SECTION ONE
Chapter 1

Introduction To Artificial Reef Research Diving: Theory And Practice

By Joseph G. Halusky

Artificial Reef Research Diving has its roots in Scientific Diving and Diving Technology which have evolved since the invention of self-contained underwater breathing apparatus (SCUBA) in the early 1940's. Early explorers of the undersea made use of SCUBA technology to observe and document new discoveries that were reported in scientific publications, movies, the media and popular literature. In the 1950's, SCUBA equipment was first introduced to the scientific community in the United States, through the efforts of researchers at the Scripps Institute of Oceanography. Since then, the use of SCUBA and surface supplied diving technology has evolved to become as indispensable as the microscope, as a tool for scientific data gathering.

Scientific Diving & Diving Technology

Scientific Diving and Diving Technology are not the same research effort. Scientific Diving is the conduct of underwater operations by divers with the expressed purpose of gathering information in any basic or applied scientific discipline. These include such disciplines as archeology, biology, engineering, physical oceanography, geology, etc. It is diving FOR science, where diving is merely a research tool. Diving Technology, on the other hand, is the science OF diving, where the subject of the research is diving. It is applied research which is focused on increasing man's ability to function safely underwater. It includes such research disciplines as human physiology, hyperbaric medicine, human engineering and life support equipment design etc. It is important to recognize the difference between the two.

Artificial reef research diving follows Scientific Diving methodology that is focused on safely gathering meaningful and objective data about artificial reefs. It is not Diving Technology research unless it is focused on improving the divers ability to gather artificial reef data.

Scientific Diving Safety

Safety is of paramount importance in Scientific Diving research and never should be compromised for data. In Diving Technology research, however, their may by times when researchers go beyond the commonly accepted limits of safety to test a new diving concept or to extend human capabilities underwater.

Recognizing the difference between scientific diving and diving technology has implications for planning, safety and the establishment of standards which apply to their respective underwater research procedures. Diving Technology research, for example, could require testing new life support equipment, or new gas mixtures at exceptional exposures. These procedures may require the diver to be a test subject to work outside the limitations of "traditional" safety standards. In Scientific Diving, however, exceeding traditional safety standards is rarely acceptable. Scientific Diving procedures are limited by the current level of Diving Technology that is available to the diving scientist.

There are also implications for proper dive planning, organizational procedures and the establishment of special safety standards for Scientific Diving, when compared to sport diving. In sport diving, for example, the objective is recreation. In a sport dive plan, bottom time is maximized, and all precautions are made to minimize stress and work, maximize enjoyment, comfort and safety. Abrupt changes in the environment, as limited visibility, thermoclines or heavy seas may be sufficient reason to abort a recreational dive, without hesitation.

The word safety in Scientific Diving takes on new implications beyond that of sport diver safety. Since the mission of the scientific diver is to gather data, safety implies the safe return of the diver with the data. The job of gathering data places a burden beyond what the sport diver may normally be accustomed to when underwater. Not only is the scientific diver concerned with the safety of the dive team, but is also concerned about diver performance. They must concentrate
on the task(s) of gathering quality information, objectively. Stress and distractions imposed by the environment, a limited air supply and increased hazards (compared to a safe laboratory), severely limits the amount and quality of information which can be gathered underwater. Procedures for simplifying data gathering tasks and securing it must be considered in the scientific dive plan. A scientific dive plan may require diving under less than desirable (uncomfortable but safe) conditions if the project's objective is aimed at the study of the effects of these conditions on marine life, or the opportunity for getting the data is rare.

Simply stated, ALL dive plans for scientific diving missions must first maximize diver comfort, and minimize stress, work loads, time pressure and the number of tasks each diver must perform. A comfortable diver will produce high quality data. If he is distracted by an unnecessary concern for survival he simply will not give adequate attention to his assigned task, and the quality of the data will suffer.

Special safety standards for scientific divers have been developed by the American Academy of Underwater Sciences (AAUS). They have been accepted by the federal office of Occupational Health and Safety Administration (OSHA). See Appendix A for AAUS Scientific Diving Safety Standards. Divers engaged in underwater research activities should adopt the AAUS standards for their organization to insure compliance with OSHA's minimum requirements for scientific divers.

Scientific Diving Limitations

A diving scientist's mission is to collect precise, accurate (see Chapter 2) and objective information underwater. Any impairment to his cognitive abilities, whether from environmental stressors, limitations of life support equipment or safety requirements will limit the precision, accuracy and objectivity of the data collected. In some cases, if the diver is severely stressed, or task loaded, the data actually may need to be discarded because of its questionable reliability.

Leadership & Scientific Diving

The conduct of undersea research using SCUBA as a primary tool has many limitations which require careful planning and adherence to the "Buddy System". Adoption of a "buddy system" automatically implies that two or more individuals are involved with the project, therefore a structure for leadership emerges.

In sport diving, leadership may consist of an agreement "You follow me!" and the team swims away. In a scientific dive, the task of collecting information adds a significant level of complexity to the leader-follower relationship. For example, someone must decide: What data will be collected? How it is to be collected? Who is going to write it down and transcribe it to paper after the dive? Who is going to carry any instrumentation that may be required? Who will operate it? Who is going to monitor dive time and issue warnings as bottom time runs out or some hazardous marine life intrudes in the study area? This increase in complexity demands that divers communicate and coordinate long before the actual dive and agree to lead and/or follow where appropriate.

A research team of more than two persons is likely to be the rule on most research projects. Some scientific dive programs use a three person dive team. Two divers engage in the collection of the data, and the third one serves as the team leader and safety monitor. This enables the data collectors to concentrate on the research task(s) at hand. Frequently, a project will require more than one team. Underwater mapping usually requires two or more teams to complete the data gathering task. As the number of persons involved increases, so does the need for leadership, communication and coordination.

The chief scientist and the dive master for any research project must apply their best leadership qualities to prepare their dive teams. Procedures for gathering data underwater are typically established by the chief scientist. This is the person who has determined what data needs to be collected that will fulfill the research project's requirements. Most often, the divers do not have the same level of expertise that the chief scientist has in the research being conducted. For example, a fish biologist may want the divers to observe a certain species of cryptic fish. Divers unfamiliar with that species, may at first, have difficulty finding the fish, even though it may be quite prevalent on the reef. The chief scientist must, in this case, extend his leadership role to include training the divers to an acceptable level of competency needed to produce the desired quality of data.

In any at-sea operation, all diving activities which are conducted from a boat, must also have a surface crew and additional rescue equipment, such as a chase boat. The need for coordination and communication with this crew increases the level of complexity of the operation. The need for firm leadership and communication becomes even more apparent.

The obvious conclusion is that the quality and amount of data collected during an underwater expedition will directly depend on the amount and quality of leadership and organization put into it. Expedition planning, leadership and risk management strategies are at the heart of successful reef research projects. Chapter 11 "Underwater Research Project Management" provides a more comprehensive discussion of this subject.
Scientific Diving Tasks & Data Collection

Properly trained and well-equipped scientific divers are capable of performing a wide variety of tasks underwater. Great discretion must be used, however, regarding how much the individual diver is expected to do in the limited bottom time available to him. Task loading (assigning the diver too much to do) will result in poor quality data if the diver becomes stressed by even the simplest changes in the environment. Good scientific dive planning will limit the tasks a diver must perform and will establish a standard of acceptable performance. Complicated tasks may require two or even three dive teams to accomplish, especially if data gathering instruments must be deployed.

Great care must be given to break each task down into its simplest steps and individual action patterns. Then a step by step analysis of each action should be considered in the dive plan. For example, the task of taking temperature using a glass thermometer seems simple enough at first. When broken into its action patterns, it takes on a new meaning: "1) Remove thermometer from protective case when at the desired depth; 2) Read temperature after mercury has stabilized; 3) Return thermometer to protective case; 4) Write temperature, depth, time and date on underwater slate; 5) Proceed to next data recording station or task. Note: record any "unusual" temperature changes and the depths where observed."

These five steps each carry additional implications for the dive plan. The thermometer needs a case that won't get lost when the thermometer is removed from it, so it should be on a lanyard. The diver will need a watch, and a slate with a sharp pencil on a lanyard, to record the data. The diver will need to know where and when to actually take the temperature, and be aware of any unanticipated changes. He will also need to know if the temperature is to be read to the nearest degree, one-half degree or two degrees of accuracy, or is it to be taken three times at each station and averaged. What appeared to be a simple taking temperature has now become a formidable task, unless the procedure has been carefully thought through and STANDARDIZED by agreement before the dive.

Generalized Tasks of Diving Scientists

The following list is organized according to the level of complexity from the most simple to the most complex of generalized tasks that scientific divers can perform.

SEARCH - simple preliminary examination of the study area to assess what is there.

OBSERVE - looking, listening, or otherwise perceiving organisms or physical conditions to include the documenting of the information in some fashion.

COLLECT - capturing or taking of living or non-living specimens for later analysis. Includes photography and sound recording as well as use of environmental instrumentation.

MEASURE - collecting numeric information regarding spatial relationships, horizontal/vertical distances, sizes and relative positions between study subjects. Mapping.

COUNT - numerically quantifying the occurrence of events, organisms or behavioral activities.

SURVEY - careful examination and re-examination of selected areas for the occurrence of certain events, or for comparisons.

MONITOR - regular collection of certain data parameters of the same environment over long time periods to document physical and/or biotic changes.

EXPERIMENT - replicated manipulation of variables to document their effects and determine causal relationships. In a field setting, all variables cannot be controlled. Underwater research projects commonly employ the use of combinations of these generalized tasks. For example, a fish population study may require searching, collecting, and counting to document fish occurrence at a single site. Comparing sites may require additional surveying or counting and even monitoring.

The procedures for gathering data underwater will largely be determined by the original purpose for the research project and the task level needed to fulfill that purpose. If the purpose of the project is to describe what invertebrates are covering a reef structure, then there is no need to survey, monitor or use experimental procedures. A simple collection may be enough. If, however, the project is to determine what and how many invertebrates are on a reef, then the more elaborate surveying or counting methods may be needed.

Collecting Data

Data is simply information. It may be a written or voice description of something or some activity or phenomena observed. It may be a number or count of something that is recognized according to a category, such as number of Barracuda or Sharks observed. Data may consist of measurements of something such as temperatures, depths or distances between things as for maps. It may be actual specimens, videos or photographs, properly labeled and catalogued.

Raw & Reduced Data

Data can exist in two forms, raw data or reduced data. Raw data is the actual information as it was gathered when the observation was being taken. It might appear on standardized "Data
Data Collecting & Preservation Guidelines

The collection and preservation of the raw and reduced data from underwater projects requires adherence to a few basic guidelines listed below:

- Create a standardized basic raw data sheet. This should be simple and easy to understand (fail safe). Be consistent and avoid frequent changes to the sheet.
- If there is a change (from the standard) in data collection procedures, it must be noted on the raw data sheet.
- Data must be intelligible to any reader. Avoid complex coding symbols. If they must be used, make such a code key is on the data sheet.
- Dive log is part of the data.
- Put the Complete Date, Location, and Name of Observer on Every raw data sheet, to include year, month and day.
- Use pencil or indelible ink --- no felt tip pens, unless they are waterproof.
- Remember, "0" is a real number. It means you looked for something and did not find or observe it. If you made no observation at all, you should enter a dash (-) or a "Not Applicable" (N/A) symbol on the data sheet.
- Make backup copies of all raw data sheets and store them in a separate location, as soon as possible.
- Make sure original or authenticated copies of raw and reduced data gets into the archives (see Chapter 12).

Summary

Underwater research as it applies to volunteers involved with artificial reef research is the special adaptation of sport diving technology to scientific diving. It does not require the use of sophisticated methods or equipment that may only be available to the scientific community.

There are a few considerations applicable to all underwater research projects which are fundamental to credible scientific research. This "Introduction" and following chapters deal with those things considered by the authors to be fundamental to artificial reef research. Perhaps the best review of these fundamental principles can be summarized through a list of basic concepts presented in this handbook.

Artificial Reef Research Divers Basic Concepts

Summary

1) Artificial reef research diving follows Scientific Diving methodology. Scientific Diving is the conduct of underwater operations by divers with the expressed purpose of gathering information in any basic or applied scientific discipline. It is diving FOR science and is limited by diving technology. The chief scientist is responsible for the science methods used on a project.

2) Safety is of paramount importance in Scientific Diving research and never should be compromised for data. Since the mission of the scientific diver is to gather data, safety implies the safe return of the diver WITH the data. The project divermaster is responsible for safety.

3) Never should the chief scientist and dive master be the same person.

4) ALL dive plans for scientific diving missions must maximize diver comfort, and minimize stress, time pressure and the number of tasks each diver must perform. A comfortable diver will produce high quality data.

5) The quality and amount of data collected during an underwater project will directly depend on the quality of leadership and organization put into it. Expedition planning, leadership and risk management strategies are fundamental to successful underwater research. The leadership must establish a standard of safe and acceptable performance.

6) The procedures for gathering data underwater will largely be determined by the original purpose for the research project and the task level needed to fulfill that purpose. Procedures must be carefully thought through and standardized by agreement before the dive.

7) It is imperative that the original or authenticated copies of raw data sheets, along with the reduced data sheets are preserved in the archives. If the data never gets into the archives, then all prior efforts are a waste of time.
Chapter 2

The Science And Technology Of Artificial Reefs

by Robert L. Jenkins

Sport divers' lives and activities have been greatly affected by both science and technology. Science has identified the natural laws which affect what happens to our body underwater and technology has applied science to design the life support equipment we use in diving. How do we define just what science and technology are? Knowing the distinction is important for the beginning scientific diver. Science, in essence, systematically explores the universe, using strict research procedures, to determine how natural laws function, and to learn how to use them. Technology is the application of the findings of science to man's advantage. It is beyond the scope of our work to go much beyond these rather simple working definitions, however, they will be sufficient for our discussion.

The purpose of this chapter is to familiarize you with what science, research, and technology are, and provide some examples of their implications to artificial reef research. In its essence, this chapter will not be telling you how to do research on an artificial reef; rather, its purpose is to tell you what science and research are about in a philosophical, and yet practical sense. We will be concerned about the "whys" of science and not so much with the methods and the means of science and technology as they are applied to artificial reefs. Those will be the subjects of the following chapters. It is the reasoning behind the "whys" that will be discussed here.

Science: A Definition

Science is a human endeavor that believes that the real or natural world is described by what it terms NATURAL LAWS.

The goal and practice of science is to discover and describe these NATURAL LAWS. In other words, science is an objective, systematic and logical discipline to examine, describe, analyze, and test the real world of natural phenomena. The resulting descriptions that are discovered through science become the natural laws we are seeking. SCIENCE IS SIMPLY A LANGUAGE used to describe a highly integrated form of knowledge about the real or natural world, with the knowledge being described by its natural laws.

Now the term natural "laws" can be misleading, for it does not imply anything that is unalterable, concrete or non-changing. A NATURAL LAW is our best overall description of a natural (phenomena) which can be understood from the best accumulated facts we have at that moment in time. As facts accumulate, our description of the natural law may change. Put simply, science describes our world by developing a specialized language for doing so. Because we are now openly refuting one of the more frequently misunderstood aspects of science (being that it is unalterable or unchanging), it is important to recognize and highlight several of the more crucial aspects of just what science is. Among these are:

1. **Science is a human invention and endeavor.** As such, it must deal with all the human weaknesses that any other human endeavor must cope with. It attempts to restrict the impact of these influences through highly disciplined practices and standardized procedures that are repeatable by others.

2. **Science is objective and not conjectural.** Facts are only those things which can be detected, observed, proven, and generally accepted. Science is always open to continual scrutiny, evaluation and re-evaluation if deemed necessary.

3. **Science is not just the documentation of events and instances in the natural world.** Rather, science is the language that we use to describe those instances through the descriptions known as natural laws.

4. **Science approximates the truth, rather than attempting to define the truth absolutely.** Old interpretations of "truth" can change and be altered as new facts are discovered (this is one of the more exciting aspects of science as it continually documents new knowledge).

It is this fourth aspect of science with which the beginning scientist/technician often has the most difficulty. We approximate the truth in science simply because in forming our descriptions (natural laws), we can never know or be able to describe all of the facts and variables which support any truth. Science is an endeavor that consistently and constantly seeks truth by the gathering, describing, and examination of all facts under all
conditions. Consequently, as we become aware of new facts, our “truths” must be re-examined and often re-defined, even to the point of being discarded. This process will have particularly important meaning in our work on artificial reefs, simply because there is so much that has yet to be learned.

It is at this point that the terms “hard science” and “soft science” come into play. There are “hard sciences” and there are “soft sciences”. These terms describe the relative strength of the facts that support the natural laws of each scientific discipline, and not the degree of difficulty of understanding them.

Going from the harder to the softer sciences, they run from: mathematics - physics - chemistry - biology - anthropology - sociology - psychology, etc.

Mathematics is the hardest of the sciences because its facts are precisely defined and built on strict numerical logic. Psychology is one of the softer sciences since its facts about human behavior are subject to the scientist himself who cannot objectively remove himself from the behaviors he describes. The science of artificial reefs, while mostly based in the relatively stronger sciences of physics, chemistry, biology, engineering and geology, is presently on the softer side of these disciplines. It should be our goal to make the science of artificial reefs “harder” than it presently is. That is: based more on strict (mathematical) objective logic, than on the more subjective personal interpretations of observed events.

This also brings us to yet another very important aspect of science: that science is a self-correcting discipline. Science has, as one of its most fundamental rules, the maxim that it can, and must, be alterable. We merely approximate the truth in our natural laws, and therefore, we must always be ready to discard a natural law or truth when the facts show it to be no longer valid. This aspect is the one people and even scientists most often forget. Any truth or natural law is only our best description at any one moment in time. It should always be open for re-examination and evaluation as our knowledge increases. Our science of artificial reefs will be no exception to this tenant. The option to re-examine and re-evaluate what we know about artificial reefs based upon an ever increasing knowledge base must always be open.

How then, do we obtain the facts on artificial reefs so that we may define and describe the truths or natural laws that govern them? And, how may we employ this knowledge to build successful artificial reefs? We will do so through both scientific research and the development of technology.

**Scientific Research & Technology**

Scientific documentation methods and technology applications are two basic disciplines you will use in your work on artificial reefs.

Scientific research is essentially an endeavor whose motive is the search for truth. Technology is the application and re-application of research results to defined goals which usually benefit someone or something. The typical development of an artificial reef is to benefit fishermen through increased populations of certain select species of aquatic organisms (more edible fish!). This usual goal should be based on sound, scientifically based artificial reef technology developed through artificial reef scientific research.

An example research project may discover that benthic reef organisms will grow on weathered concrete, but not (perhaps due to some toxic problem), grow on raw, or uncur ed concrete. Technology then would use this natural law discovery (a truth, discovered and described through research) so that weathered concrete, and not raw concrete, is used to construct artificial reefs.

Then, in order to improve the overall efficiency of our technology, further research would be done to find out just how weathered the concrete had to be before it could be used for artificial reefs. Findings of that type of research would further refine the construction of artificial reefs.

A research finding may show that complete ships, having decks and holes in the hull, make better (by attracting more game fish) artificial reefs than do plain, bare ship hulls. Again, technology would use this knowledge so that only ship hulls with holes and decks are used to build artificial reefs. In this example, further scientific research on reef technology would attempt to determine the ratio of holes and hole size to the size of the ship's hull that optimize the desired effect.

During our work with artificial reefs, both scientific research and technology may be ongoing at the same time. It is most important to remember that we must first have sound scientific research from which to build a sound artificial reef technology. We then further strengthen that technology through continuous applied research.
Well, just what exactly is sound scientific research, and just how do we do it?

**Artificial Reef Research**

Scientific research falls into two essential types: BASIC and APPLIED. Basic research is commonly known as "pure" research, which merely seeks knowledge. It has no directed goal or motive other than pure discovery as its driving force. It has no focus on a real application. It pursues knowledge for knowledge’s sake.

Applied research has a specific goal or aim which is focused on solving a problem or meeting some specified goal by searching for new information. Technological research is used to refine an already existing knowledge. In its essence, artificial reef research is applied research, for we are engaging in it to increase knowledge for specific goals. However, it will also require some technological research to refine how we may build a more efficient reef that produces a desired product(s).

To illustrate, a study to determine the numbers and seasonal changes of fish around a shipwreck is a basic or pure research effort. Doing this same study to measure the success of a wreck with respect to attracting a desired species of fish would be an applied research project. Undertaking this same study to determine how one should alter the wreck to increase the numbers of fish on the wreck would be engaging in technological research. In fact, all three types of research could be going on at one and the same time in any given project. The distinction between basic, applied, and technological research is primarily based upon the goals and objectives for the research in the first place. This research then serves as the basis for building an artificial reef technology which will then require further technological research to fine tune it to the specific geographic location where it is found.

It is important for artificial reef researchers to develop clear and well-defined goals for the research before actually starting it. While it may seem that a motive for reef research automatically exists, it is often surprising that so many do not really know the direction or reason for doing the work. It is simply just not enough to want to do artificial reef research. One must know why he or she is doing it and what specific question(s) is/are to be answered. Such a direction or goal may range from the general (what is there?) to the specific (how does concrete compare with rubber as reef substrate?), and from the simple to the complex. But, it still remains imperative that clear goals be identified for the research effort.

After the research goal or direction has been defined, a project outline should identify how that goal may, or may not, be reached, what data parameters would be needed, and if it is within the researcher’s capability. It should also identify what the project can not do as well. Once a goal has been defined, we need a method to attain that goal. It is at this point that "the scientific method" comes into play.

**The Scientific Method Or Process**

The scientific method is a chain of activities similar to the Deductive Process Outline found in Figure 2.1. The researcher takes existing knowledge, makes and documents an observation(s), and forms an idea or explanation called the hypothesis. He then designs and conducts experiments (tests) to see if the hypothesis is true or false. The experimenter attempts to directly control all but one factor (variable) in the situation to observe how it influences the data. Closely examining this variable and its effects determines the truthfulness of the hypothesis. One should not regard the experiment as being solely found in the laboratory, where all variables can be carefully controlled. Experiments can also include observations, behavior, and other similar subjects in a field setting.

Once the experimental phase has been completed, the facts are accumulated, correlated, and the new scientific law or discovery is described. The new or "discovered" law may then be used as a base to develop a new hypothesis and the process can then repeat itself. The knowledge accumulates and more laws are either formulated or discarded. At some point, when the discovered laws reveal a broader pattern, a more general explanation or description may be offered. This broader description is called the THEORY.

**Deductive Method**

The foregoing process in science is known as DEDUCTION. It takes existing knowledge and builds on it to increase the number of facts and laws to become a generalized theory (see Figure 2.1). Deduction was virtually the only identifiable scientific method used until the turn of the century, which partly accounts for its popularity as the scientific method. However, there is another scientific process.

**Inductive Method**

A researcher may gather knowledge available to him on what he is studying, and by developing a thorough understanding of that knowledge, make a rather large leap directly to a new law or theory. This method is called INDUCTION. Induction takes existing knowledge and, without experiments or other fact finding, infers the existence of
a new natural law through a purely mental process. In essence, it predicts the formulation of a natural law or theory. The new law or theory is then offered as being tentative until such time that experimental facts can be found to support or prove it (see Figure 2.1). Often the researcher who makes such a leap forward in knowledge will outline the experiments that would be needed to confirm the inferred law or theory. If such experimental proof can be found and confirmed, the new law or theory is accepted; if not, then it is cast aside or a search undertaken to explain why it was not found to be true. (See Figure 2.1)

Both induction and deduction are useful scientific methods. It is important to remember, however, that deduction needs only a small amount of knowledge from which to begin. Induction, on the contrary, requires a much larger and more diverse base of knowledge and a typically longer time for the researcher to assimilate that knowledge before it can be fully used. The deductive and inductive methods are generally combined in the real world of scientific research. For example, Darwin's Theory of Evolution was built from the accumulation of an immense base of knowledge and facts or deduction, and was also developed from a purely mental process using available theories and observation, or induction. This was a case where both the deductive and inductive processes have created a theory at nearly the same time. The Special and General Theories of Relativity were built from isolated facts of existing knowledge and Einstein's own inductive mental processes. The two theories on relativity were later confirmed by other researchers' experiments suggested by Einstein, and are good examples of the inductive scientific process being confirmed by deduction later on.

How does this apply to artificial reef research? If we use the example of the bare ship hulls versus those with decks and holes in them, the deductive process would prove the natural law: "that decks and holes attract fish" through the accumulation of data reflecting less fish being found in the bare hull reef and more fish being found in the reef made of hulls with decks and holes. Deduction would allow us to develop the natural law describing this and we would apply this knowledge to develop a technology that builds reefs from ships with decks and holes in the hull. The inductive process would start from the knowledge that fish on natural reefs prefer areas where numerous nooks and crannies are present. We would then infer that fish would prefer ship hulls with decks and holes over those that were bare. Experimental proof of our induction would then come from observations once both types of hulls were made into artificial reefs.

Artificial reef research divers will use the deductive process almost exclusively. The current small body of knowledge about artificial reefs prevents highly reliable inductive reasoning methods. Particular concern should be on accumulating field observations that are well documented. The discovery of the natural laws through this accumulation of facts (data), requires standardization in how that data will be accumulated. It is the "what", "where", and "when" of data accumulation that must be carefully considered, outlined, and maintained from the start of any research project, as well as what kind of data is to be accumulated. What then is data?

**Data & Its Successful Accumulation**

Data is information in just about any form. A datum (singular; data is plural) is really nothing more than an event in time that is observed and recorded. Data can be the total number of fish observed on a certain dive, the weather conditions, the water or bottom conditions, a photo or video of the event, or any other parameter set by the persons conducting the research. All data recorded

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**Figure 2.1**

**DEDUCTIVE PROCESS**

Existing Base of Knowledge → Hypothesis (Goal or Desired Knowledge) → Data Accumulation → Interpretation → Natural Laws → Theory

**INDUCTIVE PROCESS**

Existing Base of Knowledge → Inferred Natural Law → Data Accumulation → Interpretation → Natural Laws → Theory

The Deduction Process as Compared to the Inductive Process
must include the date it was taken and the name of the observer to properly account for the information and its credibility.

In any research project, the kind of data to be collected must be defined before it is gathered. Data accumulation has basically two important aspects that must always be considered and planned for. The first is that the data is recorded in some permanent, sharable, understandable and retrievable form. Data can be written on paper, stored in a computer or any other method defined by the person conducting the research. The actual method is unimportant as long as it is RECORDED, SHARABLE, RETRIEVABLE AND UNDERSTANDABLE. Data which is tucked away inside someone's head or recorded in a code known only to the observer, does no one any good and may actually be lost should the person leave, forget or die.

The second aspect of good data accumulation is that the data is relevant to the research goal. This is determined during the outlining of the research project where the "how," "what," "why," and "when" of data collection is decided. The accumulation of data is a lengthy and costly affair. This is especially true for artificial reef research due to the costs and time necessary to get to the study site, the limited time spent there, the time returning, preparing, and all the logistics that are needed to dive on an artificial reef. Therefore, it is very important to decide beforehand what data is needed and what data is to be ignored. The researcher must realize from the beginning that it is physically impossible to record all possible data encountered during any study.

Data Gathering Methods

Since everything that can be observed around an artificial reef can be recorded as data, great care must be given to decide what and how data needs to be recorded and by what method. This depends on the question being asked and the limitations imposed on the observer by the environment or experimental design. Occasionally, the data, or its gathering method, may need to be altered during the course of the project as new knowledge is gained, important information gaps are found or changes in the situation are encountered. Normally, this is not recommended for it makes comparisons difficult. Any changes to the type or method of data gathering must be carefully described in the records to account for differences which may be found in its interpretation later on.

Unrecorded changes in data collecting methods half way through an experiment or an observation series could lead to wrong conclusions. This can even apply to changes in the observers themselves or the instruments they were using.

Quality of Data

The quality of the data is just as important as the definition of the data that is being recorded. Data is typically ordered in a series of facts or observations that may relate to each other in some meaningful way. They must be consistently gathered and retain high quality from the beginning to the end of the observational period or experiment if the relationship is to have any meaningful substance. This may appear to be self evident; but it is surprising how often a research project becomes worthless simply because good quality data was not taken consistently. Inexperienced or uncomfortable divers are most likely to be inconsistent data gatherers.

Since data is focused by the project's goals, it is the responsibility of the research project leaders (chief scientists) to define the limits to its precision and accuracy. For example, data that records the numbers of non-edible fish present on an artificial reef may be useless if the study is solely concerned with the numbers of food fish present. If, on the other hand, a study is undertaken that compares the relative numbers of non-edible fish to the food fish on the reef, then that data taken before becomes both relevant and worthwhile. Just what is, and is not, good or relevant data must be defined by the project leaders before the project begins and must be continually reviewed during the course of its accumulation.

It must be stressed that high technology is not necessarily needed to accumulate high quality data. In fact, underwater, the most reliable data is often collected by the simplest means. For example, exceptionally good data can be collected with only a pencil, paper, or plastic slate, and a good set of eyes.

Measurements

Many types of data can be collected by the artificial reef research diver. Measurements and simple observations are probably the two most used types of data which are often combined. Some distinction between the two should be made.

Observational data is the accurate description or representation of some detectable phenomenon. Measurement is the comparison of some phenomenon or happening in the real world against a pre-defined standard or scale. Common standards of comparison from everyday life are the inch, the yard, and the Fahrenheit degree. Metric standards commonly used in science would be the centimeter, the meter, and the Celsius degree. Whatever the standard is, it is really nothing more than the measurement taken and adhered to throughout the experiment. Doing so provides continuity throughout the research project. Often
such measurement standards are already established through long use in a particular field of study, such as measuring the temperature of water in degrees Celsius. Other times, when no formal standard exists, some form of comparison, geared to the project's needs, may have to be developed by the research leader. Therefore it is important to standardize the limits needed by the study. Occasionally, it may prove necessary to change the standard for a certain measurement after entering into a research project. This may be done only if there exists the means by which the new older form of measurement may be converted with reasonable accuracy into the newer standard, such as changing inches to centimeters, etc. Establishing the defined standard by which any measurement is to be undertaken BEFORE the project is started will also help provide consistent and high quality data throughout the project.

Accuracy & Precision

It is important to define and outline the standard by which any measurement is to be taken. It is also important to define the parameters which will govern the type of measurement undertaken. The two parameters that govern any measurement are accuracy and precision. In common usage, these are often mistaken as being one and the same. In scientific research, they are quite distinct, yet equally important, aspects of any measurement.

Accuracy is the evaluation of how close one comes to the set standard by which something is being measured. Stated another way, accuracy is a measurement of how well one's individual measurements compare to the selected standard. For example, if the length of an artificial reef site is measured in meters, the measurement would be accurate to a one-meter standard if the reef site is measured to the nearest meter. If, on the other hand, one is unable to measure to the nearest meter, but may only measure to the nearest 10 meters, then we would have less accuracy, based upon the one-meter standard.

Accuracy is the means by which one gauges how closely one comes to the measuring standard for any single measurement. The relative degree of accuracy (the standard), then must be determined before the measurement is taken. It will do an artificial reef research project, or for that matter any research project, absolutely no good to undertake a measurement and then later find it is not accurate enough for the needs of the project. The degree of accuracy needed must be gauged by the goals of the project. If, for example, one wishes to measure the temperature of the water around an artificial reef site, one must determine, just how accurate one wishes the temperature measurement to be. One may decide his measurements need only be accurate to the nearest one degree Celsius. Using an instrument that measures to the nearest 1/5 of a degree, or one that measures to the nearest five degrees, will result in data that is either too costly to get or too inaccurate for the project needs. Accuracy is determined by the needs of the project; the intended use of the measurement and not the relative sophistication of the available instrumentation. Thus, a careful consideration of the accuracy needed in any measurement will help determine how the measurement is to be taken and the device by which it is to be done.

Precision is an evaluation of how often any particular measurement or series of measurements is accurate. Simply put, accuracy tells how close it is possible for us to get to the reality we want to measure, and precision tells how often we can get there using methodology and instrumentation. If one has a measurement that is accurate to the needs of the project, precision will allow the determination of how often such a measurement meets those needs. In any measurement it is very important to ask, "How often is this accurate measurement accurate?" The answer to this question will give the relative precision of that measurement. By now it should be readily apparent that a measurement may be a mixture of both accuracy and precision, as well as being either. Figure 2.2 illustrates the interrelationship of accuracy and precision.

In this figure, four darts have been thrown at three similar targets. In target A, the darts have

Figure 2.2

Target A--accurate but not precise
Target B--precise but not accurate
Target C--accurate and precise
landed in a way that is accurate but is not precise. They have hit the target but are scattered over the entire surface of the target. In target B, the thrown darts are now precise, but they are not accurate; they are close to one another, but are not in the intended target itself. In target C, the thrown darts are both accurate and precise. They are grouped both in the target and in proximity to each other (See Table 2.1).

Table 2.1

<table>
<thead>
<tr>
<th>DIVER</th>
<th>COL A</th>
<th>COL B</th>
<th>COL C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15.5</td>
<td>13.2</td>
<td>18.5</td>
</tr>
<tr>
<td>B</td>
<td>21.4</td>
<td>13.0</td>
<td>18.7</td>
</tr>
<tr>
<td>C</td>
<td>25.3</td>
<td>12.8</td>
<td>19.0</td>
</tr>
<tr>
<td>D</td>
<td>18.2</td>
<td>13.1</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Date Taken: 1/24/84  2/16/84  5/30/84

The results shown in Table 2.1 are measurements of the water temperature that were made by four different divers on the same artificial reef at the same time of day on three successive days. By reading the available literature on sea temperatures for this area, an anticipated yearly range of 15 to 25 degrees Celsius for this area of the ocean was found. The first set of measurements, Column A, shows accurate results that are not precise. These measurements cover almost the entire expected range and show little comparative value to each other (i.e., is the temperature 15.5 or 25.3 degrees?). In the second set of measurements, Column B, all four measurements are precise, but they do not appear to be accurate, as they are out of the anticipated range. The reasons for both of these problems can be varied: inaccurate thermometer; poor choice of expected range, or the temperatures may indeed be this, and the day on which they were taken was an anomaly. Whatever the reason, the results indicate that something is not right and deserves to be checked out. Column C, the third set of measurements, gives both accurate and precise results. They are at once accurate, for they are in our expected range, and are precise since they are close to one another.

It is interesting to note several features of measurement and how they are affected by accuracy and precision.

1) Both accuracy and precision are largely determined by the standard of measurement that is set before the measurement is undertaken. Our choice of how and by what instrument a measurement is taken will affect how accurate and precise that measurement is.

2) The precision of any measurement can be simplified simply by narrowing the accuracy range of that measurement. By closing the gap between both ends of the measurement range, one can force oneself into highly precise measurements. For example, you may decide your reef maps need to be accurate to within 10 meters for every 100 meters actually measured. By changing the acceptable accuracy range to five meters for every 100 meters measured, you have increased the precision of the resulting maps. Of course, the price of this improvement is an increase in time and instrument needed to achieve this level of accuracy.

3) Accuracy of a measuring device, such as depth gauge using an analog needle, requires an estimate be made between a series of similar measurements. A single measurement can be accurate but it can never be precise. A more precise method would be to measure the depth from the same gauge five times, and average the readings. Of course, to verify the accuracy of the instrument it should be calibrated against a known measurement.

4) Measurements that are accurate and precise do not have to correspond exactly to one another. They merely have to be relatively comparable, as expressed in Column C of Table 1. This is where the science of statistics comes into play.

Statistics and its methods have been developed to measure measurements in relation to each other and thus determine their meaning relative to each other. The relative importance of both accuracy and precision is therefore set in the beginning of the project. Surprisingly enough, observational data also fits these descriptions of accuracy and precision for measurements.

Observation

Like any other data method, observation is a way in which to gather perceived and recorded phenomenon or events in time. It is normally conducted with any of the five senses: seeing, tasting, hearing, feeling, and smelling. Any scientific instrument can be used as an extension of any one of these senses. Essentially, an observer must be objective and not subjective in his/her observations. Objective in this sense means that the observer records accurately what is observed and does not impart any of their own ideas, desires, or interpretations into the observation. For example, one could document from a single observation, that a certain species of grouper is present on an ar-
tificial reef. However, one could not determine if the grouper somehow affected other fish on the reef until a series of observations were made to document the Grouper's effect. This interpretation could not have been made based solely on the first and only observation.

Observations are, therefore, objective recordings of sensed phenomena from the real world. This is not to say, however, that observations cannot be intuitively based. They can certainly be intuitive, particularly when one is engaged in the inductive process of scientific investigation. To pursue the example above, one may observe the grouper on the reef and intuitively sense, based upon previous experience with the reef, that it is having a negative impact on the reef. One could then formulate and conduct an objective study to determine if this is indeed true.

Observations not only need to be accurate, they should use the most descriptive terms possible. They need to be precise in that they should be repeatable under the same circumstances. The point at which observations can trick one is that they are made by the person conducting the research. It is well known that we often observe things as reflections of our own inherent experiences, prejudices, and desires. We tend to change (bias) our descriptions based on prior experiences. This is why we must maintain every possible effort to be totally objective when making observations. As artificial reef research divers, we must always be aware of our biases and how they may affect the work being done. For example, if a diver does not believe that non-edible fish have any impact on an artificial reef, he could choose to ignore them, and thus, never be able to measure the real impact that they may have on the total reef system. True objectivity in science is not arbitrarily "turning-off" of one's self. Rather, it is the knowing of one's own inherent biases and how they may affect the data.

**Time & Data**

The final aspect to be considered in data accumulation is the element of time. It takes, as mentioned earlier, a great deal of time (and thus money) to collect and record data. This is of great importance in artificial reef research, since so much time is consumed in just getting to and from the research site. Time is, therefore, one of the most precious commodities in artificial reef research. This is where all the careful planning and goal outlining mentioned earlier will have its greatest impact. Spending time planning the research while bouncing on the boat over the research site is just plain wasted. Planning is best done on shore before the dive. This includes planning for safety and maximizing research time at the study site.

Science is largely a repetitive endeavor, and it takes a great deal of time and many observations to build up the data base to make the research meaningful in the first place. It is important to realize that good reef research will not result from a single dive on any artificial reef. It will be the repetitive, sometimes seemingly monotonous work built up over extended periods of time, even over many years that will yield the most worthwhile results. Once again, caution must be used not to change data collecting methods because of their monotonous. Time must always be taken into consideration when planning and outlining the final research project. Furthermore, time also has impact on the final step in conducting the research; the interpretation of all the data and experimentation that has been going on up until now. One must constantly take the time (between data collections) to evaluate what one has done in order to direct one's future work on artificial reefs.

**Interpretation & Organization**

Science, as outlined in the foregoing pages, is the overall method by which one discovers the natural laws which are the language used to describe the real world. It is the means by which, the artificial reef research diver will discover the world of the artificial reef. Observation, experimentation, and research are the methods of finding and describing the facts upon which this language will be based. Since we are conducting science, it now becomes necessary for us to explain this work so that others may know and make use of it. The step in which one formulates his explanation of the meaning of his work is known as INTERPRETATION. Interpretation is the analysis of the research findings from which the natural law and ultimately the theories, is developed into some communicable form. The interpretation can also be called the conclusion, or summary, of the work which conveys the discovered knowledge. Of all the steps involved in research and the scientific process, this will be the most difficult, the trickiest, and the one that requires the most experience to do properly. This is where the non-scientist must seek the advice of professionally trained scientists.

The principle reason that the interpretation or conclusion process is so difficult is that it is extremely easy to reach quick and often wrong conclusions before enough facts have been accumulated. As artificial reef research divers, our hardest task will be to keep from jumping ahead to the end of the research process and prematurely formulating an interpretation about the research results before the project is complete. In doing this work it will always be tempting to take some single observation or other small aspect of this work
and build it into a rather grand fact. This is understandable, for the hardest thing any researcher or scientist must learn is that he or she must be patient and wait for the build-up and accumulation of data that will either prove or disprove any given hypothesis. The scientific literature, and indeed the popular literature through the media, is already scattered with the remains of research interpretations which were based on either too little data or on the premature interpretations of that data. For the artificial reef research diver, one of the most effective ways to avoid any premature interpretation is to have a full understanding of what his role and limitations are and how that role as a research diver (technician) is carried out. He should leave the interpretation in the hands of the professionally trained researcher.

**Role of the Research Diver**

In the past, research was usually carried out through the efforts of single, professionally trained individuals who did the observations and measurements, performed the experiments, accumulated the data and facts, and then did the interpretative work to formulate the laws and theories. During the past hundred years or so this has changed to more of a team approach. It is through this team approach that you will most likely be working as an artificial reef research diver. Because of the diverse nature of the disciplines involved in artificial reef work (i.e. population dynamics, invertebrate zoology, fisheries science, marine engineering, etc.), no single diver or set of diving partners can do all the work necessary to conduct research on artificial reefs. Therefore, the role of the artificial reef research diver is principally analogous to that of the laboratory technician in a modern day research laboratory. These technical people are responsible, by virtue of their training, to do the observations and data gathering pertinent to the research project and compile the data in a manner relevant to that project. It is the professional scientist who should interpret the data collected by the artificial reef research divers.

The modern research team usually has a primary researcher, called the Principle Investigator, who leads the research effort to meet the goals of the research project. This primary researcher may be a scientist or even a small team of scientists leading the research. It will usually be this principle investigator who will set the project’s research goals, standards, evaluate the data, do the final interpretation and analysis of the data, and finally if applicable, publish the results. You, as the technical person, who collects the data, will play an integral and pivotal role in the research simply because so much depends on your diving and data gathering skills. The entire artificial reef research process depends on the accumulation of relevant, accurate, and precise data for its success. That is the reef research diver’s function. A hypothesis will be supported or rejected on the basis of the data taken. The natural laws or theories that emerge will only be as good as the data that they are derived from. In no small sense, the success of any artificial reef research project will depend almost entirely upon the quality of its data; hence, the divers who are responsible for obtaining it.

**Summary**

Science is a series of steps used to discover natural laws. Scientific knowledge is built from data collected over time and the findings from past research and studies. In building our science of artificial reefs, we will be exploring new territory, discovering new facts, and expanding our knowledge of the real world. We can do so, however, only because we are basing our work on the beginning on the knowledge gained by those who went before us.

The advent of the volunteer, artificial reef research diver into the world of science is an exciting one. It is perhaps one of the first real opportunities in which a non-scientist can not only experience the fun and joy of doing science, but can also have direct and meaningful input into the world of scientific research without having to have the extensive training typical to most scientific disciplines.

**References**


Chapter 3

Some Basic Considerations Of Underwater Scientific Photography

Joseph G. Halusky

Photography is a powerful tool for a diver/researcher. It enables the diver to return to the surface with a visual record of his subject as it was observed for moment in time. The camera-equipped diver can gather a large amount of data with a few snaps of the shutter, reducing the number of tasks he might need to get the same information manually. With proper accessory equipment and/or technique, the camera eye can capture phenomena invisible to the human eye by using infrared film or by stopping rapid motion.

Many "scientific" photos share characteristics common with "artistically" composed photographs, however, there are subtle differences. They vary in the value of the story they tell, in their eye appeal and in their composition. The "artistic" photos value is in its aesthetic eye appeal or unusual quality while scientific or documentary photos derive their value from the amount, quality, credibility and accuracy of the data (information) which they contain. Principally, the data photo is used to reconstruct and document some event and to capture qualitative and/or quantitative information about the subject. Often a series of data photos is taken to record the progress of a project or experiment or to show a progression of change over time, such as "before" and "after" photos. Of course, a good scientific photo can also have a high artistic value and vice-versa.

Basic Components of a Documentary Photo

Since the primary intent for a scientific photo is to record data, each photo should have certain key elements with it to make it acceptable as a scientific document. The key elements should appear on or in each photo. Information is placed on the photo after the film is processed and the print made. Information is placed in the photo at the time the picture is taken, and thus becomes part of the photograph itself.

Key Elements of a Scientific Photograph*

1. **Date and time photo was made.**
2. **Location where photo was taken (includes depth and precise geographic location).**
3. **Name of photographer.**
4. **Scale of photo. (The size of the subject should relate to some known object, such as a ruler, pencil or coin.)**
5. **Orientation of photo. (The subject of the photo should be related to some known benchmark such as distance and direction from a known point or experimental variable.)**
6. **Exposure information. (Film speed, shutter speed, f-stop and any special lighting and filters.)**
7. **Project Identification -- Name or code number.**

* Indicates information which must accompany each photograph.

Basic Methods for Underwater Scientific Photography

Camera technique used by scientific photographers is generally no different from techniques used by amateur or professional photographers. All "tricks of the trade," therefore, can be applied and will not be discussed herein. Many suitable texts already exist on camera techniques and the reader can refer to them for further information.

The scientific photographer is faced with deciding between two photographic approaches to
approach. It is the nature of the question being studied which determines the method used.

**Single-Event Photo Method**

- **Definition:** In this method, the data needed is contained in a single photograph. It is a photo of a subject or phenomenon as it occurs. e.g., photo of a fish, or a fish behavior; pictures of scenes, activities, etc.
- **Method:** Single photo using still camera.
- **Application:** Used to:
  - document "it happened";
  - illustrate the "who, what, where, when and how" of some event;
  - record patterns (as fish markings, distribution on reefs);
  - record angular relationships, colors, interactions between individuals (as hermit crabs and their shells or cleaning behavior of fish at a cleaning station);
  - show relationships with their environment;
  - document experimental procedure, methods and progress.
  - can easily be made available for publication.
- **Disadvantages:**
  - cannot document relationships over great distances;
  - is inaccurate for comparing individuals not in the same photo or for survey information;
  - cannot show elements of change over time (however, single-event photos can be analyzed when made part of a series);
  - as a single photo, it cannot be used for assembling quantitative data or making population estimates.

**Systematic Photo Series**

- **Definition:** In this method, the data is obtained by comparing a series of photos which were taken so that each photo is related to others in space and/or time. Example: series of photos taken to make a strip map or a movie film. A movie is a group of still photos taken in time series.
- **Method:**
  - **a)** Series in relation to a benchmark -- Photos taken in order, at regular intervals from a known benchmark. (Bottom survey of invertebrates along a transect line from a permanent benchmark.)
  - **b)** Series in relation to time -- Photos taken at regular intervals of time of the same subject to show change. Movie or time-lapse. (Growth of the same coral colony.)
  - **c)** Series in some pattern -- Photos taken along a randomly placed transect using a predetermined pattern, not necessarily related to a benchmark or regular time interval. (Used in population surveys of a variety of reefs.)

Note: Generally it is best to include photo identification information (see Key Elements) in the photograph series rather than on the photo after processing.

- **Application:** Series of photos can be used to:
  - survey an environment to obtain numerical data, such as a strip census or to measure distribution of organisms in relation to identified parameters or benchmarks;
  - make maps;
  - measure relationships between individuals such as in fish schools (Slow motion movies);
  - measure animal behavior action patterns;
  - measure growth rates or otherwise unperceivable changes as with time lapse photography of slow moving organisms on reefs.
- **Disadvantages:** The series of photos:
  - takes more preparation and more space than the single event photo, and may require special viewing equipment. (Loss of one photo could destroy value of the series);
  - not as useful for organism identification since the photo series is not oriented to just one subject, but instead oriented in space and time. (A fish may not stay within the limits of your survey area when the photo is being taken);
  - may be costly, depending on the measurement and orientation equipment needed to get the series;
  - usually requires more than two divers and more coordination and time to obtain the series;
  - may be difficult to analyze since the data exists in more than one photograph.

**Storage and Retrieval of Scientific Photos**

Taking the photo or photo series is only a small portion of the work surrounding scientific
photography. A photograph is like any other "specimen" or "data sheet" that should be safeguarded and filed for later use. Project photographers should consult with the archivist to insure their work is entered into the archives properly. Careful consideration should be given to purchasing cabinets and film holding devices since photos, video tapes, movie film and negatives may have special handling and storage requirements. Like any specimen, each photo and negative should be labeled with the minimum information on it to include: date photo taken; location and photographers name.

Organizing the photos for later retrieval can be the greatest challenge. This requires a cataloging system and some procedure for loaning out the photos for those needing to use them. Library techniques for assigning topic headings for various photos would be useful for organizing the photo archives. One excellent publication titled "Organizing Your Photographs" by Robi (1986) offers many good suggestions for filing the photos and even computerizing information about them for quick retrieval. Photos should be cross indexed with the original data and dive log sheets stored in the reef data archives. One good way of achieving this is to store a photo log sheet in the specific reef site files, or project file.

Summary

The diver/scientist/photographer has at his disposal a powerful, time-saving tool for documenting underwater phenomena. He must, early in his project design, select the appropriate camera technique and method (single event or systematic photo series) by which to gather his data. When considering photography as a tool for data gathering, careful consideration must be given to: limitations of the equipment, lighting and film; environmental parameters which affect photography; length and cost of the study; the nature of the question being asked; and the need for accurate photo record documentation.

Suggested References


Church, Jim & Church, Cathy. (1986). The Nikonos Handbook, Herff Jones Yearbooks, PO Box 3288, Logan, UT 84321


Chapter 4
Oceanographic Data Collection And Reef Mapping

Christopher P. Jones

The collection of oceanographic data by divers is an important part of any artificial reef program. The data are needed for: site selection, assessment of physical changes to the reef over time and assessment of biological productivity. While some physical site selection data can usually be gathered during a single dive, assessments of biological productivity and reef stability require many dives over an extended period of time.

The data are not the only consideration. Just as important are such things as measurement techniques, documentation of time and location of measurements, storage and retrieval of data (See Chapter 12: "Archives"). Unless the measurement techniques are standardized, and unless the time and location of the measurements are known, the data will be of no value. Standardized techniques for data gathering can help the diver make the most efficient use of bottom time and get maximum use out of the data. Reef maps can provide one of the best ways to handle data and to document changes to the reef structure over time. The type of map to be used (and the oceanographic data to be measured) will depend upon the goal of the data collection program.

The important thing to remember is that the reason for collecting data and noting artificial reef changes is to increase our understanding of reef behavior under certain oceanographic conditions and to improve siting and construction techniques. Unfortunately our present understanding of hydrodynamic forces on reef elements and submarine soil mechanics does not allow for accurate prediction of reef stability. Furthermore, expensive data collection programs using sophisticated equipment are required to make even approximate predictions. Since most artificial reef projects have minimal funding, data collection programs must be simplified; siting and construction decisions must be based on limited information and carefully researched principles. Divers will play an important role in collecting data and monitoring reefs so that these principles can be refined and improved. Oceanographic data as used in this chapter will include such parameters as: current direction and magnitude; direction, height and period of surface waves; bottom sediment characteristics; water temperature, salinity, turbidity and dissolved oxygen; and water depth.

There are only a few references dealing specifically with the stability of artificial reefs (Kim, et al., 1981; Ask, 1981). However, there are numerous references dealing with submarine soil mechanics and hydrodynamic forces related to pipelines and offshore construction; much of the information will be applicable to reefs (Grace, 1978; Chang and Ford, 1978; American Society of Civil Engineers, 1974; American Society for Testing and Materials, 1972; Schenck, 1975; Herlich, 1981). The NOAA Diving Manual (Miller, 1979) is also a good general reference for reef divers.

Reef Stability

Stability of an artificial reef can be defined as the ability of the reef to resist settlement displacement and deterioration. The long-term stability depends upon many things: reef material(s), water depth, waves and currents, bottom sediments, etc. A reef monitoring program should be designed to document any changes in reef structure and orientation, as well as material deterioration. The program should gather sufficient oceanographic data to correlate changes in the reef with these data. The reason for looking at reef stability is to note changes in the reef elevation, structure or materials that affect the biological productivity of the artificial reef. These changes can occur gradually over a long period of time or they can occur suddenly, particularly during severe storms. For these reasons, monitoring programs should include periodic dives at a reef site, and should allow for dives after storms as soon as conditions safely permit.

Important changes can be divided into five categories: settlement, siltation, collapse, disintegration and scattering. The first four all result in a loss of reef, while the fifth results in a dispersal of reef materials over a wide area.

Settlement and Siltation

Settlement occurs when the bearing capacity of the bottom sediment is not sufficient to support the reef elements or when the sediment liquefies during storm conditions -- the reef sinks into the bottom. Siltation occurs when waves and currents
carry sediments into the reef area, where for one reason or another they settle out, slowly burying the reef elements.

Bottom characteristics should be investigated carefully as part of any artificial reef site selection process. This is to ensure that settlement will not occur, or if it does, that the expected settlement will not be a problem. Settlement of a reef can be monitored by driving one or more steel rods or pipes into the bottom at the reef site and measuring the elevation of the reef elements with respect to the tops of the rods. Settlement can be monitored by measuring the distance from the tops of the rods to the sediment. The rods can also be used as horizontal and vertical control points for mapping efforts.

**Collapse and Scattering**

Collapse is used to describe the movement of reef elements from their original configuration to one of a lower profile. Individual elements remain intact during this process. Scattering occurs when reef elements spread out over the bottom (low density materials such as tires are susceptible).

Measurements of collapse and scattering will be more involved, due largely to the nature of reef materials subject to these changes - the elements are usually small and placed in large quantities (tires, appliances, culvert, rubble, etc.). In order to measure collapse and scatter accurately, the diver must have a complete and accurate post-construction map showing the locations and positions of the reef elements. He must then return to the site later to construct another map. Mapping can be accomplished with tape and compass, or with more sophisticated (and expensive) equipment. Raymond (1981) describes such a project, where sidescan sonar and underwater photographs were used to map a tire reef.

Ideally, differences between the maps should be due only to collapse or scatter, but this may not be the case. Poor conditions, limited visibility and errors in measurement will all be reflected in the differences between the maps. Divers should recognize that bottom time limitations and other constraints may not allow them to precisely locate individual reef elements, and that maps will therefore contain some errors. This is acceptable, provided that divers accurately map the boundaries of the reef, and the shape and height of its major features. These data will allow gross changes in reef structure to be documented. Remember, it will not be worth the effort to map large numbers of individual elements within a reef site, except during highly unusual circumstances.

**Disintegration**

Disintegration refers to the deterioration of reef materials. This occurs most commonly with automobiles, appliances and other elements made of thin sheet metal that corrode rapidly.

Disintegration may result in localized or total failure of a reef; it may occur slowly or rapidly, depending on the type of material used to construct the reef and the forces acting on it. Documenting deterioration will require that photographs and/or notes describing condition at the time of placement be compared with similar records from a later date.

In many cases, deterioration will be obvious (e.g., a broken hull or collapsed deck on a barge or boat). Divers should concentrate on documenting significant changes rather than the minor or not so obvious ones. They should look for such things as: changes in height, break up of large pieces into smaller ones, enlargement of major cracks and holes, corrosion and disappearance of metal sheets or wood planks, etc. It is helpful to mark a piece of metal so that divers can return to the same place to follow movement of tagged materials to document change.

**Oceanographic Data**

Collecting oceanographic data is an important part of any site selection or reef monitoring program. Divers must collect the data systematically and record it carefully. Following the procedures outlined in this chapter will help divers to gather the most important data. Using a standardized data recording sheet (see Appendix D for examples), will ensure that the necessary oceanographic data area collected, and that other important information is also recorded. This additional information should include: surface position (latitude and longitude, or LORAN), date and time (be sure to note whether times are daylight savings or standard), a brief description of meteorological conditions (air temperature, wind speed and direction, cloud conditions, etc.) and the name of the person making these observations.

Even though divers will not be able to collect data during storms (when conditions will have the greatest impact on reef stability), they will be able to collect data during "normal" conditions or shortly after such events, which are probably more important biologically. The data can be analyzed in conjunction with fish counts and other biological observations to improve our understanding of artificial reefs. Some analysis has been done (Bor-
tone and Van Orman, 1985a; 1985b) but more data needs to be collected.

**Currents**

Currents are one of the most important factors affecting reef stability. It is the flow of water past an artificial reef that creates hydrodynamic forces capable of shifting reef elements, scouring or depositing sediments, reducing the bearing capacity of the bottom and supporting the community of filter feeders.

Unfortunately, the strongest currents (and the greatest movement of reef elements) usually occur during severe storms - when divers cannot make observations. If a self-recording current meter can be installed at the reef site, measurements of storm currents can be obtained and correlated with observed displacements of reef elements. Even if a self-recording current meter cannot be installed, a post-storm dive on a reef as soon as conditions safely permit will yield valuable information.

Currents at a particular location can be the result of several things: waves, tides, winds or large-scale current systems (e.g. the Gulf Stream). Currents can move in one direction or they can be oscillators (divers often refer to oscillator bottom currents as "surge" or "wave surge"); they can change speed or direction rapidly or they can be slowly varying; they can be nearly uniform throughout the water column or they can change from surface to bottom. For these reasons, current measurement programs should be thought out carefully. Over time it will be possible to establish a current data base at a reef site, just as meteorologists have established climatological norms and extremes for sites on land.

This data base should include the following information: surface position; date and time of measurement; surface current speed and direction (note that current direction is specified as the direction in which the water is moving toward - this is opposite to the convention used for winds and waves, which are specified according to the direction from which they come); bottom current speed, direction and distance from the bottom to the point of measurement (since the velocity decreases as you get close to the bottom). Be sure that bottom current measurements are made "upstream" of any reef elements or obstructions (including other divers) that might distort the flow field. Note any rocking or movement of reef elements when the measurements are made.

Current measurement techniques need not be complicated. In fact, the simplest are sometimes the best. At the surface, measure the time it takes floating debris or foam to pass an anchored vessel. Dividing the vessel length by the measured time yields the current speed; a compass provides direction. Bottom currents can be measured in a similar fashion. Observe the time it takes fine sediment or other particles suspended in the water to travel a measured distance along the bottom. Dye pellets can be carried to the bottom in waterproof packages by divers and then opened; the dye will color the water and allow for speed and direction measurements to be made. These simple techniques have some advantages over the use of handheld or other types of current meters. First, there is much less cost involved, and second, low velocities that are below the threshold for current meter operation can still be measured.

The most practical way for reef divers to improve our understanding of reef stability is by making systematic current measurements and observations of reef movement. Since it is difficult to predict accurately the effects of currents on artificial reef elements, simple correlations between currents and movement must be developed from the data collected. Nevertheless, it is useful to review the forces that will act on a reef element so that divers will have a basic understanding of them. (See Figure 4.1, which illustrates the various forces acting on a single reef element in the presence of a current with velocity $V$.)

**Figure 4.1**

The forces indicated in the figure are described below:

- $W$ = the weight of the reef element in air
- $F_B$ = the buoyant force acting upward on the element (note that the difference between the weight and buoyant force is the submerged weight)
- $F_V$ & $F_H$ = the soil forces acting on the element that tends to resist settlement and lateral movement, respectively
- $F_D$ = the drag force acting in the direction of water movement
- $F_L$ = the lift force acting on the element in the vertical direction due to the flow around an asymmetrical element of to the alteration of the flow pattern around the element due to the presence of the bottom
- $F_i$ = an inertia force present only in accelerating (wave-induced) currents

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Note that the hydrodynamic forces (F_d, F_l, F_r) depend upon the speed of the current and the area or volume of the reef element; if the speed increases then these forces will increase also. Likewise, if the size of the element subjected to the current increases then the forces will increase.

The magnitudes of the hydrodynamic forces also depend upon certain empirically determined coefficients. For example, the drag force can be described by the following equation:

\[ F_d = \frac{1}{2} \rho C_d A V^2 \]

Where \( \rho \) is the density of the water, \( A \) is the projected area normal to the current and \( C_d \) is the drag coefficient. In general, \( C_d \) will vary with the shape of the element, the roughness of the element and the speed of the current (i.e., \( C_d \) is not constant, but a function of \( V \)).

It is difficult without detailed field and laboratory studies to calculate the drag force and other hydrodynamic forces on a reef element, particularly if it is of an odd shape or if it is surrounded by other elements which distort the flow field.

Surface Waves

Most waves are caused by wind. As the wind blows over the water surface energy is transmitted to the water and waves are formed. Wave characteristics depend on the wind speed, the distance over which it blows (the fetch) and the length of time that it blows. The sea surface at a particular location may be calm or very irregular, depending upon local winds and the presence of waves generated at far away locations; the surface may be composed of waves travelling in a single direction or of waves travelling in several directions.

Waves are classified according to the ratio of their length to the water depth as deep water waves, intermediate waves or shallow water waves. Deep water waves are those whose length is less than twice the water depth; shallow water waves are those whose length is one-half the water depth. Intermediate waves lie in between. This distinction is important since waves not only affect the sea surface, but also the water column below: waves generate oscillating currents that extend down into the water (see Figure 4.2). The water particles under a deep water wave tend to move in circular orbits, while those under intermediate and shallow water waves tend to follow elliptical paths.

The magnitude of the water particle motion is greatest at the surface and decreases with increasing depth. There is little decrease in the case of shallow water waves - currents at the bottom are almost as strong as those at the surface. Deep water waves, on the other hand, only affect the water column down to a depth approximately equal to one-half the wave length. Thus, while a diver might find it impossible to work in 50 feet of water with surface waves greater than several hundred feet in length, he would not even be aware of waves shorter than 100 feet in length. The effects on reef stability would be analogous: deep water waves would affect reef elements while intermediate and shallow water waves might move the elements (and bottom sediments) easily.

Observing waves at the surface will involve three things: estimating wave height, wave period and wave direction. This will be relatively easy if only one wave train is present, but may be more difficult if two or more are present. Nevertheless, the same procedures apply - just try to observe individual wave trains separately. If the sea is too confused, estimate the characteristics of the dominant wave only.

Wave height, Figure 4.2, is the vertical distance between the top (crest) and the bottom (trough) of the wave. If waves are very regular, the height of each successive wave will be nearly identical. If wave heights vary, the "significant wave height" should be estimated - this is the average height of the highest one-third of the waves. Estimate wave heights to the nearest foot.

Wave period is the time it takes successive wave crests to pass a fixed point. When wave period is measured, record the total time it takes \( n \) wave crests to pass, then divide by \( n-1 \), where \( n \) is large enough to average out variations in period. Round the result to the nearest second. A convenient value for \( n \) is 11 since the total time is then divided by 10 - an easy calculation. Count only the passage of crests from the larger waves and neglect the smaller ones, if the surface is irregular.

**Figure 4.2**
Wave direction is the direction from which the waves are coming, not the direction in which they are moving. For example, waves approaching from the northeast would be recorded as 45°. Measure direction to the nearest 5°.

Water Temperature

The temperature of seawater tends to vary with season, location and depth. Seasonal temperatures can vary by 10 degrees centigrade, or more, depending on latitude. Regardless of season and location, there is usually a difference between surface and bottom temperatures of a few degrees (this may not occur in some cases where water depths are shallow and where the water column is well-mixed). This temperature drop may be gradual from surface to bottom or it may be sudden, occurring at an interface between two distinct layers of water called a thermocline. In some cases where water depths are great, there may be three (or more) layers and two (or more) thermoclines.

When water temperatures are measured as part of a reef sitting or monitoring dive, the water temperature should be measured in situ, just under the surface, above and below a thermocline, and near the bottom. The depths at which the thermoclines lie should be noted.

Salinity

Salinity is a measure of the amount of dissolved solids in water. It is usually expressed in parts per thousand (ppt), with normal seawater having a salinity of 33 to 37 ppt. Salinity may be significantly less near fresh water sources such as river mouths, tidal inlets and offshore springs. There is a unique relationship between the density, temperature and salinity of seawater: knowing any two specifies the third. Appendix C illustrates

Unlike water temperature, salinity does not have to be measured in situ. It can be measured on board a ship or on land from water samples collected by divers. It can be measured by any number of ways, but probably the simplest is with a thermometer and a hydrometer. A more expensive but simpler refractometer uses visual method to determine salinity by measuring the refractive index of the water. It is independent of temperature. Water samples should be collected on the reef, since that is where encrusting organisms and fish will be. There is no need to take water samples in the water column unless pelagic species are being investigated.

Transparency/Turbidity

Transparency and turbidity are two terms used to describe the clarity of water. Transparency is a measure of the ability of water to transmit light, while turbidity is a measure of the amount of particles suspended in the water: as turbidity increases transparency decreases. These measurements will vary with the number, size and type of particles suspended in the water, and with the nature and intensity of the illumination.

One of the simplest ways of measuring water clarity is with a secchi disk - a circular disk whose surface is divided into quadrants painted white or black. Oceanographers lower the disk into the water from a ship and record the depth at which the disk is no longer visible.

Divers can also employ a secchi disk, but in a slightly different way by measuring the horizontal distance along the bottom to a point when the disk is no longer visible (See Figure 4.3). Note that divers must be careful not to stir up bottom

**Figure 4.3**

![SECCHI DISK](image)

20 cm
sediments when this technique is used; if clarity is
to be measured on a dive, this should be the first
task performed so that diver activity during other
tasks will not affect the results.

Dissolved Oxygen

Dissolved oxygen affects the health and distri-
bution of fish species, shellfish, and other crea-
tures inhabiting a reef. Unfortunately, it is difficult
to measure accurately. Since it varies with tem-
terature and pressure, water samples cannot be col-
cected and brought to the surface for analysis
unless special techniques are employed. These may
be beyond the scope of routine reef monitoring.
For those that are interested, section 8.8.3 of the
"NOAA Diving Manual" (Miller, 1979) describes
procedures that can be used to collect and trans-
port water samples for later dissolved oxygen
analysis.

Bottom Sediments

Bottom sediment characteristics are one of
the most important factors controlling the stabili-
ty of an artificial reef. If the bottom has a low bear-
ing capacity or if it is susceptible to liquification
during storms, reef elements will settle.

In general, it is very difficult to accurately
estimate the bearing capacity of bottom sediments
with either in situ or laboratory tests. This is due
to the fact that the results depend upon the type of
test performed and the degree to which the sedi-
ment sample is disturbed during sampling and test-
ing. However, there are some basic correlations
between the type of sediment, its resistance to
penetration and its bearing capacity. These will be
discussed later in this chapter.

First, it is necessary to adopt a sediment clas-
sification system (see Appendix D). Bottom sedi-
ments can be composed of a variety of types and
sizes of particles. Clay, silt, sand, gravel, shell
and rock are those most commonly encountered.
The finer particles (clay and some silt) are cohesive -
there are electrochemical forces between par-
ticles that account for most of the strength of the
sediment. The coarser sediments (sand, shell and
gravel) are cohesionless and rely solely upon fric-
tion between particles for strength.

Rock may occur in large formations or as
fragments suspended on or in other sediments. It
sometimes occurs as outcrops on the bottom, but
is usually overlain by sediments a few inches to
several feet in thickness. Rocks occurring off-
shore of Florida are sedimentary in origin, with
sand and/or shell cemented together. These sedi-
mentary rocks possess varying strengths, and in
some cases may fracture or wear readily.

Gravel is a term used to describe small
pieces of rock ranging from many centimeters to a
few millimeters in diameter.

Sand particles are smaller than gravel, but
larger than silt. The division between sand and silt is
from .05 - .074 mm, depending upon the classifi-
cation system used. Most sand-sized particles oc-
curring offshore are quartz particles or shell
fragments.

Silt particles are smaller than sand but larger
than .002 - .006 mm in size. Silts can display
some cohesive properties, but this is due usually to
the presence of small amounts of clay particles.

Clay particles are very fine (.002 to .006
mm, depending upon the classification system
used). The most common clay minerals are mont-
morillonite, kaolinite and illite. Clays can be very
sensitive (losing much of their strength when
disturbed).

Sediment Correlation

Since there is a fairly good correlation be-
tween sediment type (i.e., size) and strength, it is
important that the reef diver be able to differentiate
between them. This can be accomplished in two
ways. First, sediments of various sizes can be ob-
tained and kept in containers for visual comparison
with sediment samples obtained from reef sites.
This method is useful for distinguishing between
gravels, coarse, medium and fine sands.

The second way of differentiating between
sediment sizes is more useful for distinguishing be-
tween coarse-grained sediments, silts and clays. It
involves placing a sediment sample in a jar of
water, shaking it and letting the particles settle.
The sand and coarse-grained sediments will settle
out in less than 1 minute, the silt particles will set-
tle in 10 minutes to 1 hour, while the clay particles
may take several hours to settle (Bowles, 1977).
By noting the thicknesses of layers, one will
have an idea of the proportions of different size
sediments in the sample.

In general, fine-grained sediments such as
silts and clays should be avoided when siting artifi-
cial reefs, unless rock lies close to the sediment sur-
face. They are usually soft and reef materials
placed on them will tend to settle. Sediments com-
posed of sand, shell and gravel provide greater
strength and are preferred. Even these sediments
are subject to occasional settlement problems.
This usually occurs during periods of high wave
activity. The waves set up cyclic variations in the
pressure of water contained in the pores between
the sediment particles. When the pore water pres-
sure equals the pressure exerted by the submerged
sediment, the soil liquefies and loses its strength.
Rock bottoms will provide a good foundation for artificial reefs, particularly when overlain by a few centimeters of sediment. The rock will limit the depth of settlement while the sediment will help stabilize the reef elements against movement caused by waves and currents.

Determining whether or not rock lies below loose sediment can be accomplished by pushing, driving or jetting a probe into the bottom until it will go no further. If rock is encountered, its depth below the bottom should be measured. Note that the reef diver is usually not interested in any more than the first meter of sediment. If rock lies deeper than that, it will be of little use in halting the settlement of a reef, unless the reef is constructed of very large elements.

Remember other factors besides bottom sediment characteristics must be considered when selecting a reef site. Water depth, the influence of currents and waves, and the type of reef materials will all affect the success of a reef. For example, steel fuel tanks with the ends removed (thus resembling pipe) were placed in 70 feet of water off Jacksonville on June 1, 1983. By June 30, 1983 some of the tanks had worked their way into a limestone bottom as much as 70 cm. The tanks were from 1 m - 2 m in diameter and 5 m - 8 m in length, with a wall thickness of about 6 mm. Concrete pipes of comparable diameters were placed at the same time, but settled only through a few centimeters of sand over the limestone. Calculations showed that the submerged weight of the concrete pipe (per m of length) was 2 to 3 times that of the steel tanks - a significant difference. Divers observed that the steel tanks rolled back and forth with only 1 - 2 foot waves at the surface, while the concrete pipes remained still. The movement of the steel tanks abraded the soft rock and the tanks worked their way into the bottom.

**Sediment Sampling**

Reef divers may be concerned with both the surface sediments and those below the surface, which can include unconsolidated sediments as well as consolidated sediments (rock).

The best way to sample unconsolidated sediments, both on the surface and beneath, is with a thin-walled core tube (usually clear plastic or PVC pipe, a few cm in diameter). The method (described in Methods Summary) provides a consistent way of sampling, while ensuring that all grain sizes present in the sediment are retained in the sample, and that there is minimal disturbance to the sample. A clear plastic pipe allows the reef scientist to examine any layers in the sediment and to perform grain size analyses on the sample. If a sediment sample is collected by hand and placed in a container, the finer particles can slip through the
fingers or be suspended in the water and the sediment structure will be destroyed.

If a surface sample is all that is required, the core tube needs only to be about 6 inches long. Partially filling a longer tube is not good practice since this allows the sample to shift in the tube and the sediment structure to be altered during handling. The tube should be pushed fully into the bottom, capped at the top and then sealed at the bottom with a flat plate or the diver's hand. The tube is then removed, inverted and capped at the bottom. Be sure to mark the tube so that the location and time of sampling are known; make sure the top of the sample is marked as well. Procedures for obtaining longer cores are not much different, except it is usually necessary to drive the tube into the bottom. Simple impact corers have been devised to make this task simpler (Naval Civil Engineering Laboratory, 1985; Sanders, 1968).

An important consideration in obtaining samples of unconsolidated sediments is that the location from which they are obtained be representative of the area being investigated. Otherwise, the sample will not be useful in characterizing the sediments in the area; it will give reef scientists a false impression of what the bottom is like. Pooling multiple samples from the same site will be more representative than a single sample.

Mapping

Mapping is a crucial part of artificial reef research. Physical and biological measurements may be of little value if the locations of the measurements are not known, or if divers cannot return to the same points later to take additional measurements. Reef divers should become familiar with basic mapping techniques so they can use them during site surveys and monitoring surveys.

Divers should strive to make accurate, rather than precise, maps (see Chapter 1 for discussion of this). The desired degree of accuracy should be determined before any diver enters the water, based on the intended use of the data, bottom time limitations, etc. Remember, it will take much more time to make measurements accurate to one meter than it will to make measurements accurate to five meters or ten meters; in some cases the less accurate measurements may be sufficient.

Figure 4.5 and the following table will assist reef divers in determining the accuracy requirements for locating an object. Note that for a certain allowable position error, the allowable angular error decreases and the length of a measured distance increases. For example, if an object must be located within five meters of its actual position, the maximum allowable angular error over a distance of 50 meters is 5°; the maximum allowable angular error over a distance of 100 meters is 2 1/2°. In most cases, however, short the measured distance, an angular error greater than 10° be considered acceptable for mapping purposes.

Establishing Control Points

Whenever bottom features, reef elements or data collection stations must be located, a point (or points) of reference must be available, otherwise, there will be no way to accurately relocate them. These points of reference, called control points or bench marks, should be established around and/or through the reef site so that no object or feature is very far from a control point. This also insures that if a control point is disturbed or lost, another can be re-established easily.

Control points can be made of anything that is durable, that will remain in the same location and that can be easily located and uniquely identified, perhaps with its own tag or number. A good choice for many areas will be steel rods or pipes. They should be long enough so that the top will be two or three feet above the bottom, after the rod or pipe is driven into the bottom several feet. Both horizontal and vertical measurements can be referenced to the control points. Each point should be given a different name, number or letter to distinguish it from the others. It will be necessary to label the points underwater to avoid confusion during mapping.

Once control points are installed, distances (measured to the nearest meter) and azimuths between the points should be measured so that their positions with respect to one another can be deter-
mended. An azimuth is an angle measured clockwise from north; azimuths will lie between 0° and 359°. The elevation at the top of each control point should also be determined (use a depth gauge to do this). Divers may wish to refer to any basic land surveying text for a discussion on how to check the accuracy with which control points have been mapped (look for discussion on traverse closure and adjustment).

Please note that the exact position of a control point (i.e., latitude and longitude or LORAN coordinates) need not be determined. Without very sophisticated (and expensive equipment, it will be impossible to perform this task. Instead, the approximate surface position corresponding to a control point should be determined so that the divers can repeatedly find the control point and make accurate measurements using it as a point of reference.

**Locating Objects on the Bottom**

In order to locate an object (or data collection station), it is necessary to reference it to one or more control points. The horizontal position can be found given any one of the following:

- the distance and direction from a single control point or bench mark.
- the distances from two control points and an approximate direction from either control point.
- the distances from three control points.

These are illustrated in Figure 4.6. Note that in the case where an object is located using two control points, distance measurements alone will not suffice. For example, suppose an object is determined to be 25 m radius from point one and another arc with a 35 m radius from point two reveals that there are two intersections of the arcs. Thus, there are two possible locations of the object for the given distances. In order to determine which location is correct, an approximate direction from either control point to the object is required. If three control points are used, the arcs will intersect on only one point and directional information is not needed.

Divers should be careful when making measurements to pull the tape taught (gravity and currents may both cause the tape to sag or distort, causing measured distances to exceed actual distances). Divers should also be careful when measuring distances along a slope or from a point on the bottom to another point above the bottom. In such cases, the distance measured by the tape (the slope distance) will be greater than the true horizontal distance (see Figure 4.7). This error can be accounted for, if a diver measures the depth at both ends of the tape with his depth gauge (be sure to use a good quality, oil-filled gauge or electronic dive computer which measures depth and be sure to use the same gauge to measure at both ends). The true horizontal distance is related to the slope distance and the difference in depth (elevation) of the two points by the following equation:

\[ X = S^2 - D^2 \]

\[ X = \text{true horizontal distance} \]

\[ S = \text{measured slope distance} \]

\[ D = \text{difference in depth between the two points} \]

Be sure to use consistent units, i.e., if X and S are measured in meters, make sure that D is measured in meters, not in feet.

**Vertical distances can be measured as described above - by reading a pressure gauge at two locations and taking the difference between that two readings.**

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**Figure 4.6**

![Diagram](image1)

**Figure 4.7**

![Diagram](image2)

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References


