Tide Pool Transect

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During the past seven years at the Bowdoin College Marine Institute for High School Teachers we have tried many methods of gathering meaningful data on marine ecology. Ecologic studies both above (eulittoral: rock, sand, and mud substrates) and below (sublittoral) the intertidal zone have been interesting and useful, but none of these has proved as intellectually stimulating and enlightening as our work on the tide pool transect. We call this a tide pool transect since we establish a line (much as a transect) from ocean edge through or beside several tide pools and sample each tide pool along the line. This method of study, with some added refinements, has also been found successful by one of us (Zottoli) for a college class in marine biology. From our experiences it seems apparent that this procedure should have wide applicability as a teaching tool in studies of the intertidal zone.

Although this report is based on studies of rock substrate tide pool, the procedures and suggestions should be useful for any area where a series of tide-water pools is available.

Site Selection and Timing

Along the Maine coast one experiences little difficulty in locating an adequate site for a tide pool transect. In one area that we have used for class studies we have at least six adequate rock pools located at different levels above the mean low-tide mark. Analysis of these pools for species diversity reveals that if only two pools and the ocean edge were available we would still be able to show adequate ecologic differences.

Our most troublesome situation for site selection has been the problem of wave wash at the ocean edge. Some control over this may be achieved by selecting a shore station that fronts at an acute angle to the wash of the wave pattern. Sites on shore may be particularly dangerous during periods of onshore winds or in areas where there is a big difference between high and low tide; in the Bay of Fundy, for example, where the tidal range may be 8 m or more, the velocity and force of the incoming water is exceptionally great. It is a good plan to have a throw-ring life preserver on hand as well as a (mandatory!) first aid kit. Workers would be well advised to wear cleat-bottomed sneakers or boots.

Timing is important, especially if one is to do any extensive ecologic study on tide pools. As a handy index one can say that the study should be started at a low-tide time (refer to tide tables published by the Environmental Science Services Administration) minus the length of time required to complete the shore station analysis. Thus, if low tide occurs at 3 P.M. and it takes 30 minutes to complete analysis of the low-tide shore station, one should start sampling at 2:30 P.M. (see procedure below). Much greater exposure, and usually more tide pools, can be obtained if one selects for spring low tides rather than for neap tides. Excellent contrasts may be obtained if the tide pool series is sampled at low tide

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one afternoon and then again, 12 hours later, at low tide early in the morning, preferably before sunrise. One of us (Zottoli) has been successful in studying tide pools at intervals for a 29-hour period (table 2).

If, as is the case in many parts of the world, you have an area where the total tidal sweep is small (0.5-m amplitude in Florida *vs.* a 3-m amplitude in Brunswick, Maine) you may have to replace the tide pool transect with a transect line that either crosses a spit or narrow isthmus with differing conditions on each side or one that parallels the shore yet embraces a variety of substrates (mud, sand, rock).

Site selection for any transect should be based as closely as possible on freedom from traffic. An area exposed to heavy people-pressure is often deranged for flora and fauna.

Location of Stations

Individual tide pools in the tide pool series should be positioned at markedly different levels and situated, if possible, along a straight line extending, at right angles to the shore line, from the low-tide line to the top of the eulittoral zone. Our results with classes at Bowdoin indicate that a fine series of contrasts can be found with one shore station, one station at 1 m, one station at 2 m, one station at 2.5 m, and one station at 4.5 m above mean low water (high tide, here, is approximately 3 m). If the class making the study is large or unusually energetic, any or all of the stations can be replicated (two shore, two at 1 m, etc.), providing useful comparison data and serving as a valuable check on results. This also, as we have found, introduces a healthy between-group competitive spirit.

It is the sad situation that in these days of population pressure the tide pool area should be prechecked for fouling. Since the fouling is often of human intestinal origin, an instructor should be alert to the disease potential. Although as highly instructive as a polluted–nonpolluted study might be, such could be disastrous unless the instructor is prepared to use sanitary technique in working polluted pools.

Sampling Procedure

We have indicated above that for safety's sake sampling should be done during the outgoing tide. If the instructor can plan a full-day study, he can begin at high tide and sample, at hourly intervals, each tide pool as it becomes exposed. This procedure has the following advantages: (i) all students have time to investigate each tide pool, and (ii) the time of pool exposure at examination time is the same for each pool. In this case the shore station is sampled last, just before low tide. The timing procedure recommended in site selection demands, unless the study is somewhat superficial, that separate groups examine each pool or shore station. In revisiting the area for successive studies it is important in either case to note exposure time for each pool.

The sequence of sampling for a general picture of the ecology of the pools should follow some pre-set pattern, such as the following:

1. Discussion (and note-taking) at the station of the general characteristics of the pool, noting especially any wind disturbance or current action in the pool, evidences of decay, stagnation, or pollution, and distribution of flora and fauna.
2. Temperature measurements of air, water (surface, mid-, and bottom depths), and rock surface (in and out of the pool). A simple thermometer on a string, if retrieved rapidly, will suffice for most pools. For very deep pools take the temperature of water sample as in step 4, below.
3. Sampling for chemical tests. Several inexpensive kits are available commercially; they are relatively foolproof for student use in testing for oxygen concentration and pH. Inexpensive hydrometers (urine hydrometers, for example) can be used to determine the specific gravity of sea water. Specific gravity may then be converted to salinity, using Watanabe's conversion tables. All test results should be repeated three times and the average recorded.
4. Subsurface samples for chemical tests and planktonic organisms should be obtained in a sequence from surface down so that the characteristics of the samples in each layer are undisturbed. They should also be taken by one of a variety of instruments, such as a Kemmerer sampler, which ensnares the sample without mixing it with air (Nutting, 1966). Perform the tests at once and record in chart form (as in table 1). Preserve planktonic organisms in well-labeled plastic vials.
5. Rough measurement and sketch of the pool. If depth contours are made, an estimate of pool volume can be derived. The type of rock and its mineral characteristics should also be noted, since these may well determine the pH of the pool.
6. Make quantitative counts (numbers/standard area) of dominant species. Select for this "first run" only large, easily evident organisms. Many marine algae are permanently attached to the substrate and therefore should be counted in the pool. For algae, "percent cover" within the standard area may be the best way to record distribution. Organisms that are not permanently attached may be removed from the pool, counted, and then returned. As you make your counts be sure to note the distribution of each species within the standard sampling area and within the pool. If certain species are not known, assign each a number and bring a specimen of each to the laboratory for identification. Since specimens may best be identified in the living state it is important to keep them cool, shaded, and aerated. Only one or two specimens of very common species should be pickled (70% alcohol or 1:9 commercial formalin to sea water).
7. Finally, search the pool carefully in an attempt to locate most of the different animal and plant

Table 1. Results of a tide pool investigation, July 4, 1969, Bailey's Island, Maine.

Factors	*Ocean edge*	*Pool 1*	*Pool 2*	*Pool 3*	*Pool 4*
Physical					
Temperature	17	18	18.5	23.5	25
Air (°C)	23	19.5	21.5	23.5	25
Water (°C)					
surface	17	18	18.5	23.5	25
mid-level	16.5	17	18	22	24.5
bottom	16.5	16	17	22	24.5
Pool measurements (approx.)					
Dimensions (m)	—	5.5 × 1.5	12.2 × 1.5	1.8 × 1.2	0.5 × 0.8
Depth (average in cm)	—	38	50	10	6.5
Volume (m^3)	—	10.5	30.8	0.7	0.1
Substrate	—	Metamorphic rock underlying all pools			
Cloud cover (%)	0	0	0	0	0
Chemical					
Oxygen (ppm)	8.0	12.0	9.6	13.0	11.0
pH	8.0	8.3	7.9	10.0	8.5
Salinity (%)	29.5	30.0	30.0	35.0	0.0
Biotic					
Dominant plant	*Chondrus crispus*	*C. crispus*	*C. crispus*	*Enteromorpha* spp.	—
Dominant animal	*Mytilus edulis*	*Asterias vulgaris*	*Balanus balanoides*	*Gammarus* spp.	*Aedes* spp.
Animals/plants (number of species)	6/2	14/16	9/6	3/2	—

species. Collect one specimen of each unknown species for identification in the laboratory. If rare or unusual species are moved to the laboratory, it is much safer to assign them a number (as unknown 1, 2, 3, etc.) and then return them directly to the pool. Such conservation measures may seem somewhat trivial; however, in most areas of the world, human population pressures are becoming untenable to populations of marine organisms. It is therefore important to conserve species that are in low numbers and also to impress our students with the need to do so.

Location Data

Just before low tide, and while the shore station crew is completing its work, one member from each tide pool crew should "shoot in" his station by compass with respect to the shore station or to the perpendicular transect line and a stable reference point, such as a jutting rock, dab of paint, or metal piton marker. The distance from the tide pool to the shore station and the distance from the shore station to the permanent mark can be paced or tape-measured. The position of the permanent mark with respect to mean low tide should also be known. From these records a simple location map can be made to show the rough relationships of all stations and to relocate the same stations for future studies.

Elevations for each pool above the mean low water mark can be determined by using an inexpensive sighting device (inclinometer) and a stick marked at regular intervals (Jacob's rod). Have one member of the group hold a Jacob's rod at the mean low-water mark (consult tide tables to determine the exact time of low tide). Position another individual at the location of the first tide pool and have him sight in on the Jacob's rod through the inclinometer, making sure the device is perfectly level. (A pocket level will serve both as a sighting device and a level.) The height of the tide pool (C) above mean low water (A) would be equal to the height recorded on the Jacob's rod (B) minus the distance from eye level (D) to pool level. Once this procedure has been repeated for each tide pool, a satisfactory profile can be drawn (use graph paper) to show the vertical relationship between the stations. It would be well to mark on this the extent of tidal sweep for both spring and neap tides, thus presenting a visual mockup of monthly tidal cover and exposure of the respective stations.

Specific Studies

With a baseline of general information, more specific tide pool studies may be initiated. Several such studies are as follows:

Species diversity. Record the number of different species as well as the number of individuals within each species. These figures may indicate that pools nearer the ocean edge have more species but fewer individuals per species than those upshore.

Differences in physical–chemical–biologic factors. Our experience has been that tide pools located near the high tide mark are dominated by green algae (*Cladophora, Chaetomorpha, Enteromorpha,* etc.) while those in the lower intertidal are populated mainly by brown (*Alaria, Laminaria,* etc.) and red (*Ceramium, Chondrus, Gigartina, Polysiphonia,* etc.) algae. Generally, greater oxygen and pH fluctuations occur in upper pools; this may be due to higher photosynthetic and respiratory rates (table 2). For a discussion of some of the above mentioned factors, refer to the articles by Ambler and Chapman (1950), Davy de Virville (1934, 1935), Gilharov (1967), Johnson and Skutch (1928), Lewis (1964), McGregor (1965), Naylor and Slinn (1958), Pyefinch (1943), Stephenson, Zoond, and Eyre (1933), Swami (1959), and Wilce (1959).

Seasonal differences in physical–chemical–biologic

Table 2. Partial results of a tide pool investigation, April 11-12, 1970, Halibut Point, Rockport, Mass.

Time	*pH* Upper pool	*pH* Lower pool	*Oxygen (ppm)* Upper pool	*Oxygen (ppm)* Lower pool	*Temperature (°C)* Upper pool	*Temperature (°C)* Lower pool	*Temperature (°C)* Air
7 A.M.	8.7	8.6	21	14	5	5	3
9 A.M.	10.0	8.6	21	18	5	5	4
9 P.M.	8.6	7.0	5	6	3	4	3
7 A.M.	8.9	8.5	7	10	3	4	3
10 A.M.	10.0	9.0	20	12	10	10	10
Noon	10.0	9.0	20	12	—	—	—

Ocean temperature = 4 C
Salinity = 31% for the ocean and both pools
Ocean pH = 8.3
Upper pool dominated by green algae (*Enteromorpha* and *Chaetomorpha*)
Lower pool dominated by red and brown algae (*Chondrus, Rhodymenia, Polysiphonia, Laminaria, Fucus*)

factors. This requires repeat studies at widely spaced intervals. Exposure time is a quite important consideration for such studies.

Comparison of physical–chemical–biologic factors in physically dissimilar pools located at the same tidal level. We suggest that deep *vs.* shallow or large *vs.* small pools be used for these studies.

Comparison of benthic and planktonic microorganisms in tide pools located at different tidal levels. Refer to the following articles: Aleem (1950), Ganning (1956), Droop (1953), Faure-Fremiet (1948), and Gilharov (1967). These studies require special measures (plankton nets, etc., or submerging such substrates as glass slides, etc.) and rather arduous microscopic examination for adequate resolution. Such studies are recommended for advanced-biology students.

Other ideas for worthwhile studies may be found in Bovbjerg and Glynn (1960).

Illustrative Results

The following discussion of physical, chemical, and biologic factors is based on data obtained July 4, 1969, by a Bowdoin College Marine Institute class over a three and one-half hour period (table 1).

Physical factors. At this time of the year, tide pool temperatures generally rise with an increase in pool height above mean low tide. This is probably a result of the length of time each pool is exposed to the high air temperatures. In other words, a pool that has recently been uncovered by receding tides will have a lower temperature than one that has been exposed for a longer period of time.

Chemical factors. Oxygen readings that are higher than those of the ocean may be indicative of photosynthetic oxygen production; an oxygen decrease may be caused by animal and plant respiration. The pH readings are indicative of carbon dioxide utilization in the photosynthetic process. As plants take up carbon dioxide from the water, there is a shift towards the left in the equations given below; thus hydrogen ions are removed, thereby raising the pH. When carbon dioxide is added to the water, through animal and plant respiration, there is a shift toward the right in the equations, thus releasing hydrogen ions and thereby lowering the pH.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \text{ (carbonic acid)}$$
$$H_2CO_3 \leftrightarrow HCO_3 \text{ (bicarbonate)} + H^+$$
$$HCO_3 \leftrightarrow CO_3 \text{ (carbonate)} + H^+$$

The high oxygen and pH values of tide pool #3 suggest a high rate of photosynthesis.

Biologic factors. Pool #4 is seldom inundated by sea water; it is essentially a freshwater pool throughout most of the year. It has a low species diversity, as might be expected of a pool that is continuously exposed to environmental extremes (temperature, salinity, etc.). Pool #3 is in contact with the ocean for a few hours each day. It also has a low species diversity, perhaps due to the same reasons suggested for pool #4. Pools #1 and #2 are exposed for a few hours each day; the physical and chemical conditions in the pool remain essentially the same as in the ocean. The marked species diversity that occurs in such pools is in part due to the relative constancy of such factors as temperature, salinity, and oxygen. Other factors, such as "wave wash," must, however, be operable, since pool #1 has a much higher species diversity than does the ocean edge.

In a tide pool study by a graduate marine-biology class (Fitchburg State College) on two pools at different levels over a 29-hour period the data was obtained as shown in table 2 (information on the distribution of animals and plants has been omitted). From this we note the following:

Physical factors. Temperatures for the upper pool, lower pool, ocean, and air are approximately the same; it would seem that exposed pool temperature is dependent on air temperature.

Chemical factors. With the onset of photosynthesis in the morning, one would expect an increase in photosynthetically produced oxygen in the water. One would also expect a reduction in dissolved oxygen at night, due to the lack of photosynthesis and the respiratory consumption of oxygen by animals and plants. The data follow this pattern. The fluctuations in oxygen are similar to those observed by Beyers (1963) in several aquatic microecosystems. The pH values to a certain extent mirror changes in oxygen concentration. As carbon dioxide is removed from the water by photosynthesizing forms, the pH increases. At night the pH decreases, due to respiratory production of carbon dioxide (refer to the previous discussion).

Both sets of information noted above should in no way be interpreted as published results of a scientific investigation. Many hands with varying levels of competence labored for these results. Such data are presented solely to show the range of differences available to the tide pool transect approach. Student investigations can, however, be used to uncover fertile possibilities for more rigorous studies.

Summary Remarks

The notes above are based on relatively short-term sampling periods. Despite this, and the relative inexperience of the classes studying the stations, we have found remarkable similarities in our results from year to year. It seems evident that not only will the tide pool transect demonstrate a wide range of physical, chemical, and biologic differences in a short period of time, but that such will likely show a fairly high level of predictability from year to year.

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building. Athelstan Spilhaus (1969) refers to his ideas as "the lesson of the trees." Well, whether or not most of our cities now present the aspect of a savanna, it is pleasing to read this hint of trying to make them so. I think of that passage in Thoreau's essay "A Winter Walk," where he muses on a winter morning:

> The trees and shrubs rear white arms to the sky on every side; and where were walls and fences, we see fantastic forms stretching in frolic gambols across the dusky landscape, as if Nature had strewn her fresh designs over the fields by night as models for man's art.

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Catalog of Standard Reference Materials

National Bureau of Standards Special Publication 260 is available for 75¢ from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; or from local U.S. Department of Commerce field offices, as *SD Catalog No. C13.10:260;* or from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va. 22151, as *Spec. Publ. 260/1970 ed.* Orders for this 84-page booklet should be prepaid.

This is a revised edition (July 1970) of the publication that lists the various standard reference materials (SRMs) now being distributed by the National Bureau of Standards. These materials are used to calibrate measurement systems and to provide a central basis for uniformity and accuracy of measurement. The unit and quantity, the type, and the certified characterization are listed for each material, as well as directions for ordering. New and renewal materials are announced in the *NBS Technical News Bulletin* and in scientific and trade journals; and the current status and prices will be summarized by insert sheets available at timely intervals from NBS.

Conservation Bibliography Supplemented

Conservation Education: a Selected Bibliography Supplement, compiled by Joan Carvajal and Martha E. Munzer, lists materials published between 1967 and the summer of 1970. It supplements the first bibliography (1968), published by the Conservation Education Association. The new, 44-page booklet is available at 75¢, less educational discounts, from Interstate Printers & Publishers, Danville, Ill. 61832.

FEDERAL SPENDING ON ACADEMIC SCIENCE

Federal agencies provided more than $2.3 billion for science programs at U.S. universities and colleges during fiscal year 1969, representing virtually the same level of federal funding of academic science as reported for fiscal year 1968. Of this total, the Department of Health, Education, and Welfare (HEW) supplied $1,245 million, more than one-half of the total provided by all agencies. The National Science Foundation (NSF) ranked second with $362 million, followed by the Department of Defense (DOD) with $272 million. Together these two agencies accounted for 28% of Federal obligations for academic science. The remaining 19% was comprised mainly of obligations from the Department of Agriculture (USDA), $156 million; the National Aeronautics and Space Administration (NASA), $125 million; and the Atomic Energy Commission (AEC), $121 million.

Science Resources Studies Highlights, NSF

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