:625-64.

Yoklavich, M., Cailliet, G., Lea, R.N., Greene, H.G., Starr, R., De Marignac, J., and J. Field. 2002. Deepwater habitat and fish resources associated with the Big Creek Marine Ecological Reserve. CalCOFI Report Volume 43:120-140.

Zeidberg, L.D. 2004. Allometry measurements from *in situ* video recordings can determine the size and swimming speeds of juvenile and adult squid *Loligo opalescens*. Journal of Experimental Biology 207:4195-4203.

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