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Stereophotographic Analysis of the Marine, Sublittoral Sediment-Water Interface

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ABSTRACT

Wildish, D. J., B. Frost, and A. J. Wilson. 1990. Stereophotographic analysis of the marine, sublittoral sediment-water interface. Can. Tech. Rep. Fish. Aquat. Sci. 1726: iii + 14 p.

Presented is a description of the method of deploying the Lobsiger Deep Shelf stereo camera system in a geographic survey of benthic communities on the SW Scotian Shelf. Particular attention is given to the analysis of pairs of stereoslides and suggestions are made for a sediment particle size scale, bottom roughness estimate and sediment stability index, as well as methods to determine biological characteristics. The latter includes identification to the lowest possible taxon for epifauna and mobile fauna, an estimate of bio-volume for these taxa, and a classification of community types based on trophic group typology.

RÉSUMÉ

Wildish, D. J., B. Frost, and A. J. Wilson. 1990. Stereophotographic analysis of the marine, sublittoral sediment-water interface. Can. Tech. Rep. Fish. Aquat. Sci. 1726: iii + 14 p.

Le rapport décrit une méthode visant à déployer le système photographique stéréoscopique Lobsiger servant dans les fosses pour mener un relevé géographique des communautés benthiques de la partie sud-ouest de la plate-forme néo-écossaise. On a mis l'accent sur l'analyse de couples de diapositives stéréoscopiques et l'on a apporté des suggestions en vue d'établir une échelle pour déterminer la taille des particules de sédiments, de procéder à une évaluation des aspérités du fond et d'établir un indice de la stabilité de la sédimentation ainsi que de mettre au point des méthodes pour déterminer les caractéristiques biologiques. Cette dernière composante comprend l'identification du plus petit taxon possible en ce qui concerne l'épifaune et la faune ambulante, une évaluation du volume biologique de ces taxons et une classification des genres de communautés, compte tenu de la typologie du groupe trophique.

INTRODUCTION

This study is an attempt to develop a semi-automated, quantitative, photographic system for monitoring the sea floor. It was felt that underwater photography offered a number of advantages over conventional grab sampling, most notably the time required for analysis. The system used incorporates recent advances in underwater photography (see Holme 1984) and should prove to be a useful tool in various aspects of benthic studies, from geological and biological spatial survey work to monitoring both natural and man-made perturbations in space and time.

Photography has been used in benthic biology at least since 1893 (Boutan 1893). It is considered to be quite accurate for estimating the abundance of epibenthic fauna (Wigley and Emery 1967; Torlegard and Lundalv 1974) but inadequate for infauna (Owen et al. 1967a). A number of methods can be used to increase the yield of ecological information from photography. Among these are (i) stereophotography in order to obtain quantitative size measurements (Torlegard and Lundalv 1974), (ii) time lapse photography to record behavior or changes over time (Owen et al. 1967b; Wildish and Lobsiger 1987), and (iii) sediment profile photography to photograph within the sediment (Rhoads and Germano 1982). The system developed by us uses any or all of the above techniques dependent on the requirements of each individual project. This report discusses only state-of-the-art methods of stereophotography as developed by Lobsiger Associates Ltd. as would be used in a preliminary benthic spatial survey, or as part of a temporal survey designed to monitor expected changes in the benthic environment.

Our study was conducted on the southwest Scotian Shelf, primarily on Browns Bank (Wildish et al. 1989), a heterogeneous region of hard-bottomed banks and soft-bottomed basins with relatively high tidal current speeds prevailing over the banks. The first step was a spatial and temporal photographic survey to try and map benthic macrofaunal assemblages and surficial sediment properties of the area. Sampling was designed to quantitatively photograph the macroscopic epifauna; however, the photographic technique is equally amenable to studying the megabenthos (Rice et al. 1982). Simultaneously, we conducted a macrobenthic grab sampling program in the same area to test the camera system results against conventional grab sampling data (Wildish et al. 1989).

MATERIALS AND METHODS

CAMERA WORK AT SEA

Work was conducted on both the J.L. HART and the E.E. PRINCE. Position fixing was accomplished with Loran C, and depth measurements made with the ship's sonar. All stations were chosen to correspond to the 7-km square grids of a physical, tidal model (Greenberg 1979) which predicts the tidal current speed of each of its compartments in the Browns Bank area.

The camera system consisted of two deep-shelf cameras developed by Lobsiger Associates Ltd., mounted to face downward in a rigid frame (Fig. 1). Focal distance from the sea floor was varied from 40-72 cm during cruises (field of view 76 by 51 cm and 105 by 71 cm, respectively), while the camera separation was set to give a 60% stereo overlap. An electronic strobe was set at 45° to the camera axis and the camera was loaded with 35-mm Ektachrome 200 film. Photographic sequencing was controlled by a programmable microprocessor. A calibrated scale grid (40 cm x 40 cm) was mounted on the frame. During

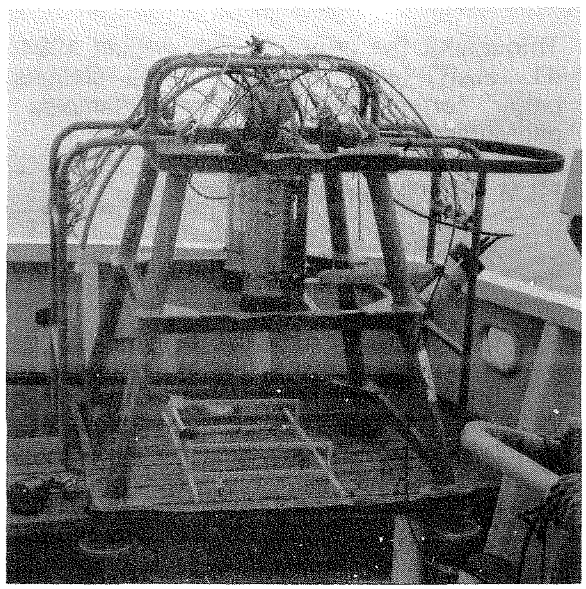

Fig. 1. Lobsiger deep-shelf camera system as deployed from the J.L. HART on the May-June 1985 cruise.

some cruises, sampling information was printed directly on the film at exposure.

The sampling strategy was to give geographic and seasonal coverage of the southwest Scotian Shelf, particularly the Browns Bank area. A total of 69 stations were successfully photo-graphed and six of them were selected for repeated photographing and grab sampling over different seasons. At each station, two photographs were taken on each of six camera lowerings made approximately 1 min apart while the boat drifted. Most photographs were taken during daylight hours. Five photographic cruises were made as follows:

23 July-2 August 1984
19-28 November 1984
2-11 April 1985
30 May-7 June 1985
16-25 July 1985

Throughout the cruise of July-August 1984, the J.L. HART was anchored at all stations for better correspondence of grab samples and photographs.

FILM PROCESSING

All film was processed into 35-mm color transparencies by a commercial film lab.

VIEWING TRANSPARENCIES

Stereo photographs were analyzed on a Wild APT-1 stereoscope equipped with a parallel guided picture carriage with transmitted illumination and a micrometer parallax bar. Stereo pair orientation was accomplished by lining up two equivalent points of the reference grid along an etched line on the picture carriage. Separation of the slides was then adjusted until both points appeared superimposed. A transparent slide overlay with parallel lines was used to aid systematic examination of the slides. A second slide overlay marked by a fine grid was used to help estimate the percent cover.

Single photographs were also viewed with a stereomicroscope utilizing the same overlays.

ANALYSIS

Each photograph was systematically analyzed by completing a standardized data sheet (Appendix 1). Analysis was restricted to the area of the photograph within the 40 cm x 40 cm (0.16 m^2) reference grid. The following methods were used to measure or observe each parameter.

Surficial sediment type

The designated sediment type of a sampling station was determined directly from chart 4039-G (Drapeau and King 1972). During the preparation of this report, an atlas of conventional, underwater photographs of the Scotian Shelf and Grand Banks was published (Lawrence et al. 1989); some of these photographs assisted in the designation of these surficial sediment types.

Current speed

The current speed was calculated for each grid box in the Greenberg (1979, 1983) model in which a station occurred. Output from this model included the flow at which 50% of the depth integrated current occurred averaged for the year 1978, as well as maximum and minimum flows for that year.

Scale factors

Horizontal measurements: All measurements in the horizontal plane were made directly from the transparency with calipers, and multiplied by the appropriate scale factor.

A scale factor was established for each 5 cm of vertical increment from the top bar of the reference frame to 20 cm below the bottom bar.

These scales were calculated from the difference between the top and bottom bar scales, extrapolated to the other distances by M = f/h (where f is the focal length of the lens in mm and h is the height of the camera in cm from the object).

These scales were used for all slides having the same geometric configuration of camera and reference frame, usually over one cruise.

Analysis of all single photographs required estimating the vertical increment of each object to be measured.

Vertical measurements: All vertical measurements from stereophotographs were calculated using a micrometer parallax bar to measure parallax, and multiplied by the appropriate parallax factor. A parallax factor (C) was determined for each 5 cm of vertical increment from the top bar of the reference frame to 20 cm below the bottom bar. This factor was calculated by $C = \Delta P = f \times B/h$, where B is the camera separation distance in cm and f and h are as previously defined. The parallax factors were used for all slides having the same geometric configuration of camera and reference frame, usually over one cruise. Vertical measurements cannot be made on single photographs.

Particle size scale

A scale ranging from 1-20, of approximately increasing overall particle size, was also used to quantify particle size (Table 1). The scale is based on percent cover of the major and secondary grade sizes. Any inorganic object in, or partially in, the reference frame was counted.

Particle sizes were measured by calipers down to a particle size of 1 mm. Particle sizes <1 mm were determined by comparison with a series of slides of known sediment type. Resolution of particle sizes below 1 mm proved difficult in many cases due to poor photographic resolution. Particle sizes were graded according to the Udden-Wentworth scale but, for simplicity of use, were grouped in categories to create the index as shown in Table 2.

Bottom roughness

This index was designed to be a measure of bottom roughness as it affects hydrodynamic flow. It is based on the principle that flow disturbance is approximately proportional to the frontal areas of projecting objects which the current encounters. It was measured from the 40 cm x 10 cm wide band across the centre of the reference grid.

Table 1. Surficial particle size scale used to classify Scotian Shelf sediments.

Predominately silt/clay (<1/16 mm)	1
Predominately fine sand (1/16-1/4 mm)	2
Predominately fine sediments (<1/4 mm) with >10% sand/gravel (1/4-4 mm)	3
Predominately fine sediments (<1/4 mm) with >10% coarse rock (>4 mm)	4
Predominately med./coarse sand (1/4-1 mm) with >10% fine sediments (<1/4 mm)	5
Predominately med./coarse sand (1/4-1 mm)	6
Predominately med./coarse sand (1/4-1 mm) with >10% gravel (1-4 mm)	7
Predominately med./coarse sand (1/4-1 mm) with >10% coarse rock (>4 mm)	8
Predominately very coarse sand/granule (1-4 mm) with >10% fine sediments (<1/4 mm)	9
Predominately very coarse sand/granule (1-4 mm) with >10% sand (1/4-1 mm)	10
Predominately very coarse sand/granule (1-4 mm)	11
Predominately very coarse sand/granule (1-4 mm) with >10% coarse rock (>4 mm)	12
Predominately pebble/cobble (4-256 mm) with >10% fine sediments (<1/4 mm)	13
Predominately pebble/cobble (4-256 mm) with >10% sand/gravel (1/4-4 mm)	14
Predominately pebble/cobble (4-256 mm)	15
Predominately pebble/cobble (4-256 mm) with >10% boulder (>256 mm)	16
Predominately boulder (>256 mm) with >10% fine sediments (<1/4 mm)	17
Predominately boulder (>256 mm) with >10% sand/gravel (1/4-4 mm)	18
Predominately boulder (>256 mm) with >10% pebble/cobble (4-256 mm)	19
Predominately boulder (>256 mm)	20

Table 2. Udden-Wentworth particle size classification.

Boulder	>256 mm	Boulder
Cobble Pebble	256-64 mm 64-4 mm	Pebble/cobble
Granule Very coarse sand	4-2 mm 2-1 mm	Very coarse sand/granule
Coarse sand Medium sand	1-1/2 mm 1/2-1/4 mm	Med./coarse sand
Fine sand Very fine sand	1/4-1/8 mm 1/8-1/16 mm	Fine sand
Silt Clay	1/16-1/256 mm <1/256 mm	Silt/clay

Only physical roughness was considered in this measure due to the difficulty of quantifying the roughness effect of biological elements. The roughness index for stereographs was calculated using the following formulae:

(i) irregular bottoms (e.g. gravel and rock)
individual frontal area = $h^2 \times f$
bottom roughness = Σ frontal areas per unit bottom area (where h is the height of the object; h^2 is an approximation for height x width; f is a factor set at 0.75 to account for the irregular geometric shapes);

(ii) relief bottoms (e.g. sand rippled sediments)
individual frontal area = $h \times w \times f$
bottom roughness = Σ frontal areas per unit bottom area (where w is the width of the object opposed to the major current direction).

In many cases the high density of roughness elements would result in some degree of skimming flow (Eckman et al. 1981). It was impossible to determine under what conditions skimming flow occurred due to the irregularity of the mostly physically dominated bottoms we encountered. No allowance for skimming flow has been included in the roughness index.

Sediment stability

This index attempted to measure sediment stability from the photographic observations. The main problem with determining sediment stability was the inability to see below the surface, or to see changes over time. Both problems can be overcome by employing additional photographic techniques, e.g. sediment profile and time-lapse photography. Our method is based on the signs of the extent of physical erosion and/or bioturbation that were obvious from the photographs. By consistently measuring these obvious signs over a large number of photographs, trends may appear despite the uncertainty of quantifying individual slides.

The index was calculated as the percent area of stable sediment in the photograph (Table 3).

The parameters used in categorizing sediment stability include the following:

- sediment particle size (sand, gravel, stones erosional, muds stable)
- presence/absence of epifauna (absence indicating erosional conditions)
- appearance of sediments (e.g. sorted/ unsorted - sorting indicating current re-working of the sediment)

Table 3. Sediment stability index.

<10% of sediments stable, erosional bedforms >2.5 cm	1
<50% of sediments stable	2
>50% of sediments stable	3
>90% of sediments stable, no noticeable erosional forms	4

- bedforms, shell lag deposits (presence of shell deposits indicating depositional conditions)
- presence of films or mats on bottom, abundance of infaunal tubes, feeding voids of demersal fish, and animal tracks, faecal mounds (all indicate stable sediment conditions).

Biological characteristics

Benthic macrofauna were classified in three categories: epifauna (E), infauna (I), and mobile fauna (M).

Epifauna and mobile fauna were identified to the lowest possible taxon, counted and a total volume estimate for each taxon was calculated. Volumes were calculated from linear dimensions using empirical relationships established for each taxa by direct volume displacement observations in the lab and linear measurements of preserved specimens (Appendix 2). No account was taken of possible shrinkage that might occur during preservation. Volume estimates from single photographs could not be made for those taxa that require a height measurement in the relationship. The infauna had to be treated differently because previous photographic studies (Wildish and Lobsiger 1987) had shown that the numbers of infaunal surface structures are not well correlated with the actual number of infauna and, therefore, that photographic results for the infauna are definitely non-quantitative. Infaunal surface structures were divisible into three main types (Fig. 2) and the presence of each was counted.

Community classification

The benthic community was classified according to the trophic state of the visible part of the community seen in the slides. The photographic data were classified using a binomial key (Table 4).

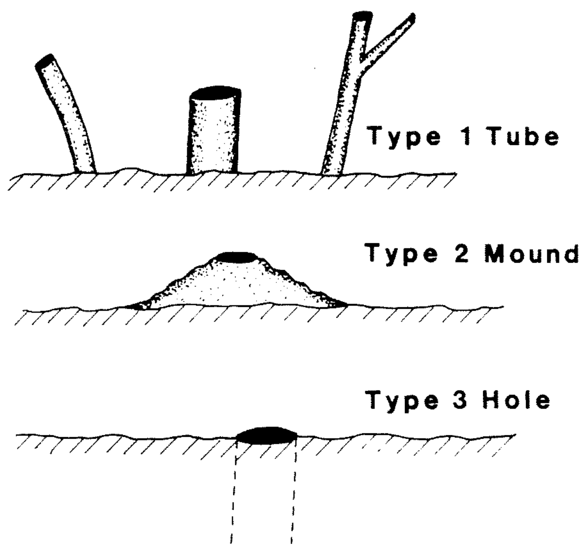

Fig. 2. Major types of infaunal, surface structures seen on the SW Scotian Shelf cruises.

The following four generalized trophic states were used:

Suspension-feeding community - consisting primarily of suspension-feeding animals.

Deposit-feeding community - consisting primarily of deposit-feeding animals feeding at the interface or within the sediment.

Table 4. Community character key.

Sediment stability - 1 or 2	1
Sediment stability - 3 or 4	3
1. Particle size predominately medium/coarse sand	2
1. Particle size includes finer and/or coarser particles	3
2. All ENT, ENS, INT $\leq$ 1 (in photograph)	Impoverished
2. Some of ENT, ENS, INT > 1 (in photograph)	3
3. Particle size has no silt/clay/fine sand	4
3. Particle size includes silt/clay/fine sand	5
4. All ENT, ENS, INT $\leq$ 1 (in photograph)	Impoverished
4. ENT, EVT, ENS relatively high, INT $\leq$ 1	Suspension
4. Other	5
5. ENT, EVT, ENS relatively high	Mixed
5. ENT, EVT, ENS low, predominately fine sediment	Deposit

Key to abbreviations: ENT = total number of all epifaunal organisms
EVT = total volume of epifaunal organisms
ENS = total number of epifaunal species
INT = total number of infaunal burrows present

Mixed community- consisting of more-or-less balanced numbers of animals of both feeding guilds.

Impoverished community - very sparsely populated.

CONCLUSIONS

Our stereophotographic analysis methods are still evolving and the above report represents the stage of development achieved by 1989. We consider that the following will markedly improve the speed of analysis:

- improved software that will perform all of the calculations automatically and present the information in a useful and attractive way;
- the use of a digitizing tablet which can be interfaced directly with a micro-computer.

We do not advocate that users of this, or a similar, system blindly follow the analytical methods described but choose those pertinent to their own studies. Thus, for example, if height measurements can be dispensed with, or measurement of the volume of mobile fauna and epifauna, the analysis for each pair of photographs can be completed much faster. Volume measurements of epifauna can be used to compute biomass if the density of the living tissue is known and, hence, production by that species using the relationship suggested by Banse and Mosher (1980). Alternatively volume can be used directly, according to its size group, to estimate production (Schwinghamer et al. 1986).

We do not suggest that underwater stereo-photographic methods can replace conventional grab sampling. Indeed, in most cases, the two methods are complementary, with grab sampling being "quantitative" where the sediment is soft, and photographic methods being necessary where the surficial sediments are hard and often impossible to sample by grab.

Typical benthic sampling strategies where underwater stereophotography might be particularly useful include the following:

- as a preliminary survey of an area to decide where grab samples should be taken;
- as a geographic survey of a large area where both benthic grab and underwater photographic techniques are used;
- as a determinant of local spatial distribution and relationships among individual macrofauna;
- as a temporal monitoring method to follow seasonal events, e.g. deposition of spring microalgal blooms or deposition of organic wastes from salmonid cage mariculture;
- as a means of estimating standing stock biomass or production of an epifaunal species such as the sea scallop, *Placopecten magellanicus*;
- as a before-after study of a pollution event such as the disposal on the sea bed of drill cutting waste to monitor environmental changes.

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REFERENCES

Banse, K., and S. Mosher. 1980. Adult body mass and annual production/biomass relationships of field populations. Ecol. Monogr. 50: 355-379.

Boutan, L. 1893. Mémoire sur la photographic sous-marine. Arch. Zool. Exp. Gen. Ser. 3: 281-324.

Drapeau, G., and L. H. King. 1972. Surficial geology of the Yarmouth-Browns Bank map area. Information Canada, Ottawa, 6 p.

Eckman, J. E., A. R. M. Nowell, and P. A. Jumars. 1981. Sediment destabilization by animal tubes. J. Mar. Res. 39: 361-374.

Greenberg, D. A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Mar. Geod. 2: 161-187.

Greenberg, D. A. 1983. Modelling the mean baratropic circulation in the Bay of Fundy and Gulf of Maine. J. Phys. Oceanogr. 13: 886-904.

Holme, N. A. 1984. Photography and television, p. 66-98 (Chap. 4). In N. A. Holme and A. D. McIntyre (ed.) Methods for the study of marine benthos. Blackwell Scientific Publications, Oxford.

Lawrence, P., K. W. Strong. P. Pocklington, P. L. Stewart, and G. B. J. Fader. 1989. A photographic atlas of the eastern Canadian Continental Shelf. Maritime Testing (1985) Ltd., 187 p.

Owen, D. M., H. L. Sanders, and R. R. Hessler. 1967a. Bottom photography as a tool for estimating benthic populations, p. 229-234. In J. B. Hersey (ed.) Deep-sea photography. Johns Hopkins Press, Baltimore, MD.

Owen, D. M., K. O. Emery, and L. D. Hoadley. 1967b. Effects of tidal currents on the sea floor shown by underwater time-lapse photography, p. 159-166. In J. B. Hersey (ed.) Deep-sea photography. Johns Hopkins Press, Baltimore, MD.

Rhoads, D. C., and J. D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method of remote ecological monitoring of the seafloor (Remots® System). Mar. Ecol. Prog. Ser. 8: 115-128.

Rice, A. L., R. G. Alfred, E. Darlington, and R. A. Wild. 1982. The quantitative estimation of deep sea megabenthos: a new approach to an old problem. Oceanol. Acta 5: 63-72.

Schwinghamer, P., B. Hargrave, D. Peer, and C. M. Hawkins. 1986. Partitioning of production and respiration among size groups of organisms in an intertidal benthic community. Mar. Ecol. Prog. Ser. 31: 131-142.

Torlegard, A. K. I., and T. L. Lundalv. 1974. Underwater analytical system. Photogrammetry Engineering 40: 287-293.

Wigley, R. L., and K. O. Emery. 1967. Benthic animals, particularly *Hyalinoecia* (Annelida) and *Ophiomusium* (Echinodermata), in sea-bottom photographs from the continental slope, p. 235-249. In J. B. Hersey (ed.) Deep-sea photography. Johns Hopkins Press, Baltimore, MD.

Wildish, D. J., and U. Lobsiger. 1987. Three-dimensional photography of soft-sediment benthos, S.W. Bay of Fundy. Biol. Oceanogr. 4: 227-241.

Wildish, D. J., A. J. Wilson, and B. Frost. 1989. Benthic macrofaunal production of Browns Bank, Northwest Atlantic. Can. J. Fish. Aquat. Sci. 46: 584-590.

APPENDIX 1. PHOTOGRAPHIC DATA SHEET

Name | Comments
Date
Time
Depth
Latitude
Longitude
Surficial sediment type
Greenberg current speed (cm/s)
Min 50% Max
Scale factor
Physical parameters
Particle size scale
Bottom roughness scale
Sediment stability
Biological parameters

Epifauna

Species		Number	Volume (cm^3)
E1		EN1	EV1
E2		EN2	EV2
E3		EN3	EV3
E4		EN4	EV4
E5		EN5	EV5
E6		EN6	EV6
E7		EN7	EV7
E8		EN8	EV8
E9		EN9	EV9
E10		EN10	EV10
E11		EN11	EV11
Totals	ENS	ENT	EVT

Infauna

	Number
Type 1 burrows	IN1
Type 2 burrows	IN2
Type 3 burrows	IN3
Total	INT

APPENDIX 1 (cont'd)

Mobile fauna

		Number	Volume (cm^3)
M1		MN1	MV1
M2		MN2	MV2
M3		MN3	MV3
M4		MN4	MV4
M5		MN5	MV5
M6		MN6	MV6
Totals	MNS	MNT	MVT

Community character

APPENDIX 2. LINEAR DIMENSION TO VOLUME RELATIONSHIP

L = Length
W = Width
H = Height

D = Diameter
DD = Disc diameter
TD = Tube diameter
CW = Carapace width

All volumes calculated are in cm^3.

Porifera: ramose (finger like)

$Volume = -4.0 + 0.8(H) + 2.32(W) + 0.026(H^2) - 0.204(W^2)$
$r^2 = 91.0\%$; n = 9
Size range: W - 1.0-10.0 cm

Porifera: simple, rounded; with or without tubular oscula

$Volume = -0.43 + 0.42 (L)(W)(H)$
$r^2 = 95.8\%$; n = 59
Size range: L = 2.5-12.0 cm

$Volume = 0.32(L)(W)(H)$
Size range: L <2.5 cm

Porifera: encrusting

$Volume = 0.53 (L)(W)(H)$
Size range: all

Cnidaria: *Tubularia* sp.

$Volume = -0.068 + 0.025(H)$
$r^2 = 70.7$; n = 6
Size range: H - 4.0-12.0 cm

Cnidaria: *Corymorpha* sp.

$Volume = -0.267 + 0.235(H)$
$r^2 = 80.1\%$; n = 7
Size range: H = 1.5-6.0 cm

Cnidaria: Colonial Hydrozoa - Thecata and Athecata

$Volume = -0.088 + 0.043(W) + 0.017(H) - 0.004(W^2) - 0.0028(H^2) + 0.00055(W^3) + 0.00015(H^3)$
$r^2 = 93.4$; n = 28
Size range: W = 2.0-10.0 cm

Volume = 0.01
Size range: W <2.0 cm

Cnidaria: Alcyonacea

$Volume = 0.6 - 12.7(H) + 14.6(D) + 6.4(H^2) - 8.7(D^2) - 0.74(H^3) + 1.52(D^3)$
$r^2 = 93.8\%$; n = 8
Size range: D = 0.75-6.0 cm

APPENDIX 2. (cont'd)

Bryozoa: erect, fan-like fronds

Volume = 0.596 + 0.285(H) - 1.24(W) + 0.391(W^2) - 0.0104(H^3) - 0.0201(W^3)
r^2 = 99.5; n = 13
Size range: W = 2.5-9.0 cm

Volume = 0.399 - 0.779(W) - 0.0160(H^2) + 0.507(W^2) + 0.00707(H^3) - 0.0915(W^3)
r^2 = 100%; n = 8
Size range: W = 1.0-2.49 cm

Bryozoa: erect, arborescent, strongly calcified

Volume = -0.0094 + 0.065(H) - 0.044(H^2) + 0.0206(H^3)
r^2 = 89.6%; n = 10
Size range: H = 0.4-3.0 cm

Bryozoa: erect, arborescent, uncalcified

Volume = -1.39 + 2.56(H) - 0.093(W) - 1.32(H^2) + 0.0601(W^2) + 0.214(H^3)
r^2 = 99.9; n = 15
Size range: W = 2.0-8.0 cm

Volume = -0.109 + 0.206(H) - 0.113(W) - 0.048(H^2) + 0.082(W^2)
r^2 = 78.1; n = 10
Size range: W = 0.8-1.99 cm

Bryozoa: encrusting

Volume = 0.018(L)(W)
Size range: all

Branchiopoda: *Terebratulina septentrionalis*

Volume = 0.358 - 1.32(W) + 1.27(W^2)
r^2 = 92.7%; n = 7
Size range: W = 0.5-2.0 cm

Mollusca: *Dentalium entale*

Volume = 0.223 - 0.152(L) + 0.0519(L^2)
r^2 = 95.4%; n = 10
Size range: L = 2.0-5.0 cm

Mollusca: Gastropoda - shelled

Volume = 1.95 - 1.27(L) + 0.211(L^2) + 0.0265(L^3)
r^2 = 99.4%; n = 9
Size range: L = 2.0-13.0 cm

Mollusca: Gastropoda - shell-less

Volume = -0.53 + 0.53(L) - 0.013(L^2) + 0.0752(L^3)
r^2 = 99.9%; n = 8
Size range: L = 1.0-5.0 cm

APPENDIX 2. (cont'd)

Mollusca: *Placopecten magellanicus*

Volume = $-44.7 + 24.7(H) - 4.41(H^2) + 0.347(H^3)$
r^2 = 99.8%; n = 11
Size range: H = 3.5-12.0 cm

Mollusca: *Astarte* sp.

Volume = $2.59 - 6.7(H) + 5.26(H^2) - 1.03(H^3)$
r^2 = 95.9%; n = 11
Size range: H = 0.6-2.5 cm

Polychaeta: *Potamilla* sp.

Volume = 0.12
n = 12
Size range: TD = 0.2-0.4 cm

Polychaeta: *Spirorbis* sp.

Volume = 0.001
Size range: all

Polychaeta: *Filograna implexa*

<u>Note</u>: Volume and number are calculated from the volume of the tube network.

$$\text{Volume} = [-10.7 + 8.26(L) + 5.55(W) - 7.53(H) - 1.99(L^2) - 0.66(W^2) + 2.12(H^2) + 0.148(L^3) + 0.0556(W^3) - 0.100(H^3)]\ [0.03]$$

$$\text{Number} = [-10.7 + 8.26(L) + 5.55(W) - 7.53(H) - 1.99(L^2) - 0.66(W^2) + 2.12(H^2) + 0.148(L^3) + 0.0556(W^3) - 0.100(H^3)]\ [226]$$

r^2 = 99.8% (empirical relationship); n = 17
Size range (tube network): L = 3.0-12.0 cm

Volume = [0.29(L)(W)(H)] [0.03]
Number = [0.20(L)(W)(H)] [226]
n = 11
Size range (tube network): L $<$3.0 cm

Crustacea: Decapod shrimp

Volume = $0.229 - 0.097(L) + 0.0158(L^3)$
r^2 = 98.3%; n = 12
Size range: L = 1.5-6.0 cm

Crustacea: *Pagurus* sp.

Volume = $-3.2 + 4.16(L) - 1.36(L^2) + 0.182(L^3)$
r^2 = 94.2%; n = 13
Size range: L = 1.5-9.0

APPENDIX 2. (cont'd)

Crustacea: *Hyas* sp.

Volume = 0.39 - 0.7(CW) + 0.43(CW^2) + 0.405(CW^3)
r^2 = 97.1%; n = 13
Size range: CW = 0.5-3.5 cm

Echinodermata: *Cucumaria frondosa*

Volume = 1.55 - 8.52(L) + 2.10(L^2)
r^2 = 94.9%; n = 6
Size range: L = 4.5-15.0

Echinodermata: *Asterias* sp., *Henricia* sp.

Volume = 1.74 - 1.36(L) + 0.267(L^2) + 0.00243(L^3)
r^2 = 98.7%; n = 18
Size range: L = 4.5-20.0 cm

Volume = 0.04 - 0.08(L) + 0.105(L^2) - 0.0056(L^3)
r^2 = 86.5%; n = 11
Size range: L = 1.0-4.49 cm

Echinodermata: *Solaster* sp.

Volume = [1.74 - 1.36(L) + 0.267(L^2) + 0.00243(L^3)] [2]
n = 2
Size range: L = 4.5-12.0 cm

Volume = [0.04 - 0.08(L) + 0.105(L^2) - 0.0056(L^3)] [1.2]
n = 1
Size range L = 1.0-4.49 cm

Echinodermata: Ophiuroidea

Volume = 0.544 - 2.36(DD) + 2.94(DD^2) - 0.611(DD^3)
r^2 = 98.8%; n = 10
Size range: DD = 0.5-2.5 cm

Ascidiacea: *Boltenia ovifera*

Volume = -2.81 + 3.21(D) + 1.01(D^2)
r_2 = 98.6%; n = 6
Size range: D = 0.8-4.0 cm

Ascidiacea: simple, rounded

Volume = -1.82 + 4.27(D) - 2.85(D^2) + 1.10(D^3)
r^2 = 94.6%; n = 13
Size range: D = 0.7-3.0 cm