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The mission of AAUS is to facilitate the development of safe and productive scientific divers through education, research, advocacy, and the advancement of standards for scientific diving practices, certifications, and operations.

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Scientific Diving and the Law: An Evolving Relationship

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Abstract

This paper will review the development of both the American Academy of Underwater Science (AAUS) and the University – National Oceanographic Laboratory System (UNOLS). Casualties and their related legal implications were central to the development of both groups, as well the need for common safety and operational standards. The role of the scientific diving exemption under the Occupational and Safety and Health Administration (OSHA) rules, and the recent interest from the U.S. Coast Guard in revising commercial diving regulations will be discussed, along with three recent high-profile casualties that have focused attention on government and scientific diving.

Keywords: OSHA, research vessel law, scientific diving law

Historical Development of AAUS and UNOLS

Both organizations have their beginnings in concerns over liability, and the special issues involved with conducting science at, or under, the sea. The origins of AAUS can be traced to the deaths of two scientific divers from Scripps in 1951, which led to the formation of the first scientific diving program in the United States. The goal of the program was to facilitate science while managing risk and liability exposure. Many groups followed the Scripps lead and developed their own programs, so that the concept of 'scientific diving' was well-established when OSHA announced their commercial diving regulations in 1977. Recognizing that the future of scientific diving was in jeopardy, existing dive programs joined together to form AAUS, and immediately petitioned OSHA for a scientific diving exemption, ultimately succeeding in 1982 (AAUS, pers. comm., 2009). Both AAUS and scientific diving have continued to grow since then, and several examinations of the low rate of scientific diving casualties as opposed to those in commercial diving have demonstrated that the exemption was merited (Dardeau and McDonald, 2007).

The development of UNOLS followed a similar path; public investment in oceanography increased substantially in the 1960s, largely as a result of the Cold War, and ship-borne science presented some unique operational and legal challenges. The first question to arise was the legal status of scientists at sea: If considered members of the crew, they would be entitled to the generous remedies of the Jones Act if injured or killed in the service of the vessel. If considered passengers, very few of the first-generation oceanographic research vessels could comply with the construction requirements of passenger vessels. The solution was to create a special status for oceanographic research vessels that would be recognized by the Coast Guard. Congress passed the Oceanographic Research Vessels Act of 1965 (ORVA), which declared that ORVs did not have to comply with passenger vessel construction requirements and that sea-going scientists would not be considered members of the crew for the purposes of the Jones Act. Implementation of the law provided a significant stimulus to further development of the U.S. oceanographic research vessel fleet (Nixon, 1987).

As the fleet grew, it became clear that coordination of ship scheduling and location would lead to a more efficient use of the resources available. Why should Scripps send a ship to the Caribbean for one of its scientists if a ship from Woods Hole was nearby? UNOLS was founded in 1972 to address that challenge. Funded by a variety of federal agencies, primarily the National Science Foundation, UNOLS has developed into an organization that provides a wide range of benefits to members of the oceanographic community. However, like AAUS, there was concern about the development of common safety standards for the fleet, mandating the use of best available practices. Indeed, one of the first projects undertaken by UNOLS in the spring of 1972 was the listing of goals and objectives for the development of a common set of safety standards. Before they could be developed, however, an incident occurred which shocked the research vessel community. The M/V *Gulfstream*, operated by Nova University, left Bigelow Lab at Boothbay Harbor, Maine on January 4, 1975 with 3 scientists and 2 crew members aboard to retrieve a series of weather buoys being tested in the Gulf of Maine for NOAA. The boat never returned. One crew member's body was recovered after an intensive search but the others were declared missing and presumed drowned. In its Marine Casualty Report, the U.S. Coast Guard speculated that "adverse weather may have contributed to the casualty." The only other cause mentioned in the report got the attention of the research vessel community: "the lack of a firm sailing plan, scheduled time for reporting in and lack of any written standard operating procedures may have contributed to the casualty" (U.S. Coast Guard, 1975). The parallels to a dive plan are obvious.

The loss of the Gulfstream motivated UNOLS to publish draft safety standards just five months after the casualty which were adopted in final form in May of 1976. Although voluntary, the guidelines were a substantial improvement to the safety culture in the fleet. However, the fleet received another shock less than two years later when another disappeared under circumstances closely resembling the loss of the Gulfstream. On the morning of December 11, 1978, the M/V *Holoholo* did not appear as scheduled at the port of Kawaihae, Hawaii. She had sailed from Honolulu on December 9, 1978 with 10 persons on board for the purpose of collecting oceanographic data and deploying oceanographic equipment off the western coast of the island of Hawaii (U.S. Coast Guard, 1981). The vessel and crew simply vanished and its loss remains a mystery today.

In its report, the Coast Guard was critical of the University of Hawaii since they had participated in the development of the UNOLS Safety Standards and yet chartered a vessel like the *Holoholo* that did not comply with those standards in many respects. The Coast Guard found that the casualty may have been prevented if the UNOLS standards had been used to evaluate the suitability of the *Holoholo* for oceanographic research. Subsequently, the Hawaii legislature passed a law that all vessels used by the University of Hawaii must comply with the UNOLS Standards. This is a clear example of how a voluntary guideline can quickly evolve into a mandatory standard because of the circumstances involved.

UNOLS and AAUS became legally intertwined when Chapter 16, Diving Operations, was added to the Research Vessel Safety Standards (UNOLS, 2009). That chapter requires that any scientific diving done from a UNOLS vessel must be conducted under the auspices of a diving program that meets the AAUS Standards for Scientific Diving Certification and Operation of Scientific Diving Programs. The voyage dive plan effectively becomes part of the vessel's safety plan. One aspect of this rules merger bears mentioning: although the On-Board Diving Supervisor reports to the Chief Scientist on the conduct of all diving operations, under UNOLS RVSS 16.3 (1) "The Master has responsibility for the safety of all activities aboard including diving."

Safety Standards: the Two-Edged Sword

Despite the casualties that were the impetus for the development of standards for both AAUS and UNOLS, both organizations have been successful in maintaining better than average loss ratios in seagoing and underwater science. Insurance for UNOLS vessels is consistently lower than similar commercial vessels because of their superior loss experience, the existence of a mandatory safety and inspection program, and the fact that commercial pressures to produce data on a tight schedule do not exist. The fact that scientific diving is exempt from commercial diving rules does not mean that it is any less regulated; in fact, the opposite case could be made. The difference is not in the degree of caution or safety, but simply in the recognition that scientific diving represents a different risk scenario.

However, problems do occur despite rigorous safety protocols because of the inability of systems management to totally eliminate the possibility of human error. A safety management system is a culture, not a series of documents, procedures and forms. When the culture fails and human error occurs, the safety standards are the first place potential litigants look for the assignment of blame (Chen, 2000). Complex activities require a complex safety regime; but the more complex the safety system, the more likely that one or more elements will be forgotten or ignored when a critical incident occurs. It is a very difficult balance to achieve, and one that requires a constant effort to maintain. The UNOLS Safety Committee recently instituted an important operational change in response to that tension: instead of revising their standards as a single unit after a term of years, the Committee will now have the option of revising, adding or deleting sections on an ongoing basis to keep the standards as timely and correct as possible.

A related issue is the 'status' problem presented by seagoing scientists and diving scientists; in both cases, the employing institution must prove that they qualify for the legal exemptions allowed by statute and regulation. For the purposes of the ORVA, for example, a scientist is only considered a member of the scientific party if the vessel is actually involved in oceanography or oceanographic instruction. If the vessel is being used for a fund-raising cruise, or simply to transport a scientific party to an island laboratory, it is in fact operating as a passenger vessel with more stringent design, construction and crew requirements and could cause the loss of research vessel status for the vessel as well as converting the scientist to a passenger under the law.

The status for scientific diving is even more complex. Under the exemption from the commercial diving regulations issued by OSHA in 1982, a variety of conditions must be met. Scientific Diving is only exempt from the commercial rules only if the program has a diving safety manual, and is administered by a Diving Control Board. The majority of the Diving Control Board must be active scientific divers who have autonomous and absolute authority over the diving program. The scientific diving must be performed solely as a necessary part of a scientific, research or educational activity by employees whose sole purpose is the performance of scientific research tasks as observers and as data gatherers. The data gathered must be non-proprietary in nature (AAUS, 2009). If just one of those elements is not present, and an accident occurs, the employer risks the application of the very different commercial diving rules.

To make things even more complex, both OSHA and the Coast Guard have jurisdiction over scientific diving, depending on where it takes place. OSHA rules and their exceptions apply when diving in state waters (out to the three mile limit). Coast Guard rules and their exceptions apply beyond state waters and when diving is conducted from U.S. flag vessels whenever they operate beyond state waters. The Coast Guard exemption for scientific diving is much less complex to apply than that required under OSHA: it applies to any diving operation "performed solely for marine scientific research and development purposes by educational institutions" (46 C.F.R. 197.202). Life would be much simpler for the scientific diving community if OSHA adopted the same standard.

On January 26, 2009, the Coast Guard published an Advance Notice of Proposed Rulemaking to amend their commercial diving regulations (DHS, 2009). It actually is an effort to reopen a controversial rulemaking process stopped in 1998 after lack of agreement on the best way to update their original rules published in 1978. There is no indication at this point that they plan to alter their scientific diving exemption in any way, but the issue merits close monitoring since much of the diving from UNOLS vessels would be affected if any substantive changes are made. The focus is to develop one set of safety standards that has strong industry support. The proposed rule would also encourage the use of third party audits to reduce the impact on Coast Guard inspectors along with further compliance documentation.

Three Recent Government and Scientific Diving Casualties

U.S. Coast Guard Cutter Healy

On August 17, 2006, three Coast Guard divers from the Healy attempted to conduct a cold water familiarization dive during an "ice liberty" stop in the Arctic ice nearly 500 miles north of Barrow, Alaska. After entering the water, one of the divers aborted the dive because of several dry suit malfunctions. The remaining two divers continued on with the dive plan, which consisted of two twenty minute dives to a depth of twenty feet. Both divers requested additional weights when in the water and departed the surface with over 60 lbs of weight. Approximately 10 minutes later, the volunteer diver tenders had each paid out 200 feet of line and both lines were taut. When the diver who had aborted the dive because of equipment malfunctions returned to the scene, the dive tenders were directed to commence hauling up the divers. Both divers were recovered lifeless, with their depth gauges reading 185 and 200 feet. Resuscitation efforts were unsuccessful.

This incident was classified as a "Class A Mishap" due to the deaths of the two divers, and the Commandant of the U.S. Coast Guard released his Decision letter on the mishap on August 23, 2007. The comprehensive 29 page report is a careful analysis of the mistakes that were made and a call for a serious examination of diving as part of the Coast Guard's mission. Some of the most glaring errors and violations noted were: 1) the dive team did not follow Coast Guard regulations which required a redundant scuba system or twin scuba bottles with a common manifold and approved cold water regulator; 2) the dive team did not have the necessary qualifications for the dive, and should have numbered four; 3) both divers were carrying excessive weight, and the unqualified diver tenders did not stop the uncontrolled descent until too late; 4) the ship's commanding officer lacked familiarity with dive procedures and approved a defective dive plan; and 5) ice liberty, polar bear swims, ice football, and the presence of alcohol in the near vicinity of the dive interrupted the attention of the diver tenders. The report concluded with 17 detailed corrective actions that have to be accomplished before Coast Guard diving could resume (U.S. Coast Guard, 2007). Since Healy is frequently used as a science platform, this incident clearly has an impact on scientific diving as well.

Alaska Sealife Center

On September 25, 2007, the Diving Safety Officer of the Alaska Sealife Center was conducting a scientific training dive with a graduate student/employee seeking certification as a research diver. The scientific diver in training began to experience problems while making his ascent, and the two divers became separated. The Diving Safety Officer called for assistance, but the lost diver's body was not recovered until 90 minutes after the two divers became separated (Halpin, 2007).

This case is a rare example of a diver fatality occurring while operating under the umbrella of the scientific diving exemption of the OSHA commercial diving rules discussed earlier. Although the

Alaska Sealife Center was not a member of the AAUS, the Diving Safety Officer was a leader in the AAUS and had extensive knowledge of the rules of scientific diving. Under those rules, the Alaska Sealife Center Diving Control Board faced the unenviable task of investigating itself, without their own Diving Safety Officer to help conduct the investigation. Despite that challenge, they did conduct an inquiry while OSHA was pressing to classify the dive as commercial in nature. The loss of the diver was tragic, and it also serves to demonstrate the difficulty faced by a volunteer Diving Control Board tasked to investigate a diving fatality.

NOAA Florida Keys National Marine Sanctuary

On March 17, 2008, a very experienced NOAA diver was lost in the Dry Tortugas after running out of air while ascending. His buddy was unable to assist him to the surface, and ultimately the standby safety diver recovered his body from the bottom. The dive was conducted under the NOAA Scientific Diving Standards, which are based on the AAUS Standards. In accordance with the NOAA Incident Investigation Procedures Manual, the incident was classified as a "Class A Mishap" due to the incident resulting in a fatality. NOAA assembled an Incident Investigation Team with diving experts from the U.S. Navy, U.S. Coast Guard, NOAA, and Florida State University. They concluded that the victim depleted his breathing supply at depth, either while on the bottom or during his ascent to the 15 foot safety stop. They found that he ignored diving safety standards and made a series of poor decisions that led to his demise. However, they also found that NOAA was responsible for employee safety and that a system of checks and balances was not in place that could have prevented the incident. They specified five issue that required further action by NOAA: 1) NOAA should more clearly delineate what constitutes "scientific diving" in order to clearly differentiate them from "working dives" subject to OSHA commercial diving rules; 2) although this dive was not conducted under NOAA's scientific diving exemption, the incident did highlight the absence of clear reserve gas supply standards for scientific dives; 3) the NOAA dive community needs to understand that working dives are to be performed under OSHA commercial diving rules; 4) a strong safety program would have targeted individuals who had ignored rules in the past and removed them from diving duty; and 5) Until the NOAA Diving Program can comply with the requirement of the current mixed gas diving regulations, lobby for a change in the regulations, or develop their own requirements, the should cease nitrox diving in scuba gear as they currently stand in direct violation of federal law. They went on to list 33 Corrective Recommendations, 14 of which were to be accomplished "immediately" (NOAA, 2008).

Conclusions

The three recent casualties discussed above have brought a heightened awareness of the dangers of diving and the complex legal and regulatory structure that surrounds the scientific diving exemption to the commercial diving rules. Comprehensive safety standards were in place in all three incidents, but they did not prevent the incidents from occurring. Operational guidelines only provide protection when they are used. Although the scientific diving exemption from OSHA commercial diving rules has been in place since 1982, it could be withdrawn as easily as it was granted if the scientific diving community does not maintain the excellent safety record it has characteristically enjoyed.

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Diver Exposure Scenario for the Portland Harbor Risk Assessment

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Abstract

Recreational, public safety and commercial diving occur in contaminated harbors. Much of this diving continues to be undertaken without adequate protective gear thereby exposing the diver to a variety of chemicals and possible health risks. The Portland Harbor Superfund site is a stretch of the Willamette River located north of Portland, Oregon. Diving practices have been observed at the Superfund site that may lead to or exacerbate exposure from contaminants in water and sediment for recreational, public safety, and commercial divers and dive tenders. These practices include the use of wetsuits, use of recreational regulators, use of hardhats not mated directly to the drysuit, lack of proper decontamination, and use of materials not suitable to decontamination. The Human Health Risk Assessment that is being done for the Portland Harbor Superfund site will include a quantification of the possible risks for divers who use wetsuits or drysuits where the hardhat is not mated directly to the drysuit. For the wetsuit exposure, dermal exposure to contaminants in surface water and sediment is assumed to occur over the entire body. For the drysuit with neck dam, dermal exposure is assumed to occur to the head, neck and hands. For both wetsuit and drysuit use, inadvertent ingestion of contaminated sediments and surface water is also being evaluated. The results of the diver risk assessment will be used to educate the dive community of possible negative health outcomes when appropriate, required equipment and decontamination are lacking. The intent of this paper is to give an overview of polluted water diving procedures and equipment that are available to protect the diver and discuss the lack of adherence to these by some divers in Portland Harbor. The risk assessment methods and exposure assumptions that will be used to quantitatively evaluate the potential risks from diving when appropriate personal protective equipment and decontamination are lacking will also be discussed. Future efforts will be targeted at using this quantitative exposure and risk evaluation to reduce polluted water and sediment diver exposures in Portland Harbor.

Keywords: polluted water diving, risk assessment of diver exposure, Portland Harbor cleanup

Introduction

The potential health risks for persons who dive in the Portland Harbor Superfund site will be evaluated as a part of the Portland Harbor Remedial Investigation (RI). This paper summarizes the agreement reached for the diver evaluation by EPA and its partners, including the Oregon Department of Environmental Quality, and the potentially responsible parties for the contamination found within the site. In the Portland Harbor Superfund site, an approximately 11 mile stretch located at the lower end of the Willamette River and north of Portland, Oregon, diving is done by several groups of people including: the public for recreation and gathering of biota for consumption; the sheriff's office for investigations and emergency activities; and, commercial divers for a variety of purposes, including marine construction, underwater inspections, routine operation and maintenance, and activities related to environmental work. In addition, both government and contracted scientific diving work is taking place for various types of sample collection. The majority of divers are expected to be commercial divers or government or contract divers diving under the Occupational Safety and Health Administration (OSHA) scientific diving exemption (OSHA CFR 1910 Subpart T). As Portland Harbor is an active harbor, commercial and scientific diving is anticipated to continue into the future, and in an intensive fashion to support the investigation and cleanup of the site over the next several decades.

Methods

Divers are expected to be exposed to contaminants in both sediment and water in the Portland Harbor Superfund site. Contaminants include metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), volatile and semi-volatile organics (VOCs/SVOCs), polychlorinated biphenyls (PCBs), and polychlorinated dibenzodioxins, and dibenzofurans. In addition, frequent sewer overflows contribute high bacteria counts during rain events (USEPA 1998). Though there are methods to limit diver exposure to these contaminants which have been widely published and available since 1985, these methods are not always employed. These methods include: keeping the diver completely dry through use of a drysuit, utilization of drygloves, ensuring materials including the drysuit are constructed of an easily decontaminated material such as vulcanized rubber (EPA, 1985), use of a full face mask that seats on a dryhood or preferably a hardhat that mates directly to the drysuit (USEPA 1985; Barsky 1999), appropriate training, and thorough decontamination such as a potable water post-dive rinse (USEPA 2001). For example, inappropriate drysuit material (neoprene) and wet gloves are being used at a site in Portland Harbor (Figure 1). A neoprene drysuit cannot be decontaminated and can spread contaminants onto the boat and potentially to the next dive operation. The reason for prevalent use of wetsuits in Portland Harbor is twofold: higher cost of drysuits versus wetsuits and river temperature. The Willamette River is Clean Water Act 303d listed (Clean Water Act § 303(d) List of Impaired Waters: http://yosemite.epa.gov/R10/WATER.NSF/TMDLs/CWA+303d+List/) as a temperature impacted area with the Lower Willamette reaching average temperatures of over 70°F in the summer months. EPA's experience is that most contractors on the Willamette River are still using or initially propose use of wetsuits. As an example, both EPA's contractor for oversight of a manufactured gas plant (MGP) site and a diver working at the MGP site noted that other divers at the site "definitely were not suited up or following the rigid health and safety requirements" and were wearing gear that "one would use for recreational diving in the tropics" (Davoli 2008, personal communication). Wet gloves are used (Figure 2), which the divers may have deemed necessary due to impingement hazards that may compromise dry gloves. Wet gloves used in polluted water cannot be decontaminated and should be disposed of after dive operations and/or specially managed to not expose tenders and divers on this or the next dive operation. Wet gloves also potentially introduce dermal exposure to the diver during the dive. A better course might be to put nitrile or rubber gardening-type gloves over the drygloves to offer some chaffing protection, and then dispose of all the gloves after the dives. Another example of commercial dive exposure in the river is a solo diver for hire who makes himself available to find lost items, such as car keys, in marinas throughout Portland Harbor, utilizing a wetsuit and recreational regulator to "dig around in the muck" using scuba or freediving to find lost items (Oregon Public Broadcasting 2008).

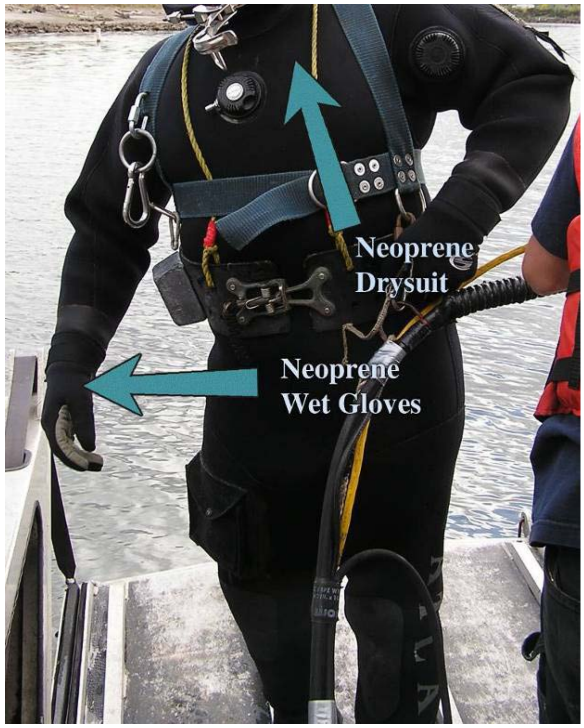

Figure 1. A diver exiting the water at a Portland Harbor Superfund cleanup site.

Figure 2. A diver exiting the water at a Portland Harbor Superfund Cleanup site.

As a part of the human health risk assessment required for the Portland Harbor Superfund site, the potential risk to divers from sediment and water will be assessed. US EPA's Superfund guidance recommends that exposure be evaluated for the "reasonable maximum exposure" (RME) as well as for an average exposure (*i.e.,* central tendency [CTE]) (USEPA, 1989; 1992). For the diver scenario for the Portland Harbor risk assessment, exposure is assumed to occur in four ways: dermal exposure (absorption through the skin) from water, dermal exposure from sediment, inadvertent ingestion of water and inadvertent ingestion of sediment.

Two scenarios have been selected for the RME based upon diving practices in Portland Harbor. For the first RME scenario, referred to as the wetsuit RME, a diver is assumed to be a commercial diver wearing a wetsuit without a full face mask and wearing wet gloves or no gloves. Therefore, dermal exposure to water and sediment is assumed to occur over the entire body. For the second RME scenario, referred to as the drysuit neck dam scenario, a diver is assumed to be a commercial diver who wears a drysuit and hardhat attached through a neck dam rather than having a helmet mated to the drysuit. This diver is also expected to be wearing wet gloves. For this diver, dermal exposure to water and sediment is assumed to occur to the head, neck and hands. For both RME scenarios, inadvertent ingestion of water and inadvertent ingestion of sediment are assumed to be the same since both diver scenarios assume face exposure, wet gloves, and inadvertent exposure in the water and on the boat. Inadvertent exposure to sediment on the boat can occur as a result of the absence of or lack of attention to thorough decontamination (*e.g.,* donning and removing diving suits that have not been decontaminated and/or handling gear which cannot be decontaminated such as a neoprene drysuit or wetsuit and eating food with contaminated hands).

An average exposure scenario will also be included assuming use of a wetsuit without a full face mask and wearing wet gloves or no gloves. For the CTE scenario, the exposure routes are the same as that for the corresponding wetsuit RME scenario but the exposure values have been reduced for some exposure parameters.

To evaluate the potential exposure and health risks for a diver, information is needed on the level of contaminants in the media (*i.e.,* sediment and water) that that diver is being exposed to as well as information on the diver's behavior (*e.g.,* type of equipment worn, frequency and duration of diving, years spent diving, and amount of inadvertent sediment and water ingestion) and the diver's characteristics (*e.g.,* body weight, surface area of the body).

For the Portland Harbor risk evaluation for divers, data collected as a part of the Superfund site Remedial Investigation (RI; http://yosemite.epa.gov/R10/CLEANUP.NSF/ph/Technical+Documents) and other studies are available to provide information on sediment and water contaminant levels that a diver might be exposed to. In the risk evaluation method described below, the information on diver behavior and characteristics is from a variety of sources.

Most of the equations, exposure assumptions, and/or calculation of exposure values are consistent with EPA's Risk Assessment Guidance for Superfund, Part A (USEPA 1989) and/or Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors," Interim Final (OSWER Directive 9285.6-03, March 25, 1991; OSWER 1991). However, others as noted below are based upon other EPA guidance, were calculated using Portland Harbor site-specific information, or were based on Best Profession Judgment (BPJ).

SEDIMENT EXPOSURE
Sediment Ingestion

For sediment ingestion by divers, the general equation for soil ingestion from EPA's Risk Assessment Guidance for Superfund (USEPA 1989) is used but chemical concentration in soil is replaced with the chemical concentration in sediment.

$$\text{Daily Intake } (\text{mg}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}) = \frac{EPC \cdot SIR \cdot EF \cdot ED \cdot CF}{BW \cdot AT}$$

where:

Daily Intake- milligrams of a contaminant in sediment (dry weight) ingested per kilogram body weight per day ($mg \cdot kg^{-1} \cdot day^{-1}$)
RME - Reasonable maximum exposure
CTE - Central tendency exposure
EPC - Exposure Point Concentration, chemical concentration in sediment ($mg \cdot kg^{-1}$ dry weight)
SIR - Sediment Ingestion Rate ($mg \cdot day^{-1}$); [both RMEs (use of a wetsuit or a drysuit with neck dam) 50 $mg \cdot day^{-1}$; CTE = 25 $mg \cdot day^{-1}$]
EF - Exposure Frequency ($days \cdot year^{-1}$) [both RMEs= 5 $days \cdot year^{-1}$; CTE = 2 $days \cdot year^{-1}$]
ED - Exposure Duration (years) [both RMEs=25 years; CTE=9 years]
CF - Conversion Factor ($kg \cdot mg^{-1}$) [10^{-6}]
BW - Body Weight (kg) [both RMEs /CTE = 70]
AT - Averaging Time (days) – [Cancer RMEs/CTE=25,550 days; Non-cancer RMEs=9,125 days and Non-cancer CTE=3,285 days].

Exposure Point Concentration (EPC or Chemical Concentration in Sediment) - It is expected that divers could dive in any part of the Portland Harbor site and, therefore, be exposed to near-shore contaminated sediment from areas throughout the site. For divers, the Willamette River will be divided into half-mile near-shore segments on each side of the river. The sediment samples in each near-shore segment on each side of the river will be used to estimate exposure point concentrations (EPCs). The arithmetic mean will be used as the EPC for the central tendency exposure (CTE) and the 95% upper confidence limit (UCL) on the arithmetic mean will be used for the EPC for the reasonable maximum exposures (RME) scenario (OSWER, 1989).

Sediment Ingestion Rate (SIR) - The sediment ingestion rates chosen for divers are 50 mg/day for both RMEs and 25 $mg \cdot day^{-1}$ for the CTE. The 50 $mg \cdot day^{-1}$ is the value for soil ingestion recommended for commercial/industrial workers (OSWER, 1991). The 25 $mg \cdot day^{-1}$ is one-half of the value recommended for workers and is based upon best professional judgment. The authors, being familiar with diving and overseeing commercial divers within the Portland Harbor site, have suggested that the sediment ingestion rate could be higher for divers for several reasons, including the fact that divers potentially have more direct contact with sediments in the water and that residual contaminant loading on the hands of divers (including those who use wet or dry gloves) may be higher and result in higher exposures when foods are consumed on the boat (D. Davoli, personal communication, 2008). Tasks that are typically undertaken which can accrue substantial diver/sediment interaction could include: hand-core sediment sampling, cap inspection including probing for native material, and anchor installation for silt-curtain dredging controls.

Exposure Duration - The recommended exposure durations for divers are 25 years for the RME (OSWER, 1991) which is EPA's recommended RME default exposure duration assumption for workers and nine years for the CTE (USEPA, 2004). The RME value (on the order of several decades) is a typical duration for a large Superfund site cleanup, and is therefore a reasonable timeframe for longer term Portland Harbor diver exposures.

Averaging time (AT) - The AT corresponding to these exposure durations are 25,550 days for estimating cancer risks for both the RME and CTE; and 9,125 days and 3,285 days for the RME and CTE, respectively, for estimating non-cancer effects(OSWER 1989).

Conversion factor (CF, $mg{\cdot}kg^{-1}$), and body weight (BW, 70 kg) - The CF is from OSWER (1989) and BW is from OSWER (1991) for workers.

Exposure Frequency (EF) - EF values were derived specifically for divers at Portland Harbor based upon discussions with commercial and EPA divers who work in the Portland Harbor Superfund site. Dive logs were obtained by EPA for a commercial diver who worked for several of the potentially responsible parties at the site in 2005 and 2006. At one site, he dived 74 times on 15 separate days. The number of dives per day ranged from three to eight. The average dive time was 24 minutes with a range from five minutes per dive up to 62 minutes per dive. For the other Portland Harbor sites, the diver dove 80 times on 20 separate days. The number of dives per day ranged from two to six. The average dive time was 25 minutes with a range of six minutes per dive up to 85 minutes per dive.

Discussions that the potentially responsible parties' contractor (D. Davoli, personal communication, 2008) had with dive companies also found that some commercial divers who perform work not related to sampling and analysis and cleanup activities (*e.g.*, diving to repair outfalls, work on ship hulls, underwater inspections) do less dives per day but spend more time (up to four hours) underwater for each dive using surface supplied air. These dive companies also stated that they dive less frequently in Portland Harbor than do those divers who are diving for Superfund cleanup purposes. In addition, Multnomah County Sheriff's Department divers also dive in the Willamette River on a regular basis, including six locations within the Superfund initial study area between 1998 and 2000 (D. Davoli, personal communication, 2009).

Based upon this information and using best professional judgment, the recommended exposure frequency that was selected for both RME divers is five days per year and two days per year for the CTE. This exposure frequency assumes that all other diving done by a diver (*i.e.*, diving done the other 360 days/year for the RME and 363 days per year for the CTE) is done outside of Portland Harbor. For the five days (RME) and two days (CTE) per year that a diver is assumed to be exposed at the Portland Harbor site, this exposure occurs at only the one near-shore half-mile segment of the site for which an EPC is being calculated. Cumulative risk for divers who may dive at more than one site in Portland Harbor is not included in these calculations. It is assumed that these assumptions will be protective for commercial divers that are performing routine activities but may underestimate the number of dives done in one or multiple segments for workers conducting hazardous waste operations, including sampling/analysis and cleanup work.

Sediment Dermal

For dermal exposure (absorption of contaminants in sediment through the skin) by divers, the general equation for dermal contact with chemicals in soil from EPA's Risk Assessment Guidance for Superfund (USEPA, 1989) is used but chemical concentration in soil is replaced with the chemical concentration in sediment:

$$\text{Daily Intake } (mg \cdot kg^{-1} \cdot day^{-1}) = \frac{EPC \cdot SA \cdot AF \cdot ABS \cdot EF \cdot ED \cdot CF}{BW \cdot AT}$$

For divers, the recommended EPC, EF, ED, CF, BW, and AT are the same as those described above for sediment ingestion:

> EPC - Exposure Point Concentration ($mg \cdot kg^{-1}$) [concentration of a contaminant in each half-mile segment]
> EF - Exposure Frequency (Events or $days \cdot year^{-1}$) [both RMEs=5 $days \cdot year^{-1}$; CTE=2 $days \cdot year^{-1}$]
> ED - Exposure Duration (years) [RME=25 years; CTE=9 years]
> BW - Body Weight (kg) [70 kg]
> AT - Averaging Time (days) – [Cancer RMEs/CTE=25,550 days; Non-cancer RMEs=9,125 days and Non-cancer CTE=3,285 days]
> CF - Conversion Factor ($kg \cdot mg^{-1}$) [10^{-6}].

For ABS, AF and SA, the following values will be used:

> Absorption factors (ABS, dimensionless) – Absorption factors are chemical-specific and are found in Risk Assessment Volume I: Human Health Evaluation Manual (Part D: Supplemental Guidance for Dermal Risk) (USEPA 2004).
>
> Adherence Factors (AF) - Adherence factors (AF, $mg \cdot cm^{-2} \cdot event^{-1}$) are taken from USEPA (2004). For the diver, 0.3 $mg \cdot cm^{-2}$ per event will be used for both of the RMEs and 0.07 $mg \cdot cm^{-2}$ per event will be used for the CTE. These values represent the activity specific surface area weighted soil adherence factors for residential adult gardeners (0.3 $mg \cdot cm^{-2}$ is the 95^{th} percentile and 0.07 $mg \cdot cm^{-2}$ is the geometric mean) and are the same values being used for in-water fishers in the Portland Harbor risk assessment.
>
> Surface Area (SA) - For surface area (SA, cm^2) for the wetsuit RME diver and the wetsuit CTE divers who are assumed to be wearing a wetsuit and to have whole body exposure, the surface area exposed is assumed to be 18,150 cm^2 (average of the mean whole body value for males and females from USEPA Exposure Factors Handbook, EPA, 1997). For the drysuit with neck dam RME exposure, only hands, head and neck are assumed to be exposed. This is equivalent to a surface area of approximately 2,510 cm^2. This is based upon 1,206 cm^2 for the head and 904 cm^2 for hands based on the average of the mean for males and females. A value of 400 cm^2 was a used for the neck based upon 6% of the trunk value (including neck) of 6,600 cm^2 (the average of the 50% value for these body parts for males and females from EPA's Exposure Factors Handbook).

WATER EXPOSURE
Water Ingestion

For inadvertent surface water ingestion by divers, a modification of the general equation for inadvertent surface water ingestion of chemicals in surface water while swimming is used (OSWER, 1989):

$$\text{Daily Intake } (mg \cdot kg^{-1} \cdot day^{-1}) = \frac{EPC \cdot WIR \cdot t_{ev} \cdot EF \cdot ED \cdot CF}{BW \cdot AT}$$

For EF, ED, BW, and AT, the values for divers are the same as those recommended for diver exposure to sediments:

EF - Exposure Frequency (Events or dives·year^{-1}) [both RMEs=5 days·y^{-1}; CTE=2 days·y^{-1}]
ED - Exposure Duration (years) [RME=25 years; CTE=9 years]
BW - Body Weight (kg) [70 kg]
AT - Averaging Time (days) – [Cancer RMEs/CTE=25,550 days; Non-cancer RMEs=9,125 days and Non-cancer CTE=3,285 days]
CF – Conversion Factor is 10^{-3} L·mL^{-1}.

For the EPC, t_{ev}, and WIR, the following values are recommended:

Exposure Point Concentration (mg·L^{-1}) – It is assumed that commercial divers can be exposed to surface water throughout in the Portland Harbor site. Therefore, for divers, all of the surface water data collected for the RI in the PH site will be used in calculating the surface water EPC for divers including single point data as well as near bottom and near surface data collected at specific industrial sites, cross river transect data, and vertically integrated data collected in quiescent areas.

For the transect samples, multiple sample events were collected both spatially and temporally. Therefore a method was developed to generate a relatively consistent set of transect data integrating results over the width and depth of the Willamette River in the site. These data will be used to calculate the arithmetic mean EPA for the central tendency exposure (CTE) and the 95% upper confidence limit (UCL) on the arithmetic mean (when possible) for the EPC for the RME scenario. The single point water data and integrated samples collected in quiescent areas are to be used as individual EPCs; while the near bottom and near surface samples will be averaged and used as the EPC for divers.

WIR - Water Ingestion Rate (mL·h^{-1}) - For the water ingestion rate, the value of 50 mL·h^{-1} is used for both the CTE and RME. This is the values recommended in USEPA (1989) as water ingestion rate for swimmers and was deemed appropriate for divers based upon discussions with EPA divers.

t_{ev} – Event Duration (h·event^{-1} or dives) - For developing values for event duration, the dive logs discussed previously from a commercial diver who works for the responsible parties were used as well as information collected by the potentially responsible parties' contractor who interviewed diving companies. From the early-action cleanup dive logs from the MGP site, the average dive time was 24 minutes with a range of five minutes per dive up to 62 minutes per dive. For the dive logs from the other Portland Harbor sites, the average dive time was 25 minutes with a range from six minutes per dive up to 85 minutes per dive. This information on minutes per dive was used with previously discussed information on the number of dives per day (see discussion under Exposure Frequency in Sediment Ingestion section) to estimate the hours per dive. The range of time spent in the water in a day is, therefore, from 50 minutes (two dives at 25 minutes per dive) to 3.2 hours (eight dives at 24 minutes per dive). The potentially responsible parties' contractors found that a diver can spend four hours in the water in one day using supplied air. Based upon these data, the recommended values for the event duration (for each day) are two hours per dive for the CTE (approximate mid-range of 50 minutes and 3.2 hours) and four hours per dive for both of the RMEs (information from the potentially responsible parties' surveys).

Water Dermal

For dermal exposure (absorption of contaminants in water through the skin) by divers, a modification of the general equation for dermal contact with chemicals in water from USEPA (2004) was used:

$$\text{Daily Intake } (mg \cdot kg^{-1} \cdot day^{-1}) = \frac{\underline{DA \cdot SA \cdot EF \cdot ED}}{BW \cdot AT}$$

For all of the exposure parameters, except DA (the absorbed dose per event in $mg \cdot cm^{-2}$ per event (*i.e.*, per day), the values EF, ED, BW, AT and SA for divers are the same as those recommended for dermal exposure to sediment :

EF- Exposure Frequency (Events or dives/year) [both RMEs=5 $days \cdot y^{-1}$; CTE=2 $days \cdot y^{-1}$]
ED - Exposure Duration (years) [RME=25 years; CTE=9 years]
BW- Body Weight (kg) [70 kg]
AT - Averaging Time (days) – [Cancer RMEs/CTE=25,550 days; Non-cancer RMEs=9,125 days and Non-cancer CTE=3,285 days].
SA - Surface Area (cm^2) - Area of 18,150 cm^2 for the wetsuit RME diver and the wetsuit CTE divers and 2,510 cm^2 for the drysuit with neck dam RME exposure.

Absorbed Dose (DA) - Several values are needed to calculate DA (the absorbed dose per event in $mg \cdot cm^{-2}$ per event [*i.e.*, per day]). These values are the EPC for surface water, t_{ev} (the event duration) and K_p (the dermal permeability coefficient of the contaminant in water in cm/hr). The EPC and t_{ev} are the same as those used above for water ingestion. K_p values are chemical specific and are found in USEPA (2004). There are many uncertainties inherent in the K_p values for certain chemicals (*e.g.,* DDT and PCBs) and these uncertainties will be addressed in the Portland Harbor Human Health Risk Assessment.

As discussed previously, the diver risk assessment being done for the Portland Harbor Superfund site focuses on commercial divers who are performing routine activities within the site. Potential risk to workers conducting hazardous waste operations, including sampling/analysis and cleanup work, should be included in an evaluation of implementation risks in feasibility study. Whether diving under the OSHA commercial diving standards, or OSHA scientific diving exemption, cleanup workers should be working under conditions that are in compliance with OSHA standards (29 CFR 1910.120), as the OSHA scientific diving exemption does not exempt scientific divers from employing personal protective equipment (PPE) and other preventative exposure measures. However, as previously discussed, EPA's experience is that divers in Portland Harbor involved in sampling/analysis do not always dive in compliance with the OSHA standards and/or do not initially propose dive plans in compliance with hazardous waste site operation (HAZWOPER) standards. Typically, items such as basic diver environmental isolation (PPE) and medical monitoring (1910.120 HAZWOPER items) are not proposed in the Health and Safety Plan, and are often only added at the request of EPA. It is a reasonable presumption that contractors doing similar work not under EPA oversight may not be equipping their divers, training their divers, or monitoring their divers for hazardous waste exposure per OSHA 29 CFR 1910.120. As a result, divers conducting hazardous waste operations and not following OSHA standards are likely exposed to risks similar to or greater than those being estimated for non-hazardous waste commercial divers in the Portland Harbor Human Health Risk Assessment (PH HHRA). This is because these divers may spend more time diving in PH and dive in multiple segments of the site that have some of the higher contaminant concentrations.

Discussion

EPA has evaluated and directed the potentially responsible parties to conduct diver exposure assessments for the Portland Harbor Remedial Investigation to ensure that risks of diving at the site for commercial, scientific (commercial or government), public safety, and recreational divers are known and may be used for outreach efforts. Though exposures are qualitatively understood to take place, quantitative evaluation has not been undertaken to date at other Superfund sites, to the authors' knowledge. The equations used for these calculations are derived from existing US EPA guidance. Input parameters are from US EPA Guidance or based on site specific concentration data and EPA staff observations and commercial contractor dive logs. EPA intends to use these results to conduct further outreach with the Portland Harbor diving community to eliminate or mitigate these exposures, and provide this quantitative approach to determining exposure to the larger diving community (*e.g.*, dive safety and rescue organizations). In addition, EPA hopes to solicit feedback on inputs used in this diver scenario for potential application at other Superfund site harbor investigations.

Elimination of exposures may involve boat based sampling techniques rather than diver based techniques, for example. Mitigation measures could involve use of added training, medical monitoring, revisions of commercial and scientific diving safety manuals and dive plans to more clearly acknowledge OSHA 29 CFR 1910.120 requirements in contaminated or possibly contaminated dive areas, and improvements in personal protective equipment. See photo 3 below for an example of personal protective equipment / polluted water dive gear in use by EPA's Region 10 unit. Note that a full face mask is used that sits directly on the dry hood, drygloves, and a suit compatible with decontamination. Outreach for these additional steps could also involve education of the dive community of OSHA requirements that pertain to both scientific and working dives within "hazardous waste sites" for the aforementioned steps (OSHA 29 CFR 1910.120).

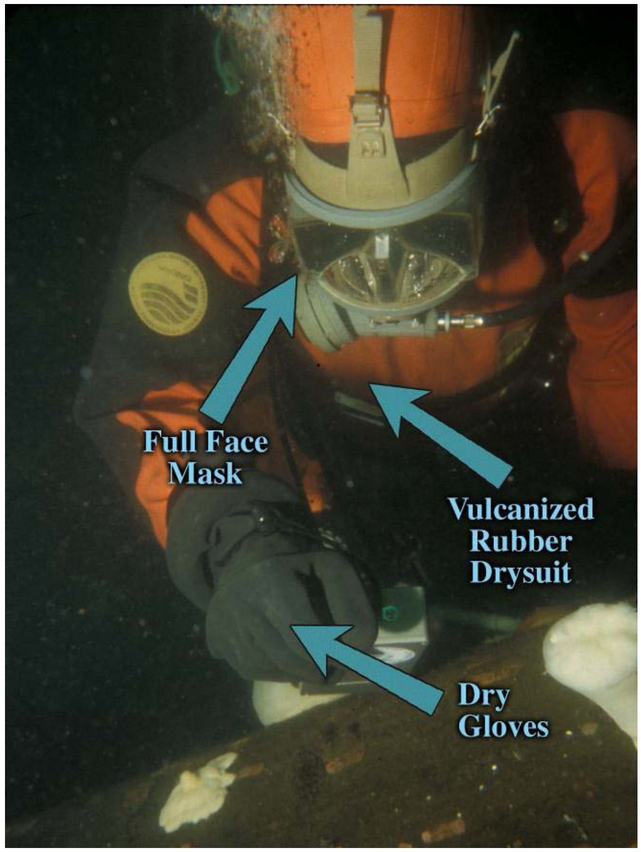

Photo 3: EPA Region 10 Diver Rob Pedersen mapping the zone of discharge along the outfall pipe at an Alaskan Seafood Processor. Photo by Sean Sheldrake, EPA Region 10 Dive Team.

Disclaimer: This paper is an illustration of steps to be taken to quantitatively evaluate and minimize exposure to the diver in hazardous environments and does not represent the official view of the USEPA or Oregon DEQ. Mention of any specific brand or model instrument or material does not constitute endorsement by the USEPA or Oregon DEQ.

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Submerged Cultural Resource Discoveries in Albania: Surveys of Ancient Shipwreck Sites

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Abstract

In August 2008, research teams representing the Waitt Institute for Discovery, RPM Nautical Foundation, the Institute of Nautical Archaeology, and the Albanian Institute of Archaeology conducted diving surveys of a 2300 yo (3^{rd} century BCE) shipwreck site near the town of Butrint in Albania. The site included dozens of artifacts, many of which were surveyed and recorded to construct detailed layouts of the area for possible future excavation and preservation. The number and duration of dives, as well as the wrecksite being in approximately 30 m of water, made the use of nitrox gas mixtures necessary despite the limitations of working in a remote foreign setting. Portable hyperbaric recompression was also a consideration as the closest facility is six to eight hours away in Italy. Future plans for this project include a field school for the university students in the capital city of Tirana and other international students in archaeological and education programs. Continued site preservation and artifact excavation will also benefit the conservation and protection efforts of the Albanian government.

Keywords: amphora, Corinthian, photomosaics, preservation

The country of Albania has an incredibly diverse cultural history. Positioned with Greece to the south, Montenegro and Kosovo to the north, and Macedonia to the East, it has been a land caught for millennia between warring empires. A well-traveled and storied terrestrial passage between Europe and the Mediterranean, Albania also has more than 350 km of rugged coastline along the Ionian Sea which has served as a major seafaring corridor for early Greek and Roman civilizations as well as contemporary sailors. This stretch of coastline has a reputation for disastrous winter storms and treacherous seas, sending countless vessels to the seafloor, often with their crew and cargo. This historical maritime heritage has inspired the Albanian government and a collaboration of US-based research organizations to investigate these largely unexplored shores to discover unknown submerged cultural resources and help author an unwritten past.

For the past seven years, RPM Nautical Foundation (RPMNF) has been actively mapping the seafloor off the Albanian coast from the shoreline to the 100 m depth contour. In conjunction with the Albanian Institute for Archaeology (AIA) and the Albanian National Trust, this intensive project seeks to locate and document submerged cultural resources and analyze the identified material record to better protect and preserve Albania's cultural maritime heritage. To date, dozens of potential targets have been identified using RPMNF multibeam sonar and SeaEye Panther remote-operated vehicle (ROV) equipment. The potential targets are displayed and recorded with IVS Fledermaus 3D software on Sony high definition monitors onboard the 37 m R/V *Hercules*, which is based out of RPMNF's Mediterranean operations base in Malta. Many miles of Albania's submerged coastline have been explored first-hand by RPMNF dive team members. A handful of discovered sites have been identified as possessing significant potential to conduct more extensive archaeological surveys and address ongoing questions about overseas trade routes. During the 2007 field season, a wrecksite fitting this description was located near the mouth of the Butrint River, which lies about 16km north of the Greek border. Intact and fragmented Corinthian-style amphora and a removable lead anchor stock were discovered at the site, most of which were lying on the soft sediment bottom interspersed amongst small rocky outcroppings at depths ranging from 20-30 m. Some sherds were partially buried in the sediment and cursory investigations revealed more groupings of intact amphora below the sediment surface. Amphora morphology (*i.e.*, body, handle, and rim shape) and comparisons to similar artifacts estimate the age of the site to ~300 BCE. The large representation of Corinthian-style artifacts suggests these amphorae were cargo in transport.

As part of continuing efforts to preserve Albania's historic artifacts and provide pertinent new information about ancient maritime heritage spanning the Mediterranean, the Butrint site was revisited in August of 2008. In collaboration with the Waitt Institute for Discovery (WID) and the Institute of Nautical Archaeology (INA), a team of divers led by Dr. Adrian Anastasi, Director of Underwater Archaeology for AIA, and Dr. Nicolle Hirschfeld, archaeology faculty at Trinity College, began underwater archaeological surveys of the submerged artifacts. Thirty person-dives totaling more than 1000 minutes underwater were conducted over the course of six days. Roving diver surveys were conducted to identify the extent of the discovered artifacts and define a boundary for the site. GPS coordinates were taken at the shoreline and at the deepest corners of the site. Although no permanent datums were installed, a central mapping point was temporarily designated and all measurements were taken relative to this point. A total of 21 intact amphora and amphora sherds were tagged and distance/bearing measurements from the central point were surveyed for nine of the artifacts. All measurements and data points were mapped and archived using 3H Consulting Site Recorder 4 (Figure 1).

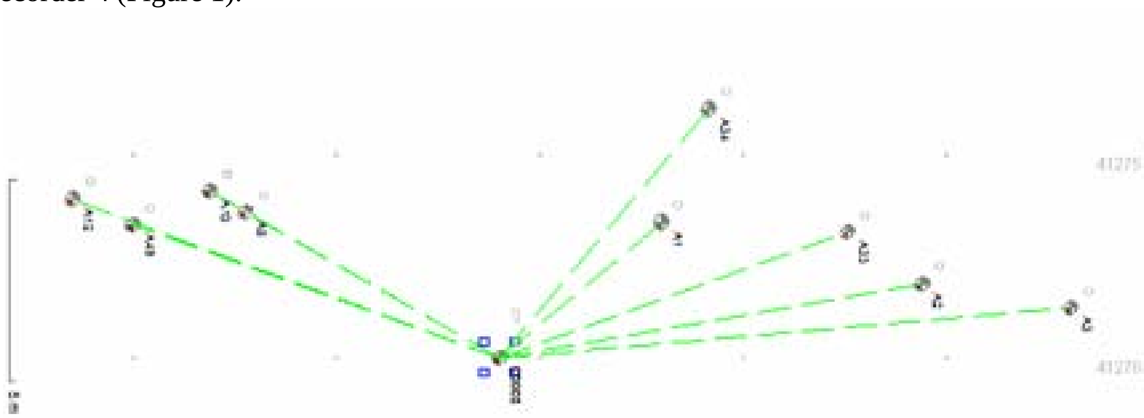

Figure 1. Preliminary survey of Butrint wrecksite. Courtesy of Dr. Jeff Royal, RPMNF.

Extensive photographs taken 5.0 m above the substrate allowed for the creation of photomosaics in Photoshop CS4 to identify and estimate the number of scattered artifacts (Figure 2).

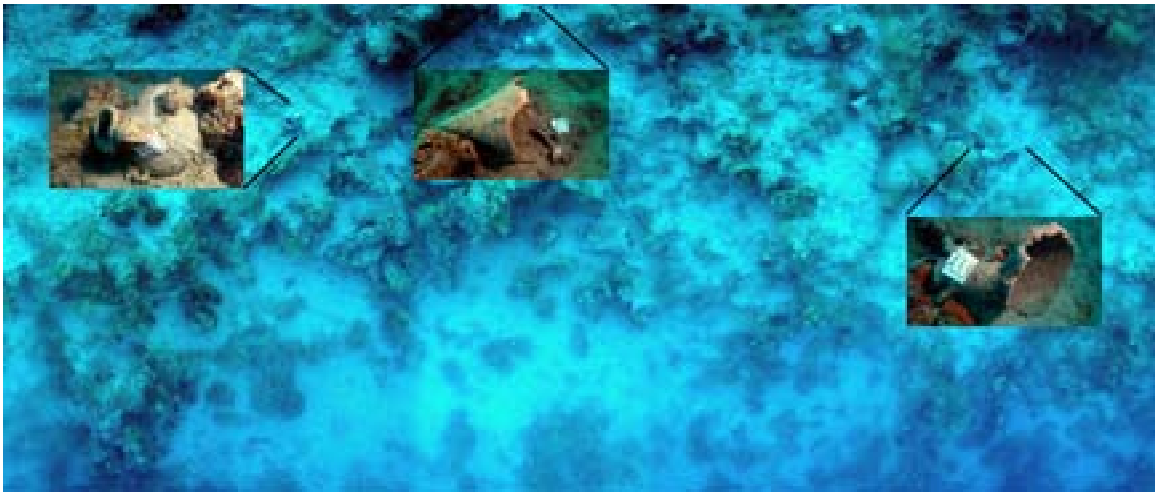

Figure 2. Partial site photomosaic overlaid with individual amphora identification pictures. Photos: Derek Smith©.

Photos of amphora groupings, site elevation, and individual artifacts were taken as ongoing photo-documentation of the site and for possible education and media use (Figures 3 and 4).

Figure 3. Examples of amphora grouping and elevation photographs. Photos: Derek Smith©.

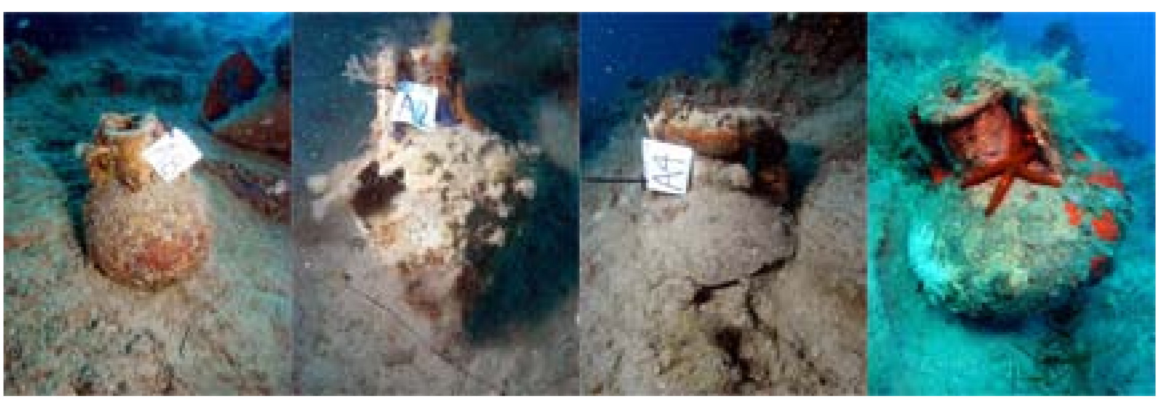

Figure 4. Examples of individually tagged amphora. Photos: Derek Smith©.

A grouping of amphora were also discovered south of the Butrint site during August of 2008 and one intact artifact was excavated and brought to the surface by divers using lift bags. The amphora was measured and photographed and its custody was turned over to AIA for further study and preservation.

Logistical and equipment support for this portion of the field work was largely made possible by resources provided by RPMNF. A 6.0 m rigid hull inflatable boat (RHIB) was used for several days to transport divers from the town of Sarande and from the R/V *Hercules* to the Butrint site. Diver breathing gases were nitrox mixtures in the 28-40% range, blended daily using two Nitrox Technologies continuous mixing membrane systems. One membrane system was installed belowdecks on the R/V *Hercules* and the other was located at the RPMNF operations base in Sarande in a shippable container supplied by its own electrical generator. Due to the extensive diving schedule conducted by RPMNF over their five month field season, the diving depths and durations, and distance to the nearest recompression facility, a Southern Oceanics SM-5 containerized, shippable offshore commercial diving system and deck decompression dual-lock hyperbaric chamber was purchased and is located at the RPMNF operations base in Sarande. A time-sensitive complication surrounding the import of medical oxygen into Albania prevented the use of this resource during the 2008 field season. However, preparations are being made to ensure the chamber's operation during the 2009 field season and for the ongoing training of personnel qualified to operate the chamber and treat injured divers if the need arises.

Submerged cultural resource discoveries in Albanian waters and continuing exploration of the country's coastline have garnered international attention over the past few years. Media outlets in Europe, China, Australia, and the United States have run feature articles heralding the potential for future discoveries and a better understanding of our cultural past from work being conducted in this area. The Waitt Institute for Discovery also collaborated with the Google Ocean team headed up by Dr. Sylvia Earle to get the Butrint site listed in the new Google Ocean layer, which highlights locations of significant importance around the world's oceans.

Future collaborations between the Albanian government and these research organizations include the possibility for an archaeological methods field school for Albanian and international students, possible excavation of discovered submerged cultural resources, and the construction of an archaeological conservation and preservation lab in Albania dedicated to analyzing artifacts from the seafloor.

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The Minerals Management Service's Seafloor Monitoring Program

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Abstract

The Minerals Management Service (MMS) is the Federal agency under the U.S. Department of the Interior that regulates offshore mineral resources (primarily oil and gas production) and alternative energy facilities on the Outer Continental Shelf. The MMS Seafloor Monitoring Team consists of a pool of scientific divers (archaeologists, biologists, and geologists) who support the Environmental Studies Program and have participated in hundreds of research projects since the agency's formation in 1982. This paper highlights two recent research projects in which MMS divers have participated. The first involved participation in a project to capture tagged sea otters off Bering Island, Russia; the second is the discovery of a U.S. Navy gunboat off the coast of Louisiana.

Keywords: archaeology, Bering Island, *Castine*, Gulf of Mexico, Pacific Ocean, sea otter

Introduction

The Minerals Management Service (MMS) is responsible for managing offshore mineral extraction, primarily oil and gas production, in Federal waters. The agency is divided into three regions: Alaska, Pacific, and Gulf of Mexico (which also includes the Atlantic); with most of the offshore development currently occurring in the Western and Central Planning Areas of the Gulf of Mexico. Currently, there are over 7,000 active leases and over 33,000 miles of pipeline in the Gulf of Mexico Region. On September 30, 2008, the Congressional moratorium on offshore drilling expired, opening most of the Outer Continental Shelf (OCS) for potential oil and gas exploration and development. The MMS is currently preparing an environmental impact statement for a proposed lease sale off Virginia in 2011, which could bring oil and gas activity to the Atlantic Region for the first time since 1984.

Until recently, the typical activities that MMS permitted were concerned primarily with oil and gas production; permitting facilities such as platforms and pipelines. With the passing of the Energy Policy Act in 2005, MMS is now responsible for managing alternative energy-related projects on the OCS as well. There are eight areas along the Atlantic and Pacific Coasts that have been designated for testing facilities. The MMS is in the process of reviewing applications for meteorological towers, or 'Met Towers,' in several of these areas and is also reviewing the first application for an offshore wind farm, the Cape Wind facility, off Massachusetts. The Met Towers are designed to collect data in order to assess the viability of these locations for alternative energy production. In addition to Met Towers and wind power generators, other types of alternative energy facilities that may develop include current power generators and wave power generators. And of course, with these new permitting responsibilities comes the potential for additional impacts to submerged natural and cultural resources on the OCS.

In addition to requiring remote-sensing surveys as part of the permitting process, one of the ways that MMS assesses potential impacts to natural and cultural resources is by contracting research studies through the Environmental Studies Program. This program was mandated through the OCS Lands

Act of 1953 to provide scientific data on environmental, social, and economic issues for the protection of marine and coastal environments. Over the last thirty-five years, MMS (and its predecessor the Bureau of Land Management) has funded over $840 million in research through the Environmental Studies Program. These studies have addressed a wide array of topics including, for example, biological studies such as the long-term monitoring of reef health at the Flower Gardens National Marine Sanctuary, in partnership with the National Oceanographic and Atmospheric Administration; oceanographic studies such as the survey of deepwater currents in the Gulf of Mexico; socioeconomic studies such as the oral history of the offshore oil and gas industry; and archaeological studies such as baseline studies of submerged cultural resources. All of the completed studies are available in portable document format (PDF) configuration on the MMS website (www.mms.gov). Currently, there are roughly 300 active studies on the books, and in the last two years, MMS has provided roughly $37 million to fund almost 60 different studies. Information on current studies can also be found on our website.

In support of the Environmental Studies Program, MMS has a small team of science divers that comprise the Seafloor Monitoring Team. Though MMS has utilized divers since the agency's creation in 1982, the Seafloor Monitoring Team officially began in the Gulf of Mexico Region with a pilot project in 1997 as a way to assess industry compliance with mitigating measures applied to offshore activities. These mitigating measures often consist of avoidance criteria of seafloor features as a condition of a permit. Today, the Seafloor Monitoring Team's mission is to ensure compliance of permit mitigations (environmental enforcement) and to support research through the Environmental Studies Program. This work is typically conducted through remote sensing and diver investigations.

Currently, the team consists of three marine archaeologists, three biologists, and one geologist in the Gulf of Mexico Region and three biologists in the Pacific Region. The team typically participates in about a dozen projects annually. These projects can range in scope from marine mammal monitoring to analysis of the health and dispersal of coral reefs to archaeological documentation of historic shipwrecks. They can also be conducted solely through MMS or in cooperation with other government, academic or private partners.

Following is a brief synopsis of two recent projects in which the MMS Seafloor Monitoring Team has participated: a biological study to monitor sea otters in the Pacific and an archaeological study that identified a late 19th-century US Navy gunboat.

Sea Otter Research

As with many furry creatures that inhabit this planet, sea otters were once regularly hunted for their valuable pelts. By the early 20th century, their numbers had dropped from an estimated population of 250,000 to less than 2,000 worldwide. Before the fur trade decimated their numbers, sea otters could be found across the Pacific Rim, ranging from Baja California, north across the Aleutian Islands, and down to Hokkaido, Japan. Through conservation efforts in the 20th century, sea otter populations have recovered in many of these areas, yet are absent or declining in others. One example of this contrast can be found along the sea otters northern-most range. The population in southwestern Alaska has been declining over the last ten years, while a neighboring population on Bering Island in Russia is thriving.

Last year the MMS Seafloor Monitoring Team assisted with an international sea otter research effort. Over a three-year period researchers from the United States Geological Survey (USGS), the Alaska SeaLife Center, the Monterey Bay Aquarium, the Russian Pacific Institute of Geography, and Komandorsky State Nature Reserve conducted studies comparing the Bering Island population with other sea otter populations across the north Pacific. Financial support was also provided by the United States Fish and Wildlife Service and the Marine Mammal Commission.

During the first year of the study approximately 30 sea otters were captured, tagged, and implanted with time-depth recorders (TDRs). The following year these animals were tracked and monitored in order to collect data on diet, activity, and geographic location. Last summer a team of divers from the USGS and MMS (Pacific Region) traveled to Bering Island to recapture tagged sea otters and remove the TDRs.

Sea otters are rather skittish creatures and recapturing them often involves a highly specialized technique that utilizes underwater scooters, a specialized trap, and closed-circuit oxygen rebreathers (Figure 1). This technique was described in detail in a previous AAUS paper (Sanders and Wendell, 1991). There are only a handful of people that have the experience and skills required to capture these animals, one of whom, Greg Sanders, works for the MMS Pacific Region.

Figure 1. Diver preparing to capture an otter (photo courtesy of Tom Campbell).

During the 2008 field season at Bering Island, 13 of the 30 sea otters tagged three years earlier were relocated; however, only two of these were recaptured with successful recovery of their TDRs. As Mr. Sanders described in his trip report, "Target sea otters were often mixed in large rafts of otters (sometimes more than 100 animals) making it nearly impossible to capture specific animals. Otters became wary of the capture boats within a few days and weather did not cooperate on several occasions. Many non-target sea otters were captured incidental to achieving the primary objective. These animals were brought to shore for measurements, assessment of body condition, tagging and subsequent release" (G. Sanders, pers. comm., 2008).

While the recapture rate was relatively low on this trip, the team was successful in completing a highly complex mission in an extremely challenging and remote environment. Transporting a half ton of specialized and unique dive equipment in today's airline security environment and through Russian ports of entry provided for many interesting stories as yet untold. Analysis of the data from the TDRs that were recovered is currently underway and will provide valuable insight into the lives of sea otters at Bering Island.

U.S.S. *Castine*

In 2003, MMS awarded a contract to PBS&J of Austin, Texas to ground-truth, positively identify, and assess the National Register of Historic Places status of up to eight selected sidescan-sonar targets in the Gulf of Mexico. For those not familiar with the National Register of Historic Places, it is the official list of the Nation's historic places and is part of a national program to coordinate and support public and private efforts to identify, evaluate and protect America's historic and archeological resources. The list is maintained by the National Park Service.

The targets selected for this study had been identified through industry-related surveys that are required as part of the permitting process for wellsite and pipeline construction on the OCS. Most of the targets selected had been recommended for avoidance as a condition of permit, but had not yet been evaluated to determine whether they were significant archaeological resources.

Fieldwork for this project was conducted as two separate work orders: the first in May 2004 and the second in May 2005. The project succeeded in documenting 14 targets, three of which were determined to be potentially eligible for listing on the National Register of Historic Places. These three targets included two World War II U-boat casualties, the tankers *R.M. Parker, Jr.,* and *Sheherazade*, both of which had been attacked in 1942 during the German U-boat offensive in the Gulf of Mexico. The third was identified as U.S.S. *Castine*, a former U.S. Navy gunboat. Of all the sites, *Castine* proved to be the most exciting and most challenging from a diving perspective.

When the initial fieldwork on *Castine* was conducted in May 2005, the only information available on this target was a sidescan-sonar image that had been collected during a 2001 remote-sensing survey (Figure 2). The contractor that interpreted the 2001 sidescan-sonar records identified this target as a probable modern wreck measuring roughly 171 ft (52 m) long by 30 ft (9 m) wide. However, the target had an interesting shape to it, which MMS archaeologists felt might actually represent something a little more significant than a modern fishing or supply boat.

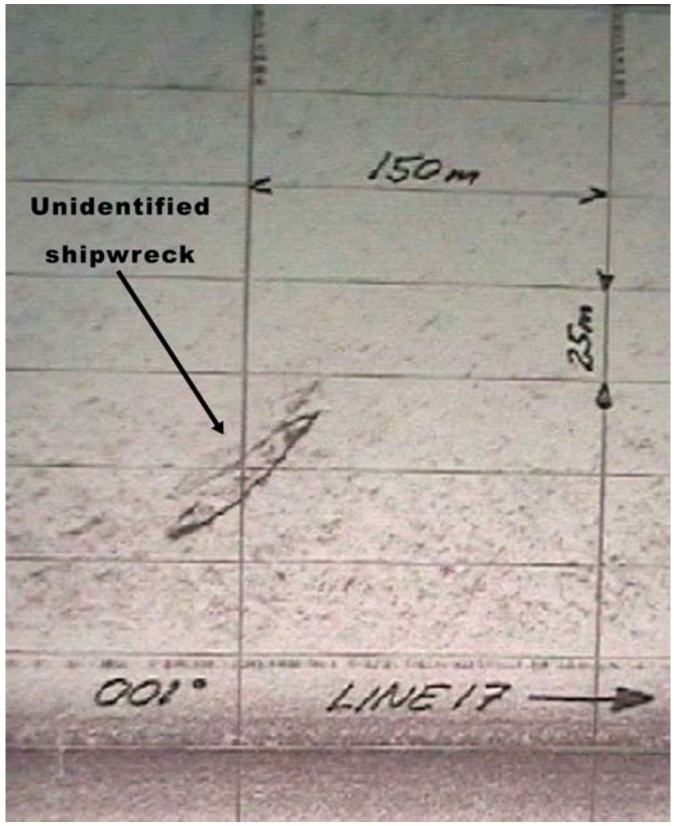

Figure 2. 2001 sidescan sonar image of unidentified shipwreck.

Castine is located about 20 miles off the coast of Louisiana in 115 ft (35 m) of water. Visibility on the site is often less than five feet and a large part of the site is covered in fishing nets, which makes it a challenging site to dive. Yet, a total of 26 dives were completed on *Castine* during the 2005 investigation over a three-day period.

Prior to diving on the site in 2005, a new remote-sensing survey was conducted in order to confirm the location of the wreck and identify any potential debris that might be associated with the site (Figure 3). When the 2005 investigations began, the identity of this wreck was unknown. However, one of the first dives completed surveyed the perimeter of the vessel structure in an attempt to identify any distinguishing features. This dive team succeeded in locating several areas along the hull line that arced out away from the hull. Discussions of these features after the dive suggested that they might be sponsons, features typically found on Navy gunboats. A quick review of the MMS shipwreck database identified the wreck as *Castine*, reported to have been lost approximately 13 miles northwest of this site. At the time of the 2005 investigation, little information was available on *Castine*, other than its reported loss location and date of loss – 1924.

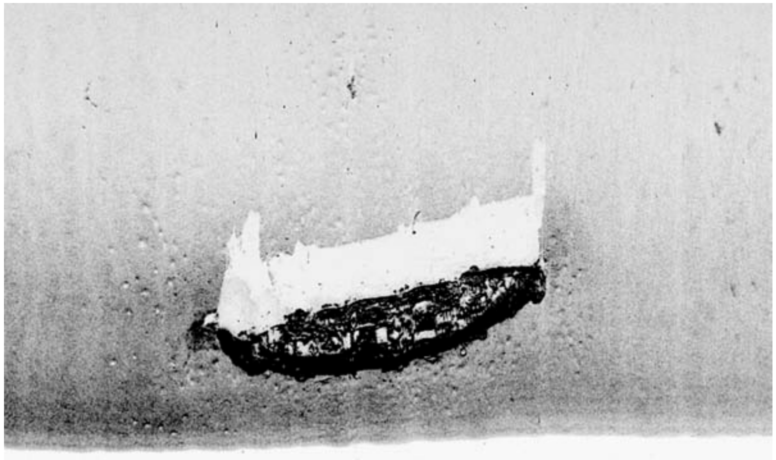

Figure 3. 2005 sidescan sonar image of U.S.S. *Castine.*

The principal investigator for this project, Bob Gearhart of PBS&J, made a call from our survey boat back to his office in Austin, Texas, and asked one of their researchers to initiate an Internet search to see what information might be available for the shipwreck *Castine*. Within a few hours we received a call back informing us that *Castine* was a U.S. Navy gunboat, originally built in 1892 and lost in 1924 (Figure 4). Based on this initial description and additional diver investigations, we felt pretty confident that we had found a rather intriguing shipwreck. Subsequent historical research, conducted after the fieldwork was complete, confirmed the identity and revealed an impressive story for this long-lost shipwreck.

Figure 4. U.S.S. *Castine* (courtesy of the Naval Historical Center, Photo No. NH 2087).

Castine was built in 1892 at Bath Iron Works, in Bath, Maine. Constructed as a gunboat for the US Navy, she was one of only two vessels of the Machias class ships, those being *Castine* and *Machias*. Both of these vessels were named after small coastal towns in Maine. Initially constructed at 190 ft (58 m) long by 32 ft (10 m) wide, and carrying a battery of eight four-inch rapid fire rifles, four six-pound guns, and two one-pounders, sea trials by the Naval Stability Board determined these vessels were too top-heavy. To remedy this situation, an additional 14 ft (4 m) was added to the length of both vessels. Modifications to *Castine* were completed in October 1894 and the vessel began its illustrious career under Commander Thomas Perry, with a crew compliment of 153 (Enright *et al*., 2006).

The history of *Castine* has been rediscovered and retold in depth in a recent Master thesis (Jones, 2007). To briefly summarize, at the outbreak of the Spanish-American War in April 1898, *Castine* was assigned to blockade operations off Cuba and Key West, Florida. There is some discrepancy in the historical record; however, some reports suggest that *Castine* may have captured the first enemy vessel, or prize, of the Spanish-American War. The war ended in December 1898, and the following year hostilities broke out in the Philippines. In January 1899, *Castine* was sent to the Philippines to join the naval blockade of the islands, and in November 1899, the surrender of Zamboanga played out on her decks. In 1900, *Castine* was stationed off Shanghai when the Boxer Rebellion broke out. And in World War I, *Castine* took up patrol off the coast of Gibraltar as an escort vessel for allied convoys between European and North African ports.

After World War I, *Castine* returned to the port of New Orleans and was eventually sold into the private sector in 1921 for $12,500. Historical documents from the U.S. Department of Commerce show that *Castine* was sold again in 1923, this time for $40,000.

Castine's final cruise began on December 12, 1924. She left out of New Orleans that day as a barge-in-tow to Sabine Pass, Texas, where she was to be disassembled and scrapped. However, a mysterious explosion on board *Castine* forced the towboat to cut her loose and abandon ship; she sank in about 20 minutes.

The remains of *Castine* were initially documented in May 2005 during an MMS-funded study to ground-truth unidentified sonar targets. The site was reexamined in 2007 under a new MMS study, which was developed to identify potential impacts to historic shipwrecks from recent hurricane activity; *Castine* was selected as one of the targets for this study because she was located about 30 miles west of the eye of Hurricane Katrina.

Two visits were made to the site of *Castine* in 2007. The first was a remote-sensing survey conducted in May of that year. The second was in October when dive operations were attempted. Unfortunately, the seastate was such that all dives attempted on the site were aborted and no additional diver observations were completed. However, analysis of the remote-sensing data suggests that little damage occurred to *Castine* during the passing of Hurricane Katrina.

As a result of information obtained on *Castine*, a National Register of Historic Places nomination form was completed and submitted to the Keeper of the Register last year. The site was officially listed on the National Register of Historic Places in March 2009.

Conclusion

Over the last 12 years, the MMS Seafloor Monitoring Team has provided scientific diving support for dozens of projects in the Gulf of Mexico and Pacific Regions. Future directions for the team will include continued support of the Environmental Studies Program, along with continued partnerships with government, academic and private partners. The team will also continue to provide support of compliance monitoring and environmental enforcement.

Acknowledgments

The author thank Greg Sanders for his comments and suggestions regarding the sea otter research section.

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Underwater Acoustic Ecology: Boat Noises and Fish Behavior

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Abstract

Scuba divers are usually oblivious to the soundscape of underwater noises. Exhaled bubbles and boat noise can often mask our being able to hear sonic fishes and "choral" reefs. For these reasons, underwater acoustic ecology has been largely overlooked until recently. Advanced diving technologies such as closed-circuit rebreathers allow divers to increase their awareness of the natural structure and tempo of the ambient acoustic world underwater. More importantly, the underwater soundscape is becoming a focus for research on fish bioacoustics with an application to fisheries processes such as spawning cycles and larvae migrations from open-ocean to reefs. This paper will highlight recent advances in underwater acoustic ecology and present some observations of boat noises and fishes reactions. The aim is to increase scuba diver awareness of the ecological importance of underwater sounds and to highlight the issue of noise pollution.

Keywords: fish sounds, fish spawning, rebreathers, Saipan

Introduction

The soundscapes of the ocean have been under appreciated for far too long. The notion that the sea was a "silent world" was conveyed early in the history of scuba diving (Cousteau and Dumas, 1953) and the idea stuck. This perspective was reinforced by the fact that human hearing is poor underwater and that the sounds of many fishes are not easily heard. Scuba divers are especially disadvantaged for hearing underwater because of the near constant stream of noisy bubbles running over their ears.

There is now an emerging awareness that many fishes produce specific courtship and spawning sounds (*e.g.,* Lobel, 1992; 2001a; 2002) and that a coral reef can also be described as a "choral reef." Research on underwater sounds and its ecological role has accelerated in recent years as the result of four scientific and technical developments. First, new technology in the form of camcorders, hydrophones and computer software has made the task of quantifying underwater animal sounds and behavior much easier (Lobel, 2001b; 2005). Second, discoveries that fishes produce species specific courtship and spawning sounds opened the feasibility for the development of passive acoustic monitoring for documenting reproductive patterns (Lobel 1992, 2001b, 2005; Rountree *et al.*, 2006; Luczkovich *et al.*, 2008). Third, loud noises from ships, sonars, seismic surveys and global climate experiments such as ATOC (http://atoc.ucsd.edu) have raised real concern about potential adverse impacts of loud underwater sounds on marine animals (McCauley *et al.*, 2003; Popper *et al.*, 2003; Popper and Hastings, 2009). Fourth, new research is showing that larval reef fishes may be using the sounds emanating from coral reefs to navigate during their migration from the open ocean to benthic habitat (Simpson *et al.*, 2004; Leis and Lockett, 2005; Mann *et al.*, 2007; Radford *et al.*, 2008).

As scientific scuba divers make the technical evolution from using open-circuit breathing systems to closed-circuit systems, they will experience a radical change in their perception of the auditory world underwater. Scuba bubbles radiate a low energy broadband noise in the frequency range of about 115-

400 Hz (Lobel, 2005). When using standard open-circuit scuba, approximately 36-40% of dive time is dominated by bubble noise that is bubbling up right past our ears. For fishes, this water disturbance is probably similar to the hydrodynamic disturbances produced by close swimming predators or competitors and to which most fishes are especially sensitive by means of their lateral line and sensory pore system. Consequently, scuba bubbles create multiple stimuli that may directly affect fish behavior. The use of a closed-circuit (*i.e.*, bubble-free) Rebreathers not only increases the efficiency of the dive time spent making underwater acoustic recordings but also alleviates a significant source of disturbance to the fishes being observed. Furthermore, rebreathers facilitate more rapid habituation of fish to a diver's presence while also extending the bottom-time available for underwater study. The point is that we are learning that the excessive noises of open-circuit scuba can be a disturbance and may also mask biologically important animal sounds. Scuba bubble noise spectra directly overlap in frequencies with fish hearing (Lobel, 2005; Radford et al, 2005).

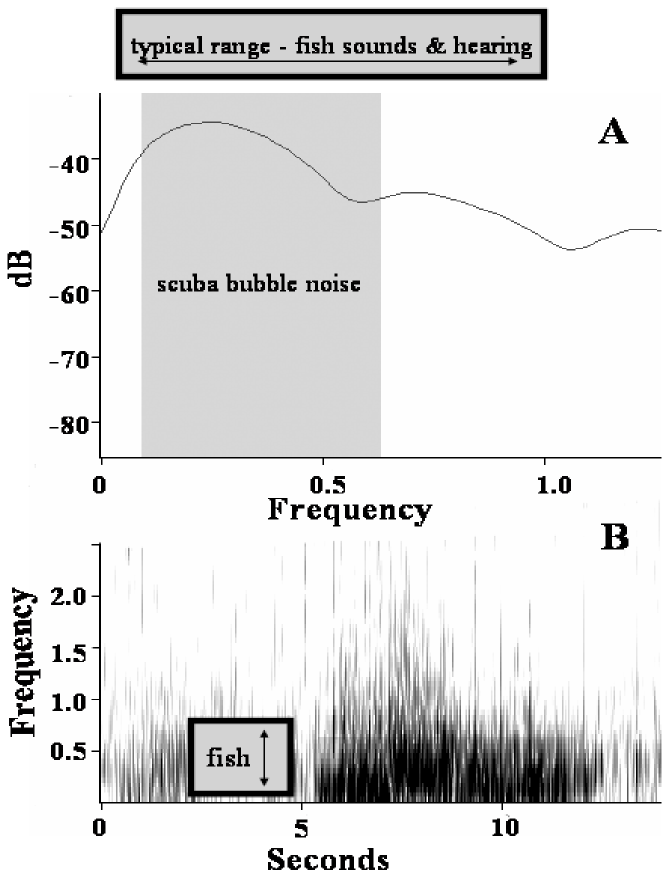

Figure 1. Schematic illustrating the frequency range overlap of typical fish sounds and hearing with (A) a power spectrum of a burst of scuba bubbles. This graph shows sound intensity (dB) vs. frequency (kHz), shaded area denotes the frequency range of the bubble noise and the boxed shaded area shows the typical range of many types of reef fish sounds and their hearing. The star specifies the dominant frequency of the signal. (B) Sonograph showing the same bubble burst plotted as frequency (kHz) vs. time. The boxed shaded area shows the typical range of many types of reef fish sounds and hearing (from Lobel, 2005).

This paper is based upon a presentation at the March 2009 meeting of the American Academy of Underwater Sciences (AAUS) where I showed audio-video clips of soundscapes from a variety of freshwater and marine habitats worldwide, described the spectrum of sounds and hearing by fishes, and demonstrated selected interference noises from open-circuit scuba, boats and submarines. This paper will describe the noise spectra from a few selected vessels and describe case studies of fishes' reactions to boat engine noise. The aim of this paper at the meeting was to stimulate discussion of developments in scientific diving and a consideration of the need for advanced silent diving technologies. The question asked by Foundation and University administrations when reviewing grant proposals is whether there is solid scientific justification for the additional expense and training of scientific divers to use closed-circuit rebreathers. The scientific questions are: how important is it to be quiet underwater, and what is the impact of various noises on fish behavior in the wild?

Methods

Acoustic Recordings
Sound recordings were made underwater using a calibrated hydrophone coupled to a digital video camera (Sony VX1000) equipped with a manual gain control. The hydrophone characteristics included a nominal flat response 10 to 3000 Hz and calibration of -162 dB re: 1V/*u*Pa. A scuba diver operated the underwater acoustic-video recording system. In order to obtain quality acoustic recordings without scuba bubble noise interference, acoustic measurements were made only between breaths. Thus, divers needed to be very disciplined in their respiratory pace and activity while recording.

Acoustic Analysis
Acoustic-video recordings were transferred from the digital camcorder to computer. Acoustic tracts were imported to the CANARY or RAVEN software programs (Cornell Lab of Ornithology) for analyses. For explanation of the sound sonogram and spectra parameters see Kovitvongsa and Lobel (2009).

Study Site
The examples of underwater sounds and observations of wildlife presented in this study were filmed in Saipan Lagoon, July 11-15, 2000.

RESULTS

Observations of Fishes and Boat Noise
During the five field days of recording in Saipan lagoon, we made two observations of rays, one surprising observation of a reef fish spawning and one observation of a cleanerfish cleaning; all with boat noises loudly dominating the background noise environment. In these four instances, the fish's behaviors did not appear affected by the boat engine noises.

1. An eagle ray, *Aetobatus narinari* (Figure 2), had been swimming in the area during the race boat experiment and it swam directly into the noisiest area immediately just after the boats departed.

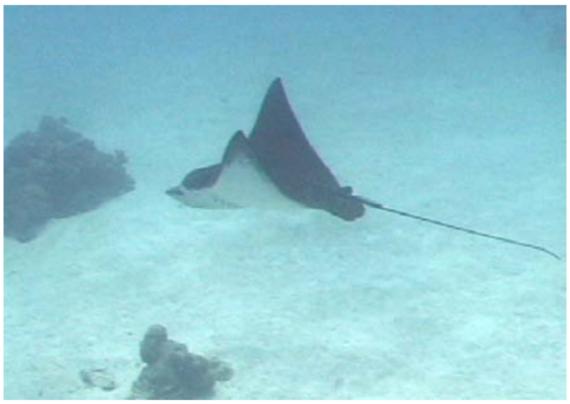

Figure 2. Eagel ray, *Aetobatus narinari*, swimming through area with loud speedboats racing overhead. Photo from digital video.

2. While towing behind the boat, we found one large stingray buried in the sand. It did not move as the loud engines of the research boat circled directly over it.

3. A pair of *Dascyllus reticulatus* (Pomacentridae) continued courting and spawning (Figure 3) during the entire time period of the race boat recording experiment where the boats circled above the fishes. (This was also the same time as the eagle ray observation). The race boats repeatedly crossing directly overhead did not seem to deter this fish from reproduction.

Figure 3. *Dascyllus reticulatus* did not seem overtly perturbed by the boat noise overhead and was not deterred from spawning. Photo from digital video.

4. The cleanerfish, *Labroides dimidiatus* (Labridae), continued cleaning behavior on the host fish *Dascyllus trimaculatus* while boat engines were loud in the background.

Figure 4. *Labroides dimidiatus* cleaning a *Dascyllus trimaculatus* while boats were noisy overhead. Photo from digital video.

Small Boat Engine Noise

The noise spectra of the boats that were cruising overhead of the spawning damselfish (Figure 3) and the cleaning cleanerfish (Figure 4) is shown in Figure 5. The boat noise was dominant in the frequency range of about 50-200 Hz, but was also significantly broadband to increase noise level at frequencies up to about 10 kHz (Figure 5).

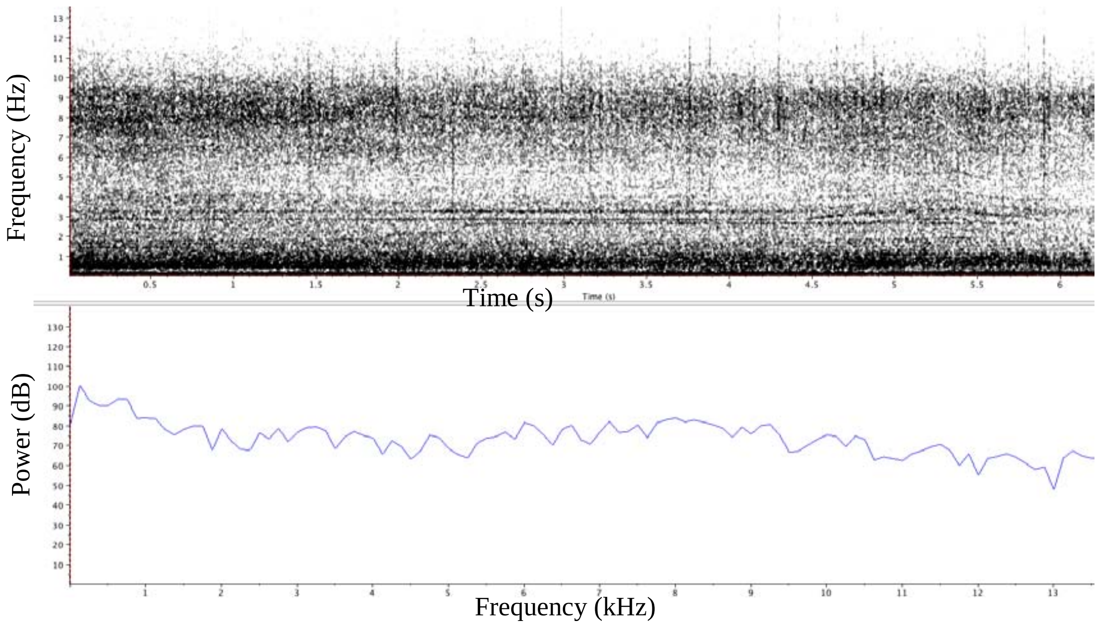

Figure 5. Boat noise from jet boats (approx 15ft in length with Honda 25 hp fourstroke engines). The top figure is the sonograph and the lower figure is the power spectrum. This boat engine noise was present when the damselfish were spawning and cleanerfish cleaning.

Large Ship Noise

Figure 6 shows a sonogram of a large Navy ship as it cruises through the channel. The recorder was located approximately 500 m from the ship. The engine and propeller noise appears as a broad dark band in the lower half (0 to 3.0 kHz) of the sonogram with very strong (dark shading) turbulent noise at the lowest frequencies. The dominant frequency was 345 Hz with an average intensity of 8.43 dB.

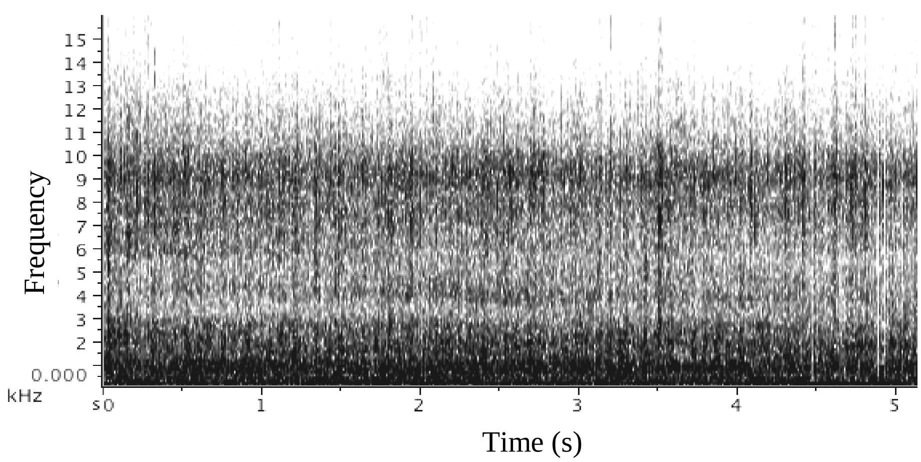

Figure 6. Engine noise from a large ship as it cruises through lagoon channel about 500 m distant.

Submarine Noise

One of the noisiest vehicles operating daily in the Saipan Lagoon is the tourist submarine (Figure 7). Although it operates by electronic engines, its hydraulic system is very noisy and creates sound over a broad range of frequencies. The yellow arrows in the figure point to the high-energy frequency noise shown as darker shading. The dominant frequency of the submarine was 388 Hz, with an average intensity of 15.7 dB measured from about 30 m distance.

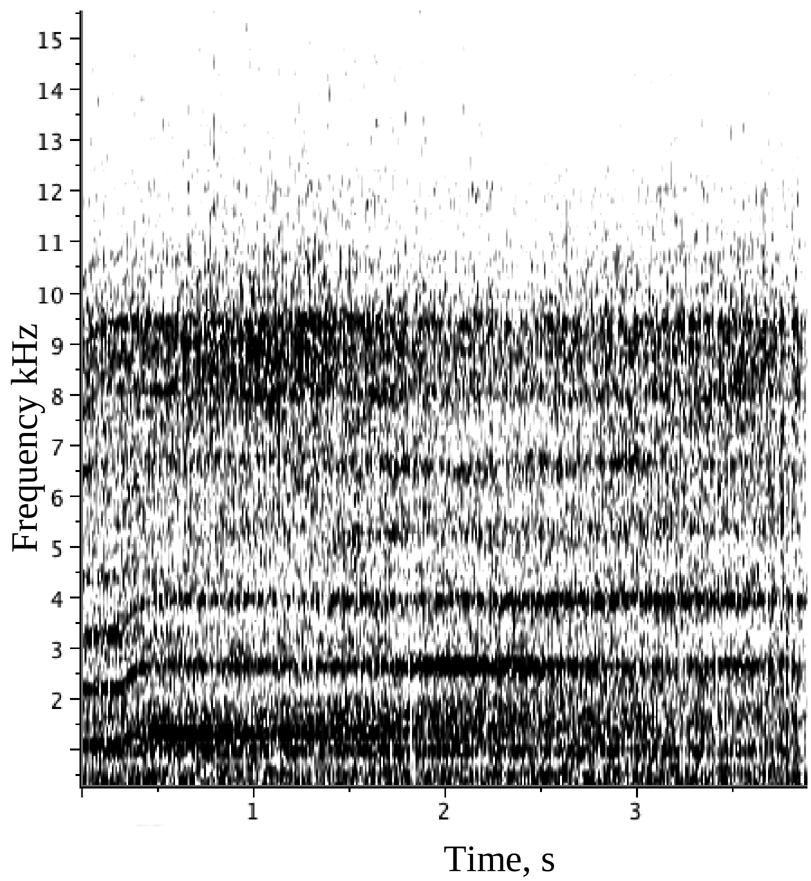

Figure 7. Noise from a tourist submarine electric engine and hydraulics in Saipan Lagoon.

Comparative Sound Levels and Dominant Frequencies of Ambient Sounds, Boats and Divers

The relative loudness (sound intensity) from the lowest (background or ambient water noise) to the loudest (the race boats directly overhead) of all the sound sources recorded are summarized in Table 1 and shown in Figure 8.

Table 1. Spectrum measurements.

Sound Source	Dominant Frequency (Hz)	Average Intensity (dB)
Background noise in lagoon	86.1	4.0
Background noise in lagoon	86.1	4.8
Reef "Sea Walkers" tourist divers	172	6.29
Navy ship about 500 m away	345	8.43
35 ft boat 250 hp twostroke overhead	474	10.6
Submarine hydraulics, closeby	388	15.7
Boat overhead, Honda 25 hp fourstroke	215	18.9

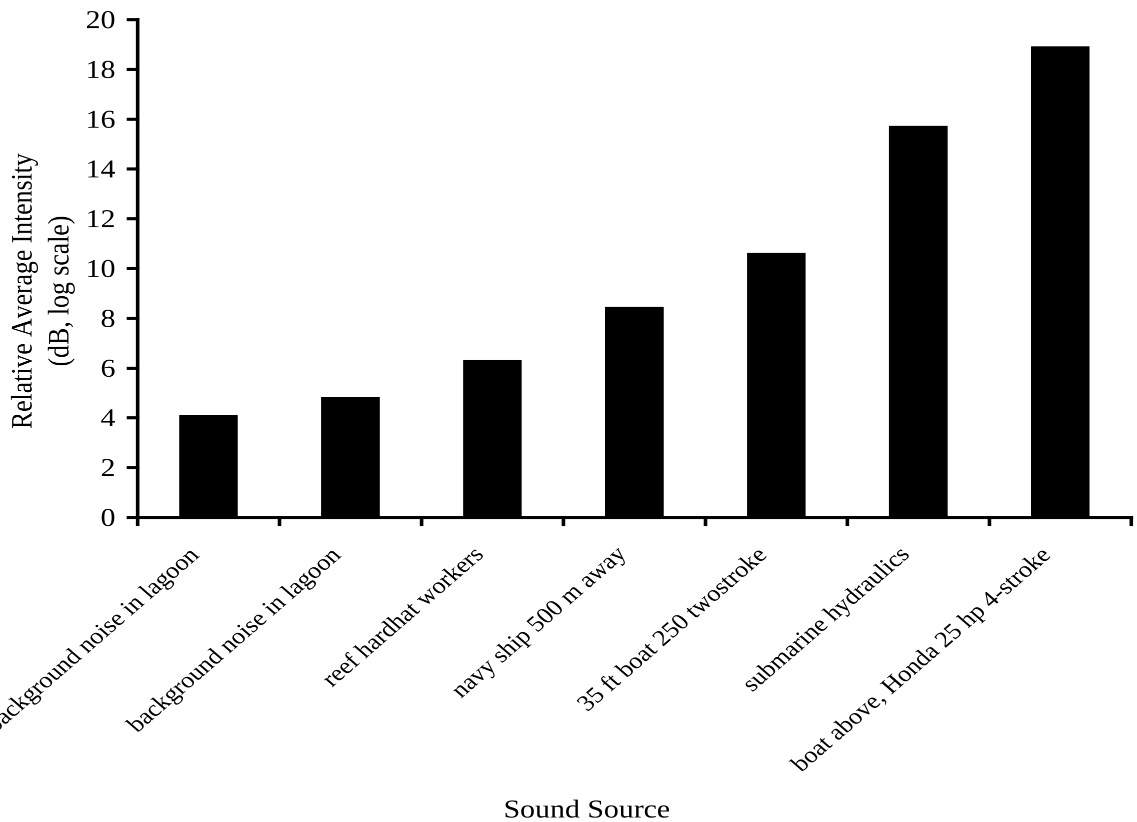

Figure 8. A graph of the data in Table 1 in increasing order from relatively quiet to loud.

Small Jet Boats

The sound from the small (ca 4 m) jet boats with 25 hp Honda four stroke engines was reduced in intensity to that of ambient noise when the boats were about 200 m from the recorder, although the dominant frequency of the boats (215 Hz) could still be distinguished from background noise (Table 2 and Figure 8). This was the boat noise that was dominating the auditory scene during the observations of the damselfish spawning, the cleanerfish cleaning and the eagle ray transiting the area.

Table 2. Spectrum measurements.

Site	Peak Frequency (Hz)	Average Intensity (dB)
Background noise	86.1	4
Race boats about 200 m away	215	4
Race boats overhead	215	17.4

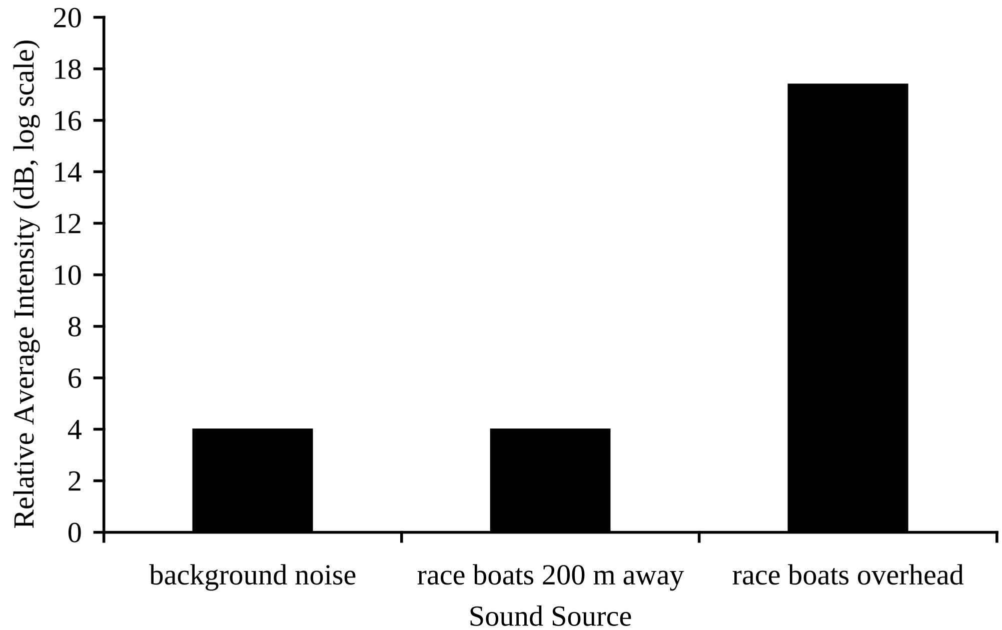

Figure 9. Comparison of ambient background noise in Saipan Lagoon to the boat noise when boats were about 200 m distant and directly overhead.

Discussion

It was readily obvious to observers that the boating activity occurring daily in the Saipan Lagoon makes it a very noisy habitat. This was one reason we were ask to assess the noise levels there. The dominant noises were from large ships transiting the lagoon channel, from the tourist submarine operating tours a few times a day, and from a huge amount of recreational boating and diving activity. The question is: does this noisy habitat adversely affect the behavior or physiology of fishes or other marine life?

The very limited observations that we were able to make did not reveal a significant overt disturbance to the fishes due to boat noise. The simple explanation is that the Saipan Lagoon fishes are already habituated to boat motor noise and now ignore it. The eagle ray we observed swam directly into the noisiest area where the race boats were operating and the stingray resting on the bottom did not move when our large boat was motoring directly overhead. The result that the rays do not seem particularly perturbed by boat engine noise is not too surprising. Rays are apparently more sensitive to sound vibrations that occur very near a sound source rather than sound pressure waves that propagate far from a source. Elasmobranchs are most sensitive to acoustic particle motions directly (*e.g.*, vibrations) rather than to sound pressure, especially at low levels (Banner, 1967). Elasmobranchs do not have a swimbladder as do many reef fishes and, therefore, are theoretically less sensitive to far field sound pressures. Even so, some elasmobranchs can respond to a low frequency source from up to 250 m (Myrberg *et al.*, 1972; Myrberg, 2001). At very loud levels, an elasmobranch is able to discriminate between sounds based upon the phased difference between particle motion and acoustic pressure (Berg and Schuijf, 1983). Sensitivity to sounds is greatest between 10-1500 Hz and elasmobranchs are particularly responsive to sounds in the 100-150 Hz range. Sudden or loud stimuli will produce a withdrawal or escape response (Myrberg, 2001). Charcharinid reef sharks are more specialized and have more sensitive hearing than do ray species examined to date (Corwin, 1989; Casper at al., 2003). Rays are not hearing specialists and apparently respond to direct and nearby vibrational noise much more sensitively than to pressure transduced sound from a distance. Based upon our limited observations in Saipan lagoon, boat noise did not agitate rays that were resting on the bottom or swimming.

The continued spawning of the damselfish, *Dascyllus reticulatus*, while intense boat noise was overhead was surprising given this fishes' use of acoustic communication in mating behavior. This observation was unexpected because as a fish with a swimbladder, it is theoretically more sensitive to a wider range of sounds than are elasmobranchs. The damselfishes (Pomacentridae), including *Dascyllus* species, are well known for their complex acoustic behavior involving courtship sounds as well as mating sounds (Lobel and Mann, 1995; Mann and Lobel 1998). Likewise, the continued cleaning behavior of the wrasse *Labroides dimidiatus* was unexpected while the boats raced loudly overhead. These two fishes should be able to hear well in the frequency ranges of the boat noise (although the hearing of these specific species have not yet been evaluated). The fact that they ignored the loud boat noises was unexpected. Under other circumstances, I have filmed whitetip sharks (in Palau) resting on the bottom that were then spooked and swam off after I approached close and exhaled a large breath of bubbles.

There are a number of plausible (but as yet untested) reasons for why the Saipan lagoon fishes in this specific instance were not overtly reactive to the boat noises. Of course, the first is that these fishes cannot hear the boat noise. This is unlikely if we generalize from existing work on fish hearing. Although the particular species in this study have not been directly tested for their auditory sensitivities, other species of damselfishes and stingrays are able to hear in the frequency range of boat noise (*e.g.*, Myrberg and Spires, 1980; Casper *et al.*, 2003; Maruska *et al.*, 2007; Kenyon, 1996). Alternatively, we can speculate that the fishes in Saipan Lagoon have acclimated to the increase noise in the environment. Acoustic impact can occur at three basic levels: 1) Direct damage to hearing receptors: this is caused by extreme sounds, which causes physical damage to the ear morphology (unlikely in this case); 2) Preliminary threshold shift (PTS): this is a permanent increase in the threshold of hearing, an unrecoverable deafening usually caused by long exposures to extremely loud noises; and 3) Temporary threshold shift (TTS): this is an increase in an animal's hearing threshold in response to loud sounds (for example, when one moves from a noisy area to a quiet location). The later two impacts are reasonable possibilities in the case of the fishes in Saipan Lagoon. This hypothesis is supported by studies on fishes that have shown that boat engine noise can damage and alter a fish's hearing threshold and cause physiological stress (Scholick and Yan, 2002; Smith *et al.*, 2004a,b; Amoser and Ladich, 2005; Wysocki and Ladich, 2005; Wysocki *et al.*, 2006; Vasconcelos *et al.*, 2007; Grahm and Cooke, 2008). At the very least, higher level of background sounds can mask important bioacoustics signals. Fishes and other animals have a hearing threshold level below which they can not hear. This threshold is determined by the higher of two levels: 1) the ambient noise level or 2) the physical limit of the animal's ability to hear. Animals cannot hear sounds that are less intense than the background noise at similar frequencies. This effect is known as masking. Masking of biologically important sounds (*e.g.*, sounds of mates, prey or predators) occurs when ambient noise levels are much louder than the signal and the frequencies overlap.

It is clear that loud noises can startle fishes and even scuba bubble noise will spook them (as most underwater photographers have experienced). The anecdotal observations from Saipan lagoon supports the notion that fish, like other animals, can acclimate to an increase in persistent ambient sounds. What this means in terms of behavioral alteration and how this may ultimately affect their survival is unknown.

Acknowledgments

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Convenient Fish Acoustic Data Collection in the Digital Age

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Abstract

Point-and-shoot digital cameras are affordable and user friendly. Furthermore, underwater housings are available for many models making these convenient accessories for divers. We tested the capability of these cameras for recording underwater sounds. Four cameras made by three major companies (Canon, Sony, Olympus) were evaluated. The cameras were compared to a professional hydrophone system and a recreational underwater microphone using simultaneous recordings during controlled playback of synthetic sounds. The test sounds were used to determine the accuracy of the cameras for recording frequency, amplitude and temporal characteristics. Results indicated that the cameras vary in their ability to record accurate underwater sounds. The cameras were limited in their detectable frequency spectra (4-10 kHz) compared to the underwater microphone and hydrophone system (16.5 kHz), but accurately represented the frequency of sounds within their range. The cameras also had a lower sensitivity to sound amplitude and were less accurate at recording temporal characteristics of sounds. In addition, the air contained within an underwater housing was shown to substantially decrease the amplitude of a recording. Digital cameras can be used for the recording of loud sounds known to be within frequency range of the camera, and for the gross description of temporal patterning. However, a hydrophone is still the best tool for accurate underwater recordings and is necessary for comprehensive scientific description of sounds.

Keywords: digital camera, hydrophone, sound recording, underwater acoustics

Introduction

Sound travels 4.5 times faster in seawater than in air (Giancoli, 2000) and can convey information in situations in which visual or chemical cues are ineffective, such as in darkness or in turbid water. Many aquatic vertebrates utilize acoustic signals for communication. Fishes produce sounds for many reasons including feeding, aggression, competition, and reproduction. The study of fish sounds is important because field monitoring can provide information about the species identity, geographic range, health, and behavior of calling individuals. These data can be collected without visual confirmation or observation if species-specific sounds and associated behaviors are known.

Fish sounds are characterized by the acoustic parameters of frequency, amplitude, and temporal (timing) measurements. These measures can be used to define and compare sounds of different species and individuals. Hydrophones have been the standard equipment used to take scientific recordings of underwater sounds. These systems have historically been very expensive and custom-made. In contrast, compact point-and-shoot digital cameras are affordable and becoming more advanced. If expensive hydrophone systems could be replaced with consumer electronics without a loss of quality and necessary detail in underwater recordings, the cost of underwater acoustic research could be greatly reduced and the amount of underwater acoustic data substantially increased.

The goal of this study was to evaluate the capability of point-and-shoot digital cameras to record underwater sound, and to determine if they are accurate enough to be used as tools for the scientific study of fish sounds.

Methods

Simultaneous recordings were made of controlled sound playbacks to test the capabilities of the cameras. Four digital cameras (Canon Powershot A570IS, Canon Powershot SD900, Sony Cybershot DSC-P150 and Olympus Stylus 1030SW), a hydrophone system, and a recreational underwater microphone system were used for comparison (Figure 1). All of these recording systems had automatic gain control and adjusted the sensitivity of the microphone based upon the amplitude of the sound. The volume of the experimental tank was approximately 1892 liters and filled with salt water (35 ppt, 19.17°C). Water depth was 103 cm and the underwater speaker was placed mid-depth at 48 cm. A Clark Synthesis (229F) underwater speaker (response range of 5-200 kHz) and amplifier were used to play the sounds. Cameras were held underwater with microphones facing the speaker at a depth of 15 cm and a distance of 1.8 m from the speaker. Test sounds were created using a Digital Function Generator from Digital Recordings (http://www.digital-recordings.com/www-dfg/www-dfg-products.html) and varied in frequency, amplitude and temporal parameters.

Figure 1. Recording systems evaluated.

Frequency Trials

Frequency accuracy was tested using pure tones of 0.5 s duration (at 100, 300, 500, 1000, 5000, 6000, 7000 and 10,000 Hz) and a 5 s frequency sweep ranging from 100-10,000 Hz. Spectrograms from the recordings of each system were compared to the known frequency of the source signal to determine the accuracy of frequency representation for each system. Spectrograms and selection spectra were also examined to determine upper detectable frequency limits for each recording system.

Amplitude Trials

Amplitude accuracy was evaluated using a 5 s amplitude sweep ranging from -80 to 0 relative decibels at a frequency of 300 Hz. Oscillograms of the simultaneous recordings from each system were compared to determine the relative recording amplitude for each system. Referenced sound pressure levels of test sounds were not measured in this study.

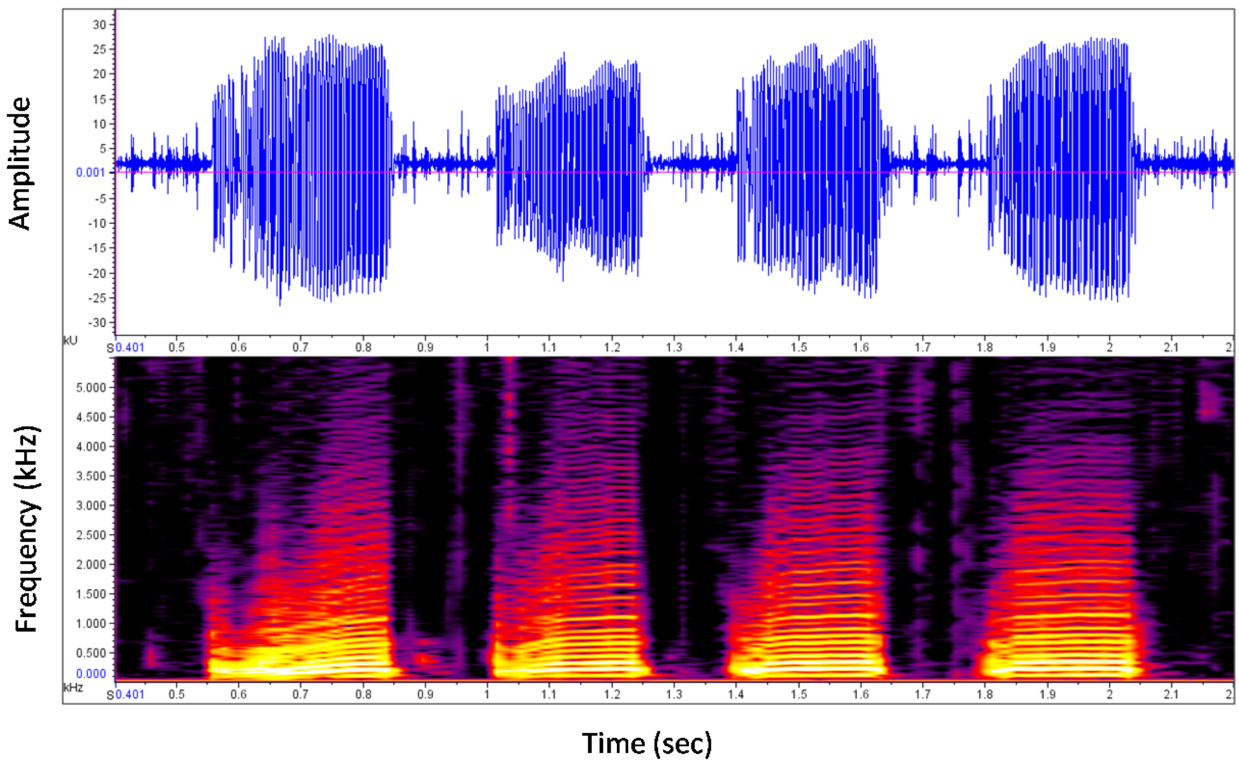


Figure 2. Spectrograms and Oscillograms: This is an oscillogram and spectrogram of the boatwhistle call of the toadfish *Sanopus astrifer*. The upper blue-colored plot is an oscillogram presenting the waveform and amplitude of the sound over time, X-axis is Time (sec) and the Y-axis is Amplitude. The lower figure is a plot of the sounds' frequency over time, X-axis is Time (sec) and the Y-axis is Frequency (kHz). The amount of energy present in each frequency is represented by the intensity of the color. The brighter the color, the more energy is present in the sound at that frequency.

Temporal Trials

Temporal accuracy was determined using four consecutive pulses of 0.1, 0.3 and 0.5 s length at a frequency of 300 Hz, each separated by one second of silence. Pulse length measurements were made from oscillograms, including and excluding reverberation, and then compared to the known source signal length to determine the temporal accuracy of each system.

Oscillograms and spectrograms of the recordings for each trial were analyzed using Raven v. 1.2.1 (Cornell Lab of Ornithology). An explanation of spectrograms and oscillograms can be found in Figure 2.

Effect of the Housing

The Olympus Stylus 1030SW camera is waterproof without a housing to a depth of 10 m. Additionally, a housing is available (Olympus PT-043) that allows the camera to be used down to a depth of 40 m. We were able to determine the effect of the housing on recordings by using two of these cameras simultaneously. The Olympus 1030SW was included in all recording trials both within and without a housing.

A second recording trial was conducted with the Olympus 1030SW without a housing and within a flooded housing to determine if effects were caused by the air contained within the housing, or the housing materials themselves. Lack of redundant equipment prevented the simultaneous test of all three housing treatments (without a housing, within a housing, and within a flooded housing). Test sounds in this trial consisted of a 0.5 second 1,000 Hz tone and an amplitude sweep of -80 to 0 relative decibels at 300 Hz.

Oscillograms and spectrograms were compared to identify effects of the housing on frequency, amplitude and temporal timing of the recordings.

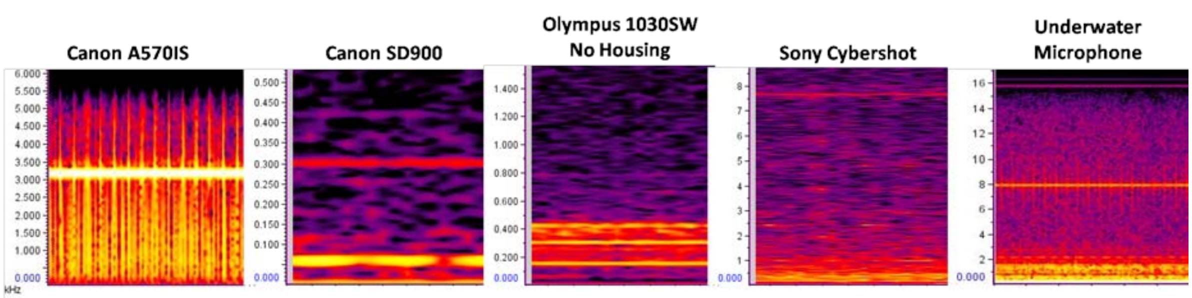


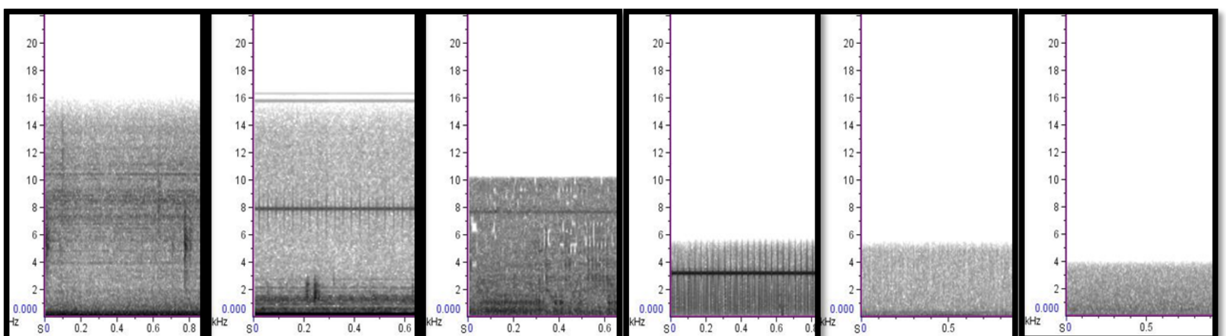
Figure 3. Electronic noise created by the camera systems themselves. Frequency of the noise varied widely between cameras so the spectrograms are not at the same scale. Y-axis indicates frequency (kHz), X-axis indicates time in seconds. The brighter the color in the spectrogram, the more energy is present in the sound at that specific frequency.

Results

Inherent Electronic Noise

Many of the systems produced inherent electronic noise that infringed on all recordings (Figure 3). The Canon A570IS was the noisiest, producing the highest amplitude noise at 3 kHz, and lower intensity noise at 100 Hz intervals from 0-3 kHz. The Sony PC-120 in the Mako housing was the next noisiest system, but produced mainly high frequency noise at 8, 16 and 16.5 kHz. The Canon SD900 produced low frequency noise (300 Hz) and the Sony Cybershot DSC-P-150 produced high frequency noise (7.6 kHz) at similar levels, but both lower than the above mentioned systems. The hydrophone and the Olympus 1030SW were the quietest recording systems and did not appear to produce inherent noise.

The hydrophone, underwater microphone, Olympus 1030SW without a housing, and the Sony Cybershot DSC-P150 did detect considerable noise in lower frequencies. However, this noise was due to ambient sound from aquarium pumps and filters present in the experimental room. This was verified by completing 10 second recordings of ambient noise in a different room using the Olympus 1030SW without a housing, the Sony PC-120 in the Mako housing, the Sony Cybershot DSC-P150 within a housing (MPK-PHB), and the Hydrophone (in water). The signals present on the ambient noise recordings differed from the trial recordings, indicating that the noise was due to external sources and not from the cameras themselves.



Hydrophone	Underwater Microphone	Sony Cybershot	Canon A5710IS	Canon SD900	Olympus 1030SW
16.5 kHz	16.5 kHz	10 kHz	5.5 kHz	5.5 kHz	4 kHz

Figure 4. Frequency bandwidth of the recording systems differed. The upper limit of detectable sound frequency range was highest at 16.5 kHz for the hydrophone and underwater microphone, and lowest at 4 kHz for the Olympus 1030SW.

Frequency Bandwidth

Frequency bandwidth, or the range of frequencies, detected by the cameras was lower than that of the hydrophone (Figure 4). The hydrophone system was capable of recording frequencies up to 16.5 kHz while the Olympus camera was capable of recording the lowest frequency bandwidth of 4 kHz. The Sony Cybershot DSC-P150 had the best frequency range of the digital cameras, and was able to record sounds up to 10 kHz, almost twice as high as the next best range of 5.5 kHz from the Canon cameras.

Frequency Trials

Frequency trials indicated that each of the cameras could accurately record frequency parameters within their respective range. In most cases, sound above upper detectable limits was not represented in the recordings. However, the Canon cameras created a sound artifact when recording sounds of frequency higher than their 5.5 kHz limit. Frequency tones higher than the limit were represented by inaccurate tones that were lower than the source signal (Figure 5). This was likely due to a phenomenon called digital aliasing, which occurs when a frequency is more than half of the sampling rate of the recorder. In this situation, the sampling rate is insufficient to accurately describe the frequency, and causes it to appear different than the source signal. The cameras that did not show this artifact may have built-in anti-aliasing filters or a higher sampling rate to deal with this problem.

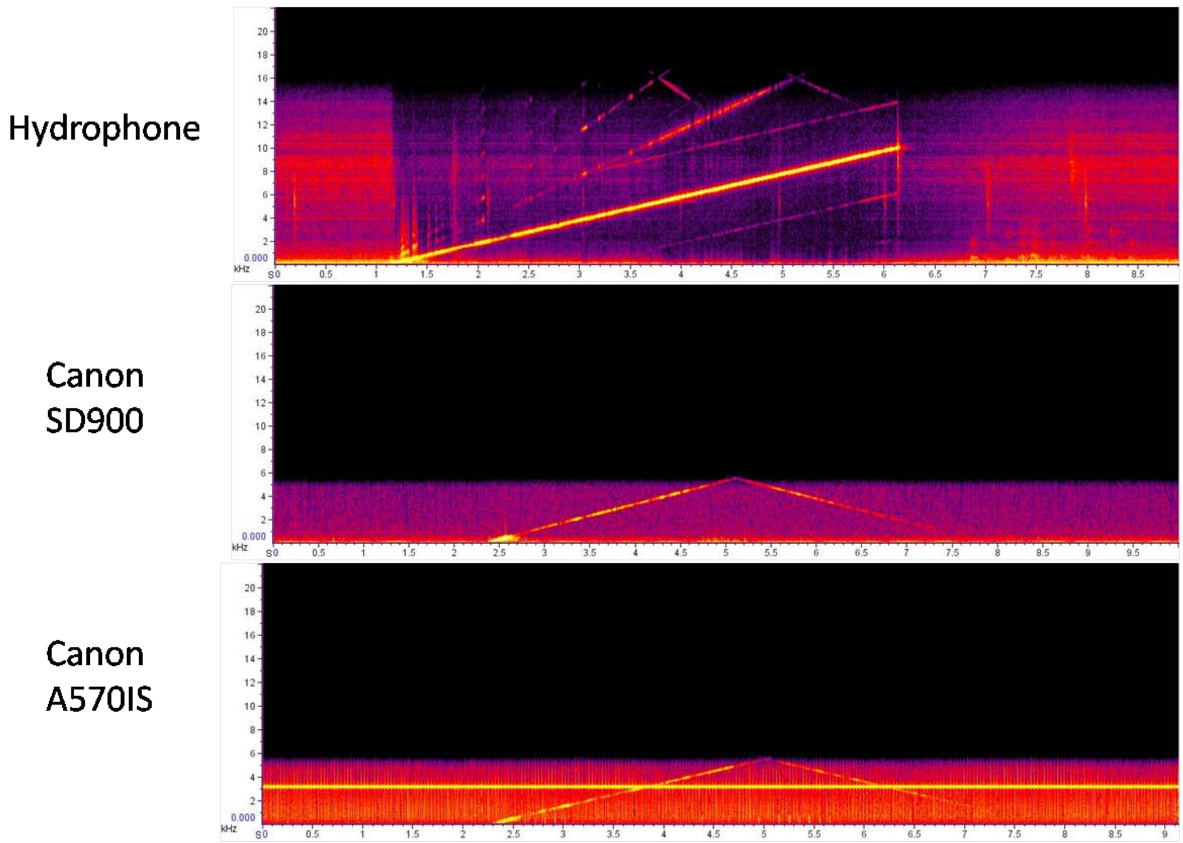


Figure 5. Canon cameras created a sound artifact for frequencies above their upper detectable limit of 5.5 kHz. This was likely due to digital aliasing stemming from an insufficient sampling rate.

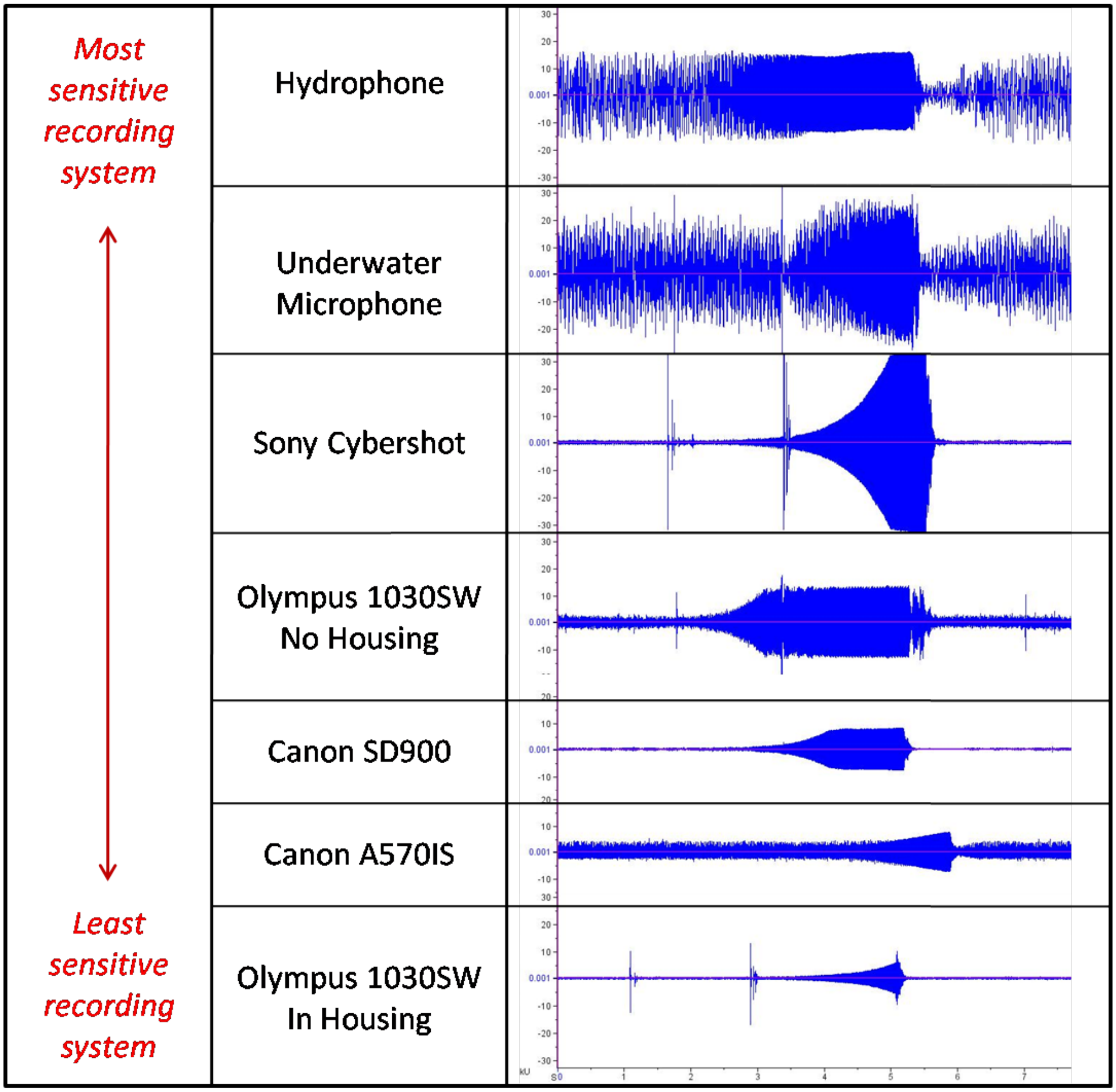


Figure 6. Variable amplitude of recordings. The hydrophone and underwater microphone detected higher levels of background noise than the digital cameras. However, the less sensitive cameras have a higher amplitude threshold and would not be ideal for detecting quiet sounds. The Y-axis is relative amplitude, the X-axis is time in seconds, and all oscillograms have the same scale.

Amplitude Trials

Amplitude trial results revealed variation in the microphone sensitivity between systems. The hydrophone and underwater microphone were the most sensitive recorders. Of the digital cameras, the Sony Cybershot had the highest amplitude recording while the Olympus 1030SW in a housing had the lowest (Figure 6). The hydrophone and underwater microphone systems also recorded higher levels of background noise than the digital cameras. However, the cameras, being less sensitive recorders, have a higher amplitude threshold for sound detection. Sounds must be louder for the cameras to detect them; therefore these systems may not be appropriate for recording low amplitude sounds.

Temporal Trials

Temporal trial results (Table 1) indicated that measurements excluding reverberation were more accurate than those including reverberation, regardless of the recording system used. Average overestimation with reverberation was 137 ms, and 52 ms without. Reverberation was often easier to distinguish in recordings from the hydrophone and underwater microphone compared to the digital cameras because the waveform was more clearly represented (Figure 7). Clarity of the waveform allows for better differentiation between source signal, reverberation (see Figure 8 for an example of reverberation) and background noise.

This was also evident in results indicating that the hydrophone and underwater microphone recordings were more accurate for measurements excluding reverberation than most of the digital camera recordings (Table 1). Ranking for accuracy in measuring temporal sound characteristics was not necessarily related to the camera company because the accuracy ranking of the Canon cameras was not alike. The hydrophone provided the most accurate measurements of temporal characteristics.

Table 1. Temporal trial pulse length measurements and accuracy ranking. Error values shown are the average seconds of over or underestimation of the source sound over all pulse length trials. Overall average error was less for measurements excluding reverberation, and the hydrophone system was capable of the most accurate recordings.

Including Reverberation Accuracy Ranking	
Recorder	Mean Error
Underwater Microphone	0.051
Olympus 1030SW In Housing	0.117
Canon A570IS	0.121
Hydrophone	0.128
Canon SD900	0.161
Sony Cybershot	0.171
Olympus 1030SW No Housing	0.209
Overall Mean Error	0.137

Excluding Reverberation Accuracy Ranking	
Recorder	Mean Error
Hydrophone	0.012
Olympus 1030SW No Housing	0.022
Underwater Microphone	0.036
Canon SD900	0.041
Olympus 1030SW In Housing	0.060
Canon A570IS	0.070
Sony Cybershot	0.126
Overall Mean Error	0.052

Effect of the Underwater Housing

The effect of the underwater housing was most evident in the amplitude of recordings. The housing attenuated, or reduced, the sound energy reaching the camera microphone by over half (Figure 9A). However, the housing had no effect on the accuracy of frequency measurements. In temporal trials the housing attenuated some of the reverberation when measuring pulse length including reverberation, although, the waveform was clearer in recordings from the camera without a housing. Consequently, the camera without a housing had better accuracy when taking measurements excluding reverberation, and thus overall better temporal accuracy.

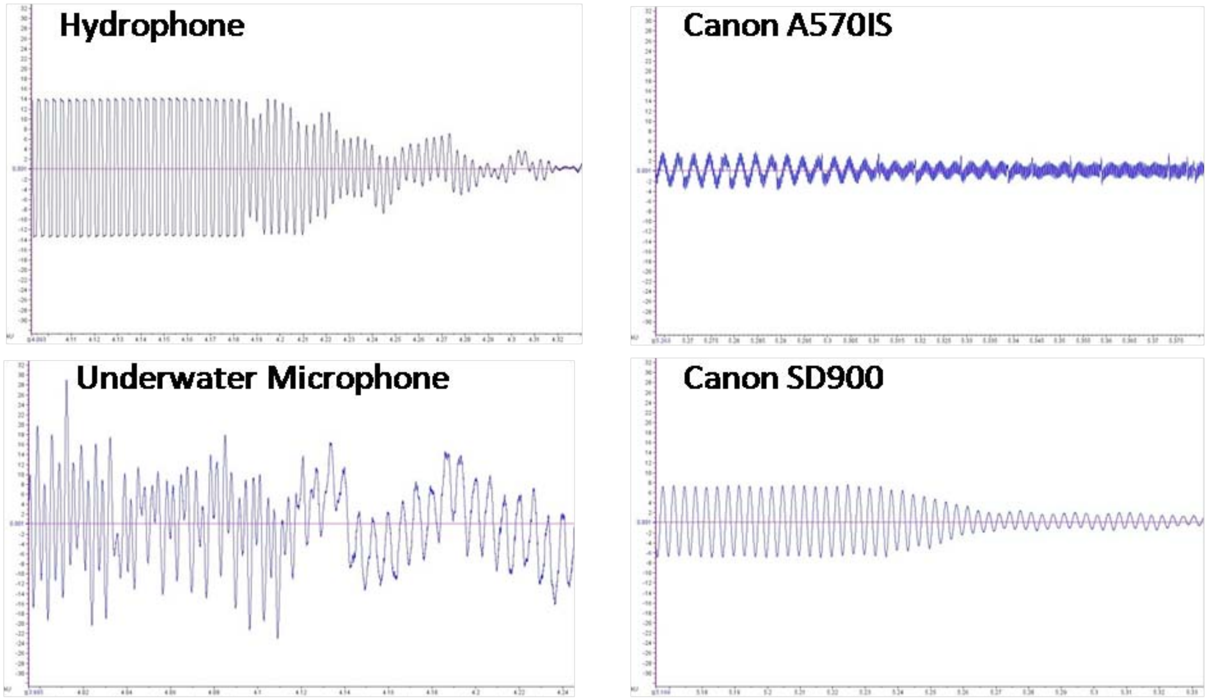


Figure 7. Sound waveform and reverberation. Clarity of the waveform varies between cameras, but is generally more easily distinguished in recordings made with the hydrophone and underwater microphone.

The additional test of a flooded housing revealed no attenuation of amplitude compared to the camera without a housing (Figure 9B), indicating that the majority of the attenuation is due to the air contained within the housing and not the housing materials themselves. However, the housing materials did decrease the amount of low amplitude sound recorded by the camera, shortening the length of the recorded amplitude sweep.

Discussion

The use of point-and-shoot digital cameras for the recording and scientific study of underwater sounds has some drawbacks:

The digital cameras were limited in the frequency range they could detect

This is an impediment when recording sounds of unknown frequency and amplitude, such as during exploratory underwater recordings. Sounds that are above the upper frequency limit of the camera go undetected or are recreated at an incorrect frequency due to digital aliasing. Aliasing is a confounding factor because sounds present on the recording at incorrect frequencies could mistakenly be assumed to be the actual frequencies of the sound source. It is necessary to test a camera system before recording to determine if it is prone to aliasing. Only Canon cameras were affected by this problem out of the three companies tested.

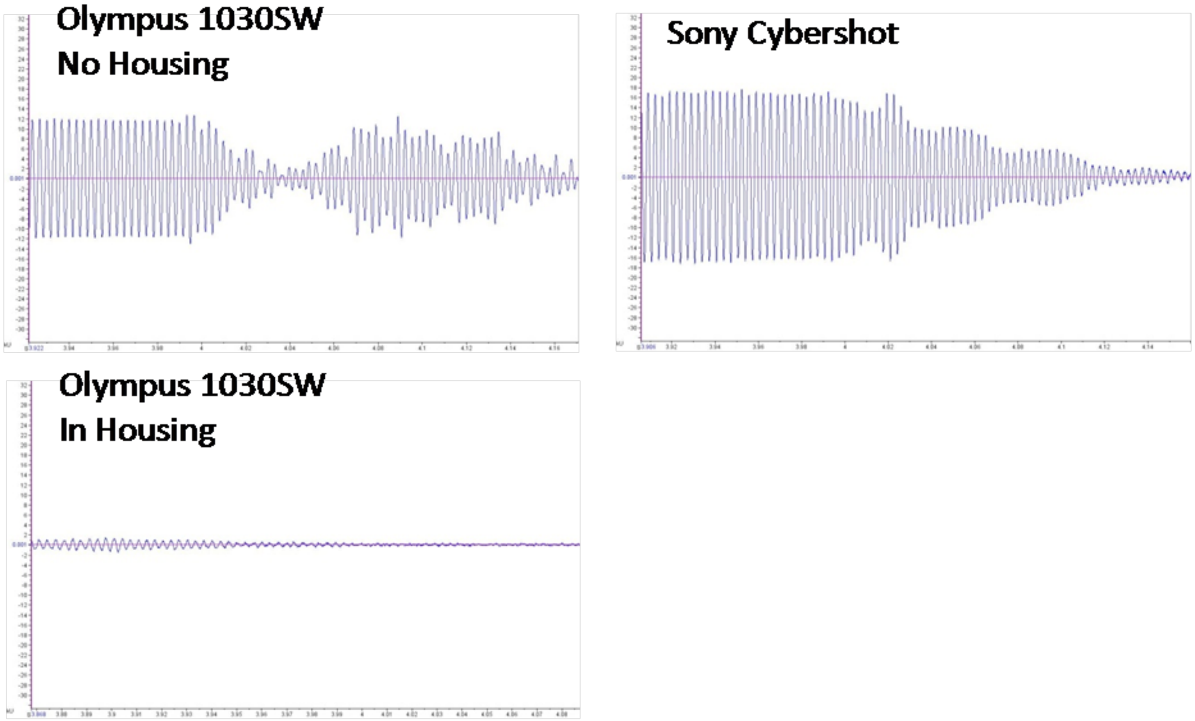


Figure 7 (cont.) The higher clarity of waveform for the hydrophone and underwater microphone is evident in more accurate measurements excluding reverberation from recordings by these systems.

Even though the cameras had a more limited frequency bandwidth than the hydrophone (up to 4 kHz for the Olympus, 5.5 kHz for the Canons, and 10 kHz for the Sony Cybershot camera), the range covered by these digital cameras includes the frequencies of the majority of fish sounds, most being produced at frequencies less than 1 kHz (Figure 10).

Sounds must be loud enough to be above a camera's detection threshold

The digital cameras were much less sensitive to sound amplitude, or volume, than the hydrophone and underwater microphone. This is a considerable deficit for the use of digital cameras in the study of fish sounds because many sounds of interest, such as the ones made during spawning, are likely to be of low amplitude so that they do not attract the attention of predators or competitors (Lobel, 2002). As such, they may not be loud enough to be detected by these systems. Nevertheless, some fish sounds, such as the boatwhistle call made by toadfish, are of high amplitude and are easily recorded by these cameras at short distances from the fish.

Temporal characteristics are not as accurately recorded as with a hydrophone

Temporal characteristics are very important in fish sound communication and are thought to carry much of the information in a call (Winn, 1964). Fish are capable of distinguishing differences in fine temporal detail of sounds down to differences of less than 1 msec (Wysocki and Ladich, 2006) and can use this temporal information for species identification (Myrberg and Spires, 1972; Marvit and Crawford, 2000; Kihslinger and Klimley, 2002), individual recognition (Marvit and Crawford, 2000),

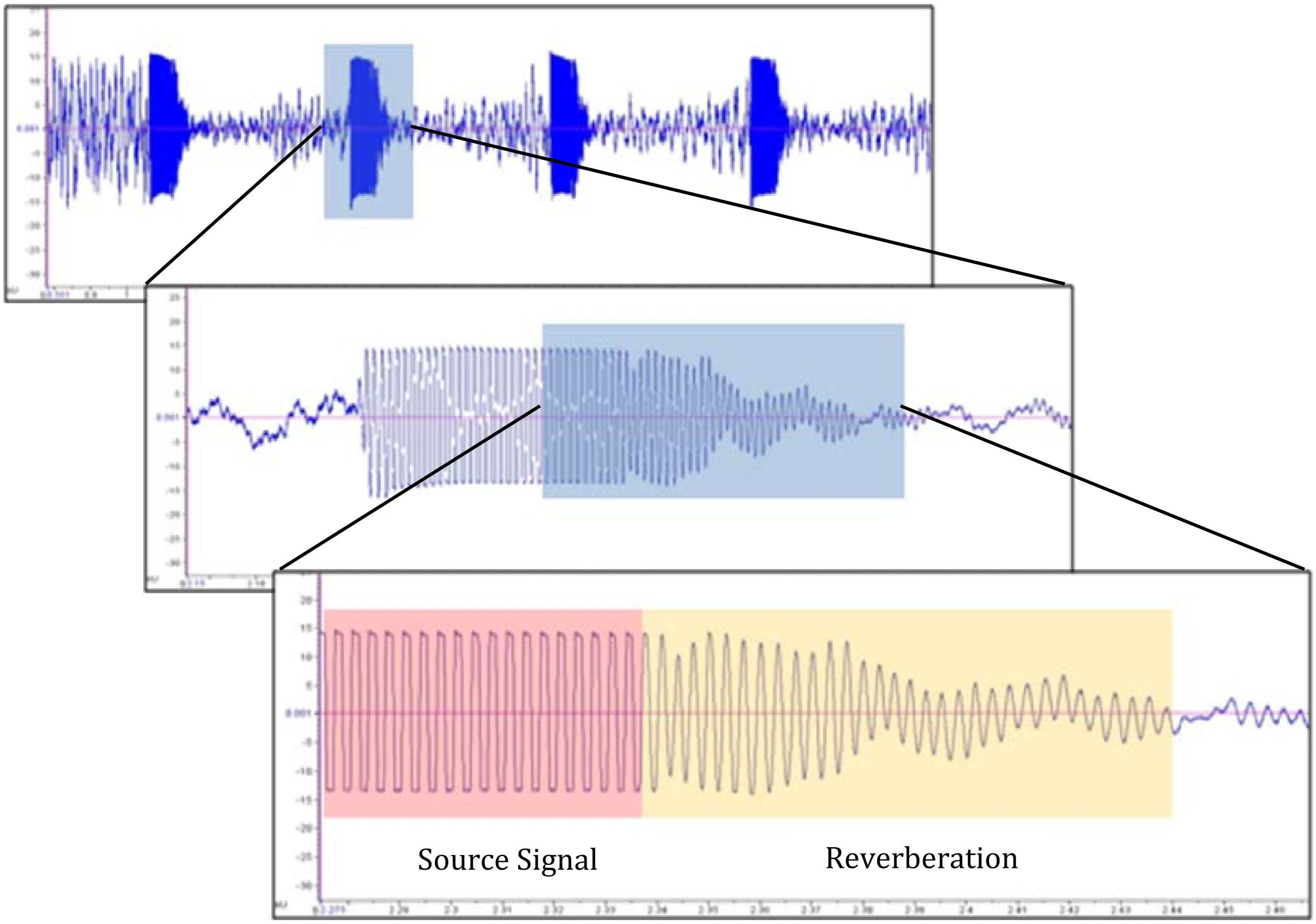


Figure 8. Clarity of the waveform allows for better differentiation between source signal, reverberation and background noise.

and possibly mate choice. Therefore, the accurate description of these sound parameters is essential in the scientific description of fish sounds, making digital cameras inadequate for this purpose.

Useful with constraints…

Digital cameras can be used for the accurate measurement of frequency and for the description of the gross temporal patterning of fish sounds, with caveats. These caveats include: the lower sensitivity to sound amplitude of these cameras may cause quiet sounds or frequencies with little energy to go undetected, and distance to the sound source will affect signal level, likely requiring that the camera be very close to the source during recording. An additional drawback of using consumer digital cameras is the inaccessibility of microphone specifications. We were unable to obtain this information from the manual or direct contact with the companies for any of the digital cameras evaluated. The consequence of this limited information is that all consumer cameras used for acoustic research purposes must be rigorously evaluated beforehand to determine suitability for a project.
Time and equipment constraints may make prior evaluation of digital cameras impracticable for those interested in using them for research.

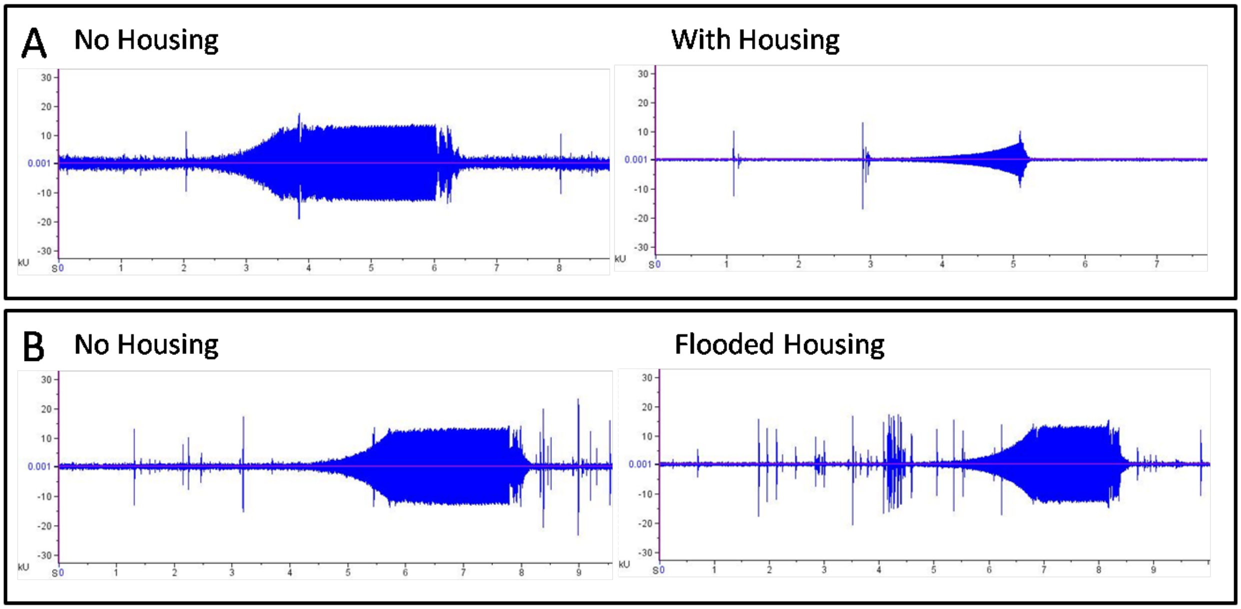


Figure 9. Effect of underwater housing on recording amplitude. Oscillograms showing amplitude vs. time for the amplitude sweep recordings from the Olympus 1030SW camera: (A) without a housing, and within a housing, and (B) without a housing and within a flooded housing.

However, if prior evaluation indicates that the frequency of the sound to be recorded falls within the range of the camera, and that the sound amplitude is above the detection threshold of the camera at the distance during recording, the digital camera can be used to gather accurate frequency data. In addition, recordings from these cameras are able to provide gross temporal information in the form of count data such as number of pulses per call, pulse repetition rate (number of pulses per unit time), and call rate (number of calls per unit time) even though they are inaccurate when recording the fine temporal detail of sounds.

The recording systems evaluated in this study rank in overall recording performance as follows: 1) Hydrophone, 2) Underwater Microphone, 3) Olympus 1030SW No Housing, 4) Sony Cybershot DSC-P150, 5) Canon SD900, 6) Canon A570IS, 7) Olympus 1030SW in a Housing. A summary of the performance rank for each system in frequency range, amplitude/sensitivity of recording, and temporal accuracy can be found in Table 3. The overall ranking takes into account recording performance in all three sound parameter areas. However, the appropriateness of a system for its proposed use must be considered. For example, the best digital camera for recording underwater sound based upon performance in all areas is the Olympus 1030SW without a housing. However, this camera has a maximum depth of 10 meters. For recordings at depths deeper than 10 meters, the best choice would be the Sony Cybershot DSC-P150, which can be taken to 40 meters within its housing.

Table 3. Recorder Performance Rankings. Amplitude Rank: Rank 1 = the most sensitive recorder, had the highest amplitude recording relative to the other recording systems. Rank 7 = the least sensitive recorder, had the lowest amplitude recording relative to the other systems. Temporal Rank: Rank 1 = the recorder with the lowest average error for measurements excluding reverberation. Rank 7 = the recorder with the highest average error for measurements excluding reverberation.

System	Frequency Limit (kHz)	Frequency Rank	Amplitude Rank	Temporal Accuracy Rank	Average Rank	Overall Rank
Hydrophone	16.5	1.5	2	1	1.50	1
Underwater Microphone	16.5	1.5	1	3	1.83	2
Olympus 1030SW No Housing	4	6.5	4	2	4.17	3
Sony Cybershot DSC-P150	10	3	3	7	4.33	4
Canon Powershot SD900	5.5	4.5	5	4	4.50	5
Canon A570IS Powershot	5.5	4.5	6	6	5.50	6
Olympus 1030SW in a Housing	4	6.5	7	5	6.17	7

A hydrophone is necessary for comprehensive scientific study of underwater acoustics

Though digital cameras can be useful for limited types of data collection, the best system for recording underwater sound is still the hydrophone. A hydrophone system detects the widest range of frequencies making it ideal for exploratory recordings of unknown sounds. The hydrophone is also more sensitive to low amplitude sounds, which is important for recording quiet sounds such as fishes produce. Furthermore, the hydrophone provides more accurate temporal data than the point-and-shoot digital cameras, which is critical in the scientific description of fish sounds.

In conclusion, digital camera systems can provide underwater recordings to acquire frequency and gross temporal data under specific conditions, but a hydrophone system is necessary for the comprehensive description of underwater acoustic sounds.

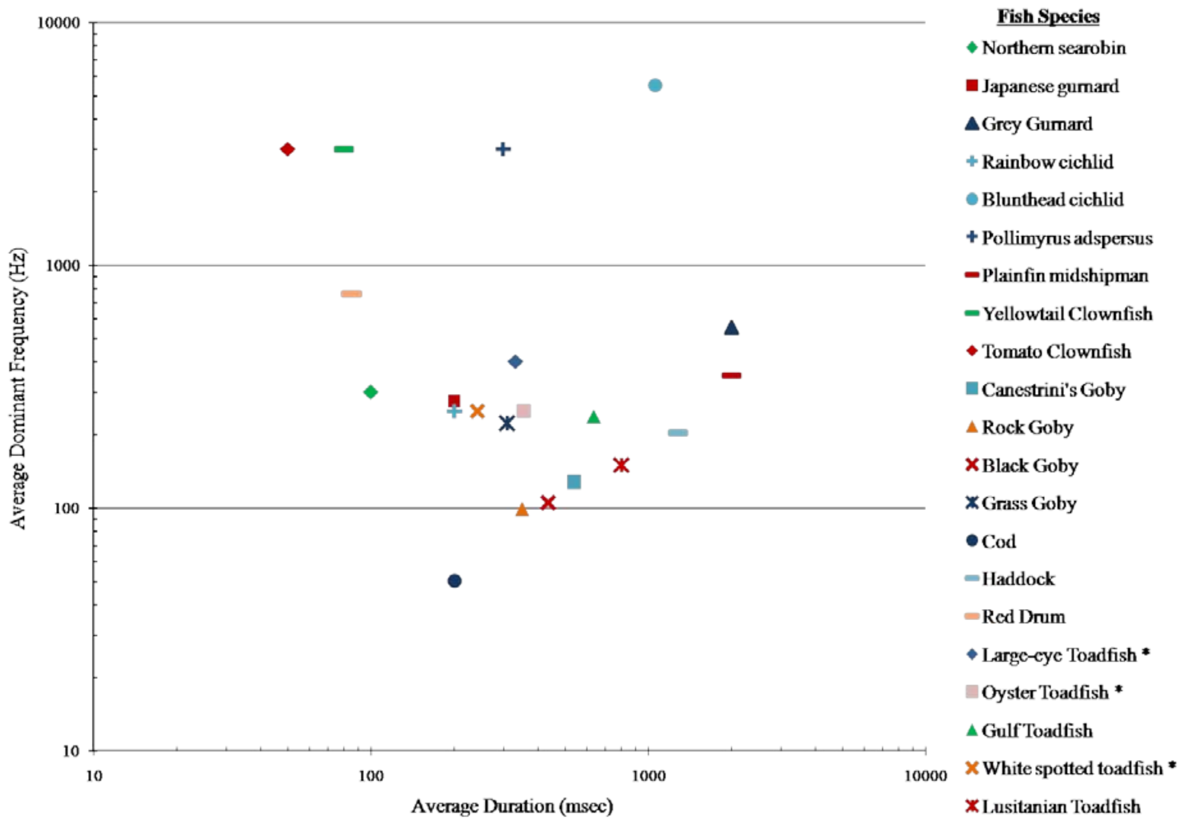


Figure 10. Fish sound frequency and duration. Many species of sonic fish make sounds within the frequency range detected by the digital cameras (up to 5,500 and 10,000 Hz), though amplitude of these sounds would be a consideration for detection capability. However, based upon frequency, most fish sounds are detectable by the digital camera systems. Data is from a literature summary in Amorim, 2006; Chen & Mok, 1988; Malavasi *et al.*, 2008; Brawn, 1961; Hawkins & Amorim, 2000; Guest & Laswell, 1978; Thorson & Fine, 2002b; and Amorim *et al.*, 2006. * Indicates our preliminary data.

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Use of Technical Diving to Study Deep Reef Environments in Puerto Rico

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Abstract

In 2007, researchers at the University of Puerto Rico – Mayagüez, Department of Marine Sciences initiated a Deep Coral Reef Ecosystems Studies (Deep CRES) project to study mesophotic coral ecosystems off southwest Puerto Rico at depths of ~50-100 m. To accomplish field operations, five divers from the Department of Marine Sciences were trained in open-circuit and closed-circuit rebreather (CCR) mixed-gas technical diving, and external oversight and guidance were brought in from the National Undersea Research Center at UNC-Wilmington. Using closed-circuit rebreathers, divers are currently working at depths of ~50-85 m and expect to extend this range in the near future. Technical diving is critical to the Deep CRES project as it allows for *in situ* surveying and sampling of deep reef environments. Divers have been able to make detailed observations of the geology, biology and ecology of these environments, careful and targeted collection of samples for more detailed studies in the laboratory, as well as precision deployments and recoveries of on-bottom oceanographic instruments. The utilization of CCRs allows for more efficient use of diving gases and, therefore, cost savings over open-circuit scuba. To support these activities a new diving-gas blending facility has been established at the Magueyes Island Marine Laboratory, allowing for on-site mixing, storage and filling of custom breathing gases. In addition to scientific goals, an important objective of the UPRM Deep CRES project is to establish technical diving capabilities and facilities at Magueyes Island Marine Laboratory to support future research in Puerto Rico and throughout the Caribbean.

Keywords: closed-circuit rebreather, mesophotic coral ecosystems, mixed-gas diving

Introduction

Although coral reefs have been a focus of intense study for several decades, few studies have examined reefs beyond depths of ~50 m (164 ft). This has largely been due to limitations of traditional open-circuit scuba techniques and the fact that most submersible or ROV (remotely operated vehicle) studies have focused on much deeper settings. In 2007, researchers at the University of Puerto Rico – Mayagüez (UPRM), Department of Marine Sciences initiated the Deep Coral Reef Ecosystems Studies (Deep CRES) project to study mesophotic coral ecosystems (MCEs) off southwest Puerto Rico at depths of ~50-100 m (164-328 ft). MCEs are defined as tropical to subtropical marine ecosystems found at depths of ~30 to 100 m (98 to 328 ft) and characterized by the presence of light-dependent (zooxanthellate) corals along with associated octocoral, antipatharian, sponge and algal communities (Mesophotic coral ecosystems, 2009). These ecosystems are especially important because they often contain unique flora and fauna, have a potentially large areal extant rivaling that of shallow reef systems, and, as they are further removed from terrestrial and anthropogenic influences than shallower environments, may serve as refugia for corals and other species during times of environmental stress (cf. Riegl and Piller, 2003). The UPRM Deep CRES project is a multidisciplinary study examining the biology, geology and ecology of these environments and has three primary objectives, which are: 1) *characterization* of deep reef environments in terms of geomorphology, reef distribution, community composition and the interrelationships between these factors; 2) determine the *connectivity* between deep and shallow reefs in terms of ecological flow and examine if deep reefs act as refugia for species threatened in shallow reef environments; and 3) determine the *vulnerability* of deep reefs to anthropogenic stress.

The need for technical diving was recognized early in the planning stages of the project as the target depth range for study (50-100 m/164-328 ft) lies beyond traditional scuba depths and no-decompression limits. Although submersible and ROV-based studies have provided critical information on deep reef habitats, these techniques have substantial short comings. Submersible operations are costly and logistically complex and can put significant limits on the spatial extent of the study area and the frequency with which it can be visited. Additionally, in both submersible- and ROV-based research, the observer is separated from the surrounding environment making detailed observations and sampling difficult. Although AUVs (autonomous underwater vehicle) have been useful in making broad-scale surveys, they are not appropriate for use on steep slopes that are characteristic of the Puerto Rico Deep CRES study area (Singh *et al.*, 2004). Only diver-based research has the flexibility to make the detailed, high resolution observations (including photography) and careful, targeted collections necessary to study the structure and dynamics of deep reefs. Mixed-gas (Trimix) diving and closed-circuit rebreathers permit divers close-range access to the environment being studied and constitute the primary access methods used in this project. Closed-circuit rebreathers were chosen over open-circuit scuba as they required less equipment and could potentially provide extended bottom times.

Methods

Training

Five scientific divers from the UPRM Department of Marine Sciences were trained in open-circuit and closed-circuit rebreather (CCR) mixed-gas technical diving. The Deep CRES dive team consists of the Department's Diving Safety Officer, one faculty member and three graduate students. Technical training began in April 2007 with a ten-day open-circuit technical training program at the Key Largo Facility of the NOAA Undersea Research Center at the University of North Carolina Wilmington. Certifications acquired at this time included the following: TDI *Advanced Nitrox Diver*, *Decompression Procedures Diver* and *Trimix Diver* and IANTD *Trimix Diver*. In June 2007, divers began CCR training at Puerto Rico Technical Diving Center in Aguadilla, Puerto Rico. From June 2007 to December 2008, divers progressively moved forward with CCR training and practical experience and acquired the following certifications: ANDI International *Rebreather Diver-Level 2 CCR* and *Technical Rebreather Diver-Level 3 CCR* and IANTD *CCR Normoxic Trimix Diver* and *CCR Trimix*.

Diving Operations

To assist with establishing technical diving procedures and protocols at the UPRM Department of Marine Sciences as well as ensure that technical diving operations were conducted with the utmost regard for safety and professionalism, external oversight and guidance for the Deep CRES project were brought in from the NOAA Undersea Research Center at the University of North Carolina Wilmington. The study area lies off the southwest coast of Puerto Rico where a broad shelf extends ~8 km offshore before dropping abruptly to oceanic depths (Figure 1). Research thus far has focused on a ~12 km section of the upper insular slope from the shelf break at a water depth of ~20 m (66 ft) down to a depth of ~85 m (279 ft). The UPRM Department of Marine Sciences Magueyes Island Marine Laboratory serves as the base of operation and provides easy access to the study area. NOAA multibeam bathymetry of the area (Battista and Stecher, 2006) was used to help locate and characterize dive/study sites. The depth grid was used to create an image of slope with the Spatial

Analyst extension in Arcmap GIS software. The map of slope provided a representation of topographic features on the bottom that were used to locate sites of interest and to extract waypoints. The map also provided a visual aid during dive briefings so divers could visualize the bottom features in relation to the study site. A Seabotix LBV 200 ROV was used to conduct vertical profiles of the slope and, in conjunction with diver observations, help to characterize different regions and identify potential study sites. The ROV was useful as it could extend beyond depths currently accessed by the divers. Divers used Ambient Pressure Diving Ltd./Silent Diving Systems LLC *Inspiration* closed-circuit rebreathers with *Vision Electronics*.

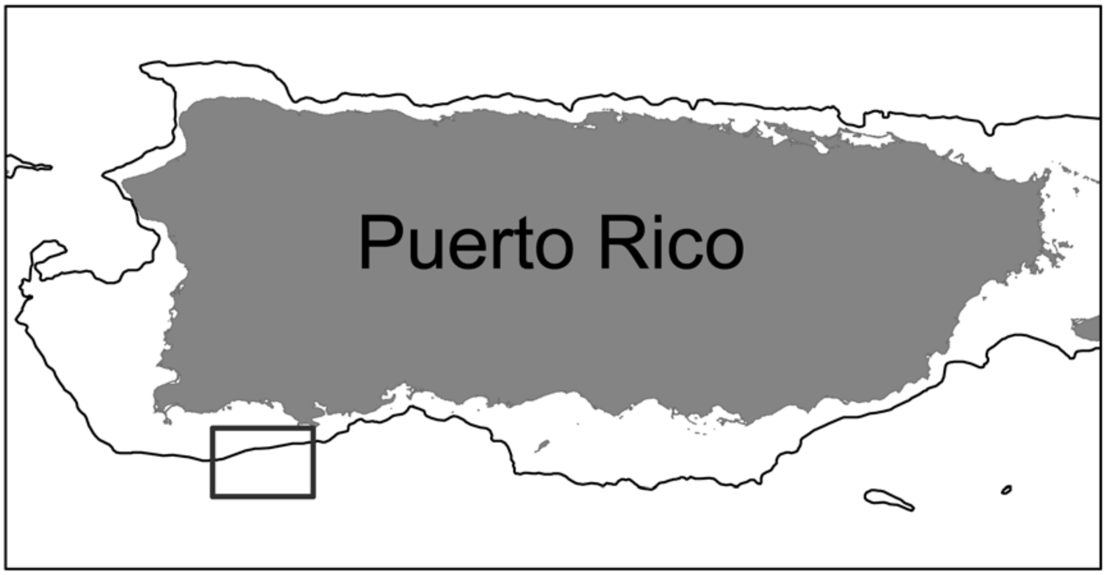

Figure 1. Map of Puerto Rico with 200 m (656 ft) depth contour showing location of study area (rectangle).

Equipment setups were centered on two-person buddy teams, with each team carrying enough open-circuit (OC) bailout gas to safely bring one diver to the surface in the event of rebreather failure. Given the high reliability of the equipment being used and the built-in redundancy within the rebreather unit (*e.g.*, dual oxygen controllers, dual displays, duel batteries, etc.), it was thought to be highly unlikely that both rebreathers on a buddy team would completely fail on a given dive. Both members of a buddy team carry OC bottom bailout mix that matches the diluent being used in the rebreather. In addition to the bottom mix, one member of the team carries EAN 36% deco mix, while the other member of the team carries 100% O_2. Two standard mixes for diluent/OC bailout are being used depending on the planned dive. For dives from 49 m to 61 m (160 ft to 200 ft) an 18/30 Trimix is used (*i.e.*, 18% O_2/30% He/52% N_2). This mixture has a maximum operating depth (MOD) of 68 m (224 ft) at a PO_2 of 1.4 atmospheres absolute (ATA). At 61 m (200 ft) and a rebreather PO_2 setpoint of 1.3 ATA, the mixture provides an equivalent air depth (EAD) of 37 m (120 ft). For dives from 61 m to 91 m (200 ft to 300 ft), a 12/50 trimix is used, which has a MOD of 107 m (352 ft) at 1.4 ATA PO_2 and an EAD of 38 m (126 ft) at a rebreather setpoint of 1.3 ATA PO_2. Divers use two decompression computers, the integrated *Inspiration* computer with a peak PO_2 setpoint of 1.3 ATA and a *VR3* set at a constant PO_2 of 1.25 ATA.

Results

Divers are currently working at depths from ~49 m to 85 m (160 ft to 280 ft) and expect to extend this range in the coming months. Diving is conducted from a live boat. Divers typically enter the water at the shelf break at a depth of ~20-21 m (65-70 ft). They then proceed down the steep insular slope to the target working depth, using geomorphic features as reference points and guides during the descent. Bottom times are typically 20-25 minutes, which includes both descent and actual time at the target depth. A typical profile for a dive to a maximum depth of ~61 m (200 ft) is shown in Figure 2. For this dive, divers entered the water at the shelf break and took ~5 minutes to descend down the insular slope to the target depth of 61 m (200 ft), where they had a working bottom time of ~15 minutes. At a run time of 20 minutes, they started their way back up the slope, essentially along the same route of the descent. Two, two-minute deep decompression stops were required at depths of ~44 m and 34 m (145 ft and 110 ft). As they arrived at the shelf break, very close to their entry point, the divers sent up a surface marker alerting the boat of their precise location as well as that they were entering the final decompression phase of the dive. On this particular dive, another ~40 minutes of decompression were required. During decompression, divers drift along with the surface marker and are followed by the boat. Thus, divers do not need to expend energy making it back to or staying on a stationary anchor point.

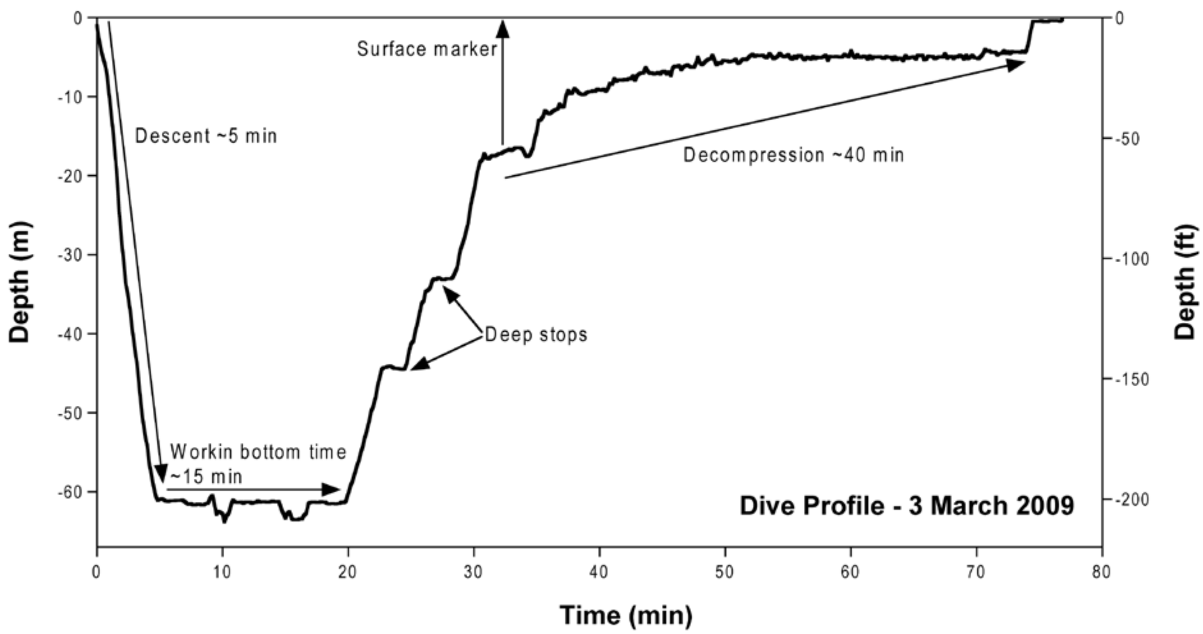

Figure 2. Typical Deep CRES dive profile for a dive to 61 m (200 ft).

In the current working depth range of ~49 m to 85 m (160 ft to 280 ft), divers have made detailed observations of geomorphology and benthic macrofauna as well as careful and targeted collection of hard substrates, sediment and macrofauna, primarily corals and algae, for more detailed study and positive identification in the laboratory. Divers have conducted over twenty continuous high-resolution benthic photo-transects ~10 m long by 40 cm wide at depths of 47 m to 70 m (154 ft to 230 ft). Individual photographs from the transects, each photo covering an area of ~40 by 60 cm (Figure 3), have been analyzed using CPCe point-counting software to determine relative abundances of major groups of benthos and substrate types (Kohler and Gill 2006). At each of these sites, rugosity measurements and fish surveys have also been conducted. Divers have deployed and recovered several on-bottom oceanographic instruments, including three acoustic Doppler current profilers at depths of 40, 60 and 82 m (131, 197 and 269 ft). Thus far, surveys and collections have resulted in several new reports of species, primarily marine alga, in Puerto Rico or the Caribbean, new deepest reports of some species of corals in Puerto Rico, and several new species of marine alga are currently being described. Preliminary results of surveys describing the geomorphology and mesophotic coral ecosystems of the area were presented at the 18th Caribbean Geology Conference, Santo Domingo, Dominican Republic (Sherman *et al.*, 2008) and a more detailed paper has been submitted to Coral Reefs and is currently in review. Preliminary results of fish surveys were presented at the 11th International Coral Reef Symposium in Fort Lauderdale, Florida (Bejarano *et al.*, 2008). In addition to scientific goals, an important objective of the UPRM Deep CRES project is to establish technical diving capabilities and facilities at Magueyes Island Marine Laboratory to support future research in Puerto Rico and throughout the Caribbean. To this end, a new diving-gas blending facility has been established at the Magueyes Island Marine Laboratory, allowing for on-site mixing, storage and filling of custom breathing gases. These facilities continue to be improved and expanded upon as the Deep CRES project and technical diving operations progress.

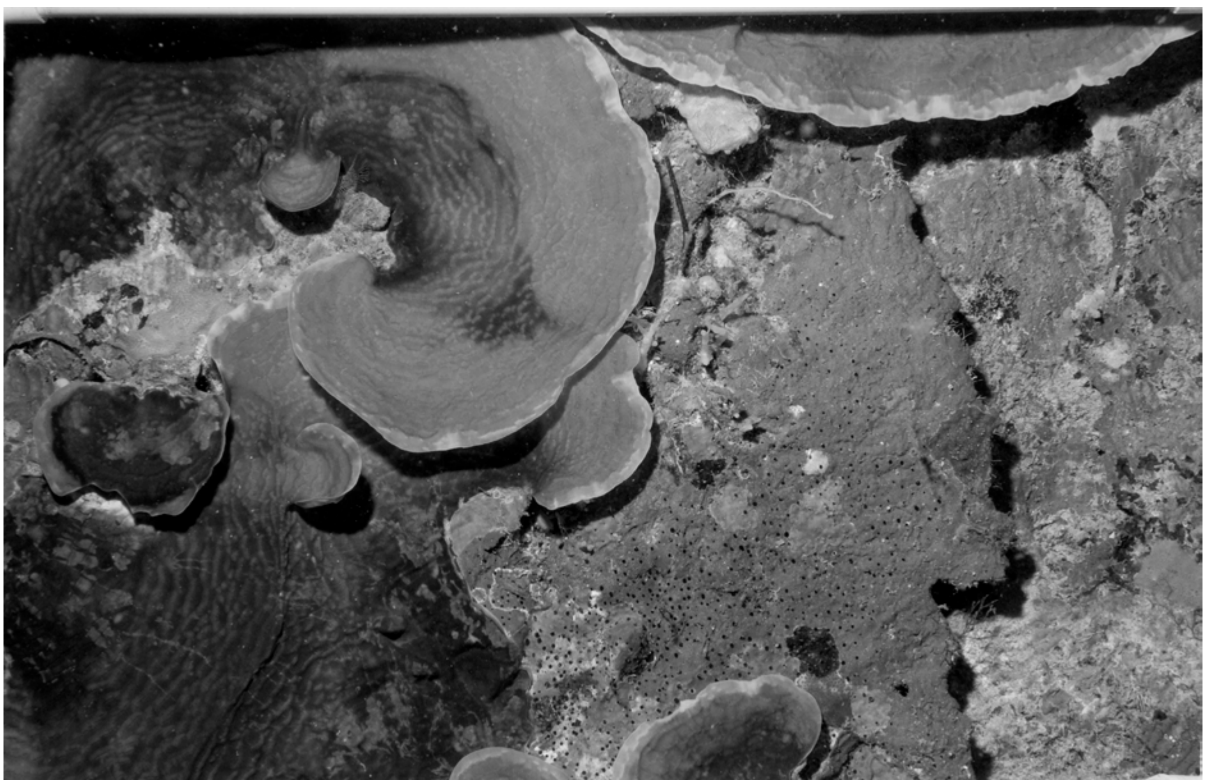

Figure 3. High-resolution photo-quadrat at a depth 76 m (250 ft). Image area is 40 x 60 cm.

Discussion

Advantages of CCR Technical Diving

Technical diving is a key component of the UPRM Deep CRES project. Full characterizations and an understanding of the fundamental ecological and geological processes that sustain and control deep coral reefs require a level of access and manipulation beyond that available from submersible- or ROV-based operations alone. The *in situ* observations of divers and their detailed and targeted sampling would not be possible using these other methods. Divers have greater maneuverability and are able to reach hard-to-access areas such as caves or under ledges. Thus, the scientific goals and objectives of the Deep CRES project can only be achieved via diver-based operations. Divers have been able to conduct precision deployment and recovery of oceanographic instruments that similarly would not have been possible using ship-based or submersible-/ROV-based techniques. Positioning of the instruments requires detailed observations of geomorphology and substrate type to choose appropriate locations for deployment. Deployment of the devices requires precision positioning and anchoring that would have been impossible to achieve by other methods. In addition, observations by divers of the characteristics and conditions of the instrument sites are a crucial component of interpretation of the instrument data. Divers are also able to employ the same research methods used in the study of shallow reefs allowing for a more meaningful comparison of results across depths.

The use of closed-circuit rebreathers has provided distinct advantages over open-circuit scuba. To supply five divers with open-circuit equipment to cover all diving operations would have required the purchase of considerably more equipment (*e.g.*, BCs, regulators, double-tank setups with manifolds, etc.) than purchasing five CCR units. The rebreathers also offer more flexibility. It is easy to change diluent mixtures to suit the planned diving by either having multiple diluent tanks available with different gas mixtures or by simply emptying and refilling the small (12.5 ft^3) rebreather tanks. Changing gas mixtures with an open-circuit setup is much more involved and costly. Having multiple double-tank setups for each diver can be cost prohibitive. Having to empty and refill doubles with a total of at least 160 ft^3 of gas can be both costly and time consuming. CCRs maintain a constant PO_2 throughout the dive, optimizing the breathing mixture according to depth and negating the need for gas switches during decompression. The entire dive is completed on the rebreather loop. CCRs have distinct scientific advantages as well. Because bubbles are not released by the CCRs, marine life behavior (fish, marine turtles, etc.) in the presence of divers is more natural and surveys can provide more accurate information on composition and behavior of the community. CCRs also provide much more efficient use of breathing bases over OC scuba. Table 1 shows approximate amount of breathing gases used by the same diver during similar OC and CCR dives. For the dives examined, the diver used greater than an order of magnitude, or about 15 times, more gas on an OC scuba dive versus a CCR dive. Thus, the CCR provides more efficient gas use and, therefore cost savings, as well as reduces gas storage and mixing requirements.

Table 1. Comparison of open-circuit scuba (OC) versus closed-circuit rebreather (CCR) gas consumption.

				Gas Consumption (ft^3)			
Device	**Depth (m [ft])**	**Bottom Time (min)**	**Run Time (min)**	**Trimix**	**Nitrox**	**Oxygen**	**Total**
CCR	49 (160)	20	54	4	–	4	8
CCR	50 (165)	20	51	6	–	4	10
OC	49 (160)	25	52	106	32	20	158
CCR	52 (170)	19	52	4	–	4	8
OC	52 (170)	15	52	77	30	12	119
CCR	69 (226)	20	92	7	–	6	13
OC	67 (220)	25	91	153	38	28	219

Lessons Learned

Two years ago, the project started with a group of experienced scuba divers with little or no technical or CCR experience. It now has a team of experienced technical divers, comfortable in the use of CCRs and routinely working at depths of ~49 m to 85 m (160 ft to 280 ft). While no major setbacks have been suffered during the process, it has been a learning experience, to say the least. NOAA multibeam bathymetry of the study area has proved to be a critical component of characterizing the environment and dive planning. GPS coordinates for optimum entry points could be extracted directly from the bathymetric data. Detailed bathymetric images also served as important visual aids during dive planning. Utilization of the bathymetric data has allowed divers to consistently access permanent benthic transect and instrument sites at depths up to ~82 m (270 ft) using only ~5 minutes of dive run time to reach the site.

Although technical CCR diving represents less overall equipment than OC scuba, on a given dive there is still a considerable amount of equipment that must be accommodated, including the CCRs, OC bailout tanks, personal dive gear, sampling equipment, camera equipment, etc. It was quickly realized that a larger dive vessel was necessary to accommodate technical diving. A larger Department of Marine Sciences vessel is currently being refurbished to serve as the primary platform for future technical diving. It is important to have knowledgeable surface support for technical dives. The surface personnel should be familiar with the entire dive operation so that they can provide routine assistance to the divers (*e.g.*, piloting the boat, assisting with water entry and exits, handling equipment, etc.) as well as being prepared to act in the case of an emergency. Surface-support personnel were not included in the original project plan, but were quickly added as the critical need was realized.

The individual studies being conducted are largely transplants of studies conducted in shallow reef settings. However, it is important to realize that a dive to 76 m (250 ft) is not the same as a dive to 15 m (50 ft). The amount of working bottom time is an issue. The diver also has many more diving-related factors to deal with (*e.g.*, closely monitoring depth, bottom time, PO_2, etc.) in addition to accomplishing scientific tasks. In many cases, the original research plan had to be scaled back to more realistic objectives attainable on deep technical dive. Similarly, on a given dive, it is important to focus on a few doable tasks. It is better to break a particular task into two successful dives than try to do too much on one dive and accomplish nothing. Technical diving of any sort obviously requires additional setup and planning time over traditional scuba. The additional complexity of CCRs adds even more time for setup, breakdown and routine maintenance. Actual time in the water is only a small part of the time that divers must commit to the project. The amount of time that divers have needed to commit to the project has turned out to be much more than expected.

The UPRM Deep CRES dive team has made tremendous progress over the last two years and achieved significant accomplishments. Still, progress on the Deep CRES project has been slower than planned. Planning does not always take into account delays resulting from equipment problems, unforeseen equipment needs, weather, other important commitments, etc. Most importantly, Deep CRES planning did not adequately take into account that technical diving is a gradual progressive process. Sufficient time is needed for divers to gain experience, comfort and confidence with new technologies, equipment and long, deep dives. The progression of the UPRM Deep CRES dive team provides an example of the time and tools necessary to establish a new scientific technical diving program.

Future Work

Work accomplished thus far has resulted in the formulation of a working model of the important controls on geomorphology and mesophotic coral ecosystems of upper insular slope environments. It is now time to test the model in other areas as well as explore new and different settings. There is an exceptional NOAA multibeam bathymetry dataset for Puerto Rico and the US Virgin Islands. It is hoped that, with additional funding, this dataset can be used to target new areas of research and exploration of the mesophotic realm.

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2008 Battle of the Atlantic Survey Methodology

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Abstract

During the summer of 2008, the *Monitor* National Marine Sanctuary partnered with several federal, state and academic institutions to record the remains of three German U-Boats lost off North Carolina during WWII. The goals of this project were to gather baseline data for future monitoring and management recommendations, as well as public outreach and education. The scope of this project was limited to a Phase II non-invasive pre-disturbance survey. Most of the traditional field methodology employed on maritime archaeological sites is designed for comparatively shallow or benign environments. The nature of this project dictated that we remain within recreational dive limits and conduct non-decompression dives, as well as respect varying environmental conditions and cultural conditions. However, the work took place in a dynamic oceanic environment in a depth range of 100-120 fsw providing limited bottom time to accomplish time consuming tasks. As a result of the limitations it was impractical to use exclusively traditional archaeological recording methods. The practices on this project employed a hybridization of methodology borrowed from traditional methods, and from deep-water survey methods in standard use at other sites in the National Marine Sanctuary System. This paper describes the diving and archaeological methods used and hopes to stimulate discussion that could lead refining these practices.

Keywords: in situ preservation, liveboating, National Marine Sanctuaries, NOAA, North Carolina, photomosaic, shipwrecks, U-boats, U-352, U-701, U-85

Research Design

During the project planning phase, the authors of this report generated a research design. The purpose of this document was to organize thoughts, propose research questions, structure methodology, provide a background history, outline personnel roles, and serve as a general guide for operations during the course of the fieldwork. The research design identified several goals and questions to be addressed during the investigation. The goals proposed included:

1) Assess the historical significance and archaeological integrity of each individual site;
2) Determine if resources were eligible for nomination to the National Register of Historic Places;
3) Identify to what degree is site preservation influenced by environmental formation processes and cultural impact;
4) Determine whether or not the sites warrant further investigation;
5) Complete a thorough exterior survey of each site and artifact inventory;
6) Produce a site map of each site for interpretation and as a representation of baseline data for use in follow-up inquiry and future monitoring at the sites; and
7) Complete detailed video and photographic surveys of the sites.

In order to answer these questions, the survey goals were designed to recover data that would identify the sites, and contribute to their nomination to the National Register of Historic Places. Only through site documentation and the recording of diagnostic features and artifacts can the nomination process be completed.

Scope and Limitations

Production of the research design was essential to provide detailed boundaries for the scope of the project. This project was designed to be a completely comprehensive investigation, and should be viewed as a preliminary baseline assessment, upon which future research can be founded. Without this baseline information it is difficult to know what questions to ask because the resource is generally undefined until this type of survey is completed. So the questions posed in this project are of a general nature with the intent to provide a more solid basis for formulated advanced questions.

The location of each site posed several limitations on efficiency. Accessing each site required anywhere between 15 and 40 miles transit offshore of North Carolina. This consumed a great deal of time getting to and from the sites, but it also meant that the sites were in locations that could only be accessed in mild weather conditions. As conditions off North Carolina vary, predicted days of inactivity were built-in and personnel spent time processing data sets during this time.

Additionally, the sites location also posed limitations underwater. High and variable currents were present, particularly at the site of the U-*701*, and visibility varied from zero to more than one hundred feet. These factors produced differing degrees of in-water efficiency from day-to-day. Furthermore, the depth of the sites, ranging from 90-115 ft deep, greatly limited the amount time that could be spent on site each day.

The sites being designated as war graves also presented some limitations that were meticulously observed. Chief among these was the inability to penetrate the site to complete an artifact inventory of the hull's contents. This limited the survey to exterior observations only. In addition, the research team did not conduct any exterior work that would impact or disturb the site in any way. This precluded sampling of ferrous materials, establishing permanent baselines or removing or manipulating anything onsite.

Fieldwork Schedule

The field component of the survey was conducted over a twenty day period from July 6 through July 26, 2008. This time was selected to take advantage of optimal conditions in diving off North Carolina. The distance between the sites necessitated two distinct legs of the project, based out of different locations.

The U-*352*, is located off of Cape Lookout and is most accessible from Beaufort Inlet. To facilitate easy access, the first portion of the project was based in the Morehead City/Beaufort, North Carolina area. From July 6 through 11 the fieldwork focused exclusively on the site of the U-*352*. Researchers were headquartered at the University of North Carolina's Institute for Marine Science. Our dive platform was the 41 foot R/V *Hildebrand* supplied by NOAA's National Center for Coastal and Ocean Science in Beaufort, North Carolina. As a result of inclement weather, only three of the planned five survey days allowed us to get on site. Fortunately, as some poor weather days were expected, the critical components of the survey were able to be completed. For the second leg of the fieldwork operations were moved to the Nags Head, North Carolina on the Northern Outer Banks. At this point the team also switched dive platforms, utilizing a 32 foot RIB, the R/V *Sam Gray* of Gray's Reef National Marine Sanctuary, and a new National Marine Sanctuaries 41 foot catamaran.

The vessels were kept at the Oregon Inlet United Sates Coast Guard Station. Operating out of Oregon Inlet provided us with the ability to access both the U-*85* and the U-*701*. As the U-*701* was located near Diamond Shoals, the weather conditions had to be ideal to access that site. Though it was farther to the site from Oregon Inlet than from Hatteras Inlet, it was decided that operating out of Oregon Inlet would provide the team with the ability to access the U-*85* easily and to access the U-*701* only when weather permitted, thus not dedicating a block of time which only afforded the ability to access the U-*701*. From July 12-26 the team focused alternately on the U-*85* and U-*701* depending on environmental variability. Using this model minimized the days we were inoperable due to weather.

Personnel and Equipment

The overall project was planned and conducted by the NOAA, Office of National Marine Sanctuaries Maritime Heritage Program, the *Monitor* National Marine Sanctuary, and East Carolina University. East Carolina University provided dive support and supplemental survey equipment.

Equipment used included traditional survey instruments such as fiberglass measuring tapes, slates, mylar sheets, clinometers, and straight edge scales. These instruments were used to recover detailed measurements of the plan and the data was later transferred to a master site plan. Photographic and videographic data was recovered using a range of instruments.

Field project personnel were divided into four teams dependent on their tasks and responsibilities during the field survey and subsequent post-field summation and report. The four teams were designated Alpha, Bravo, Charlie and Delta.

Team Alpha: Responsibilities included photo-mosaic surveys, still photography, site mapping, reports, National Register nomination, and overall project coordination. Alpha members included Tane Casserley, Nathan Richards, Joe Hoyt, Dave Alberg and Bruce Terrell.

Team Bravo: Responsibilities included on-scene site mapping and documentation, and generating site plans. Bravo members included Dave Ball and John Wagner.

Team Charlie: Responsibilities included high-definition video, still photography, development of education and outreach products, and coordination with media/web team and education personnel. Charlie team members included John McCord, Shannon Ricles, Lauren Heeseman and Jeff Johnston.

Team Delta: Responsibilities included diving medical support, diving support, stand-by diver and boat support. Delta team members included Dr. Craig Cook, Steve Sellers, Chad Meckley, Todd Recicar, Roger Mays and Chad Smith.

Site Location and Environment

All of the German U-boats included in this study lie off the coast of North Carolina's Outer Banks in an area commonly known as the Graveyard of the Atlantic (Figure 1). All three U-boats, the *U-352*, *U-701*, and *U-85* lie outside of North Carolina state waters, but within 24 nautical miles of shore in federally controlled waters and are therefore all subject to the 2004 Sunken Military Craft Act.

While position data is freely available in many formats, these are presented in degrees-decimals-minutes and are based on the WGS84 datum.
U-*352*: Located at coordinates N34°13.67'/ W76°33.89' approximately 24 miles off the coast of Morehead City, NC. The extent of the wreck scatter is confined to an area within a 100-m radius of this point.

U-*701*: Located at coordinates N35°14.330'/W75°06.690', approximately 22 miles off the coast of Buxton, NC. The extent of the wreck scatter is confined to an area within a 100-m radius of this point.

U-*85*: Located at coordinates N35°54.810/W75°17.215', approximately 14 miles off the coast of Nags Head, NC. The extent of the wreck scatter is confined to an area within a 100-m radius of this point.

Each site lies in a dynamically different environment. The waters off North Carolina, Cape Hatteras in particular, are an interface for two major oceanic currents. Coming down from the north are cold waters of the Labrador Current. From the south flows the warm waters of the Gulf Stream. The two currents carry with them different properties and support very different ecosystems. The position of the three U-boat sites is such that each lies within a distinct part of this interface (Figure 2).

The U-*85* is most influenced by the Labrador Current and is not directly impacted by the Gulf Stream. U-*352*, the most southerly of the sites investigated, is just on the edge of the Gulf Stream in an area of relatively consistent conditions. The U-*701* lies in a highly dynamic are where the Gulf Stream and the Labrador collide. This creates a high degree of variability in currents and has a noticeable effect on shifting sands, creating deep scours and deposits which shift continually. This is believed to cause periods of time when the site is buried and then uncovered.

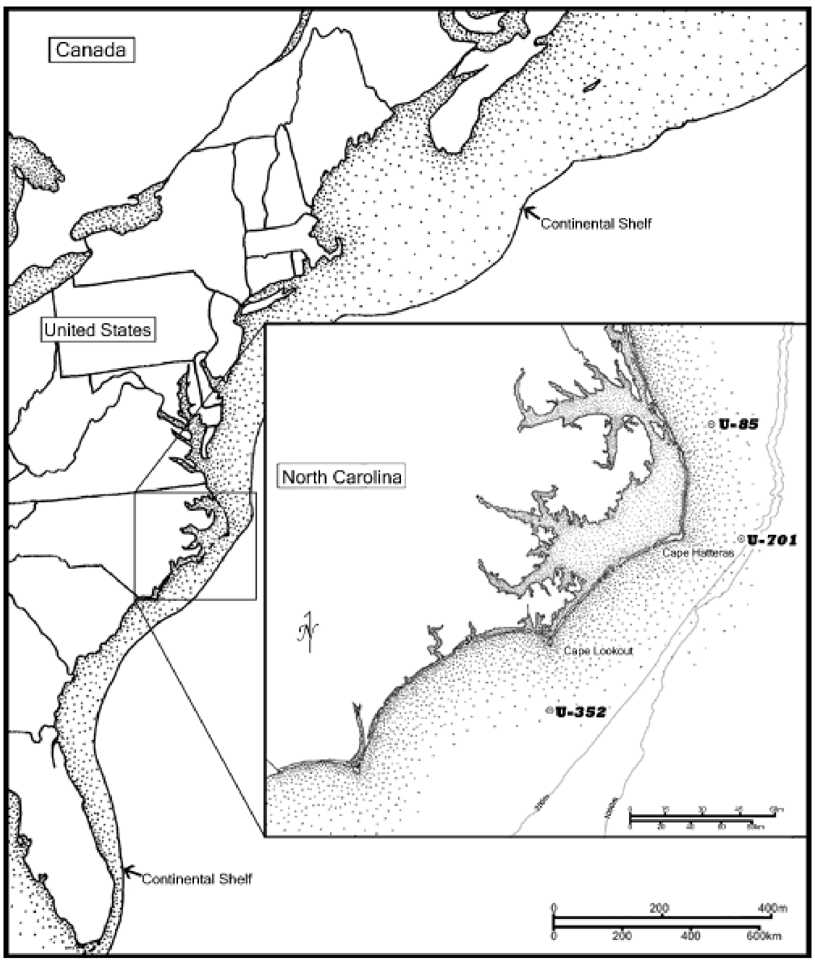

Figure 1. Depiction of the site locations in relationship to North Carolina and the continental shelf.

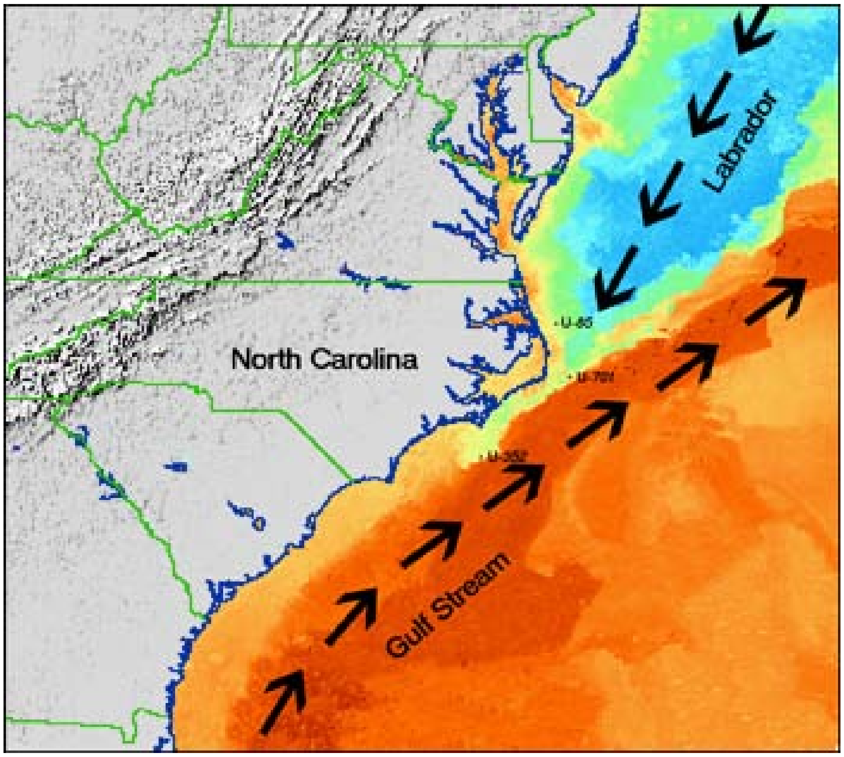

Figure 2. Image showing the convergence of oceanic currents and the location of each U-boat wreck site.

Sea life at the sites of U-*352* and U-*701* was prolific and typical of a sub-tropical marine ecosystem. The wreckage of these sites has become an artificial reef, providing habitat for a variety of organisms in an otherwise barren sandy bottom. The site is heavily encrusted with coralline algae and supports an array of sessile colonial cnidarians. On the site of the U-*352*, the density of *Hemanthias vivanus*, commonly called red barbier baitfish, was such that it often hindered photographic documentation. A similar problem with the density of amberjack (*Seriola dumerili*) was present on the U-*701*.

As this is a preliminary survey, only a general description of the sites environment is presented. Depending on future management strategies, it may be valuable to establish more concrete scientific descriptions of the environment and ecosystems present at each site. Water quality and characteristics at each site would aid in the study of corrosion potential and help researchers understand more accurately site formation processes acting on these sites. Given their location in three dynamic areas offshore, close temporal association at the time of deposition, and nearly identical construction, these sites provide a rare opportunity for better understanding environmental impacts on submerged cultural heritage in North Carolina. Additionally, a comprehensive assessment of living resources on the sites will allow the sites to be treated as holistic resources in any future management decisions.

Diving Procedure and Conditions

All diving was conducted using open-circuit scuba equipment and utilized live-boat diving procedures. All dive equipment and breathing gasses conformed to NOAA Dive Program standards. The breathing gas used was a nitrox mixture of 32% oxygen. All dives conducted stayed within recreational limits and were strictly non-decompression. The dive teams conducted no more than two dives per day. Due to the non-invasive methodology of the site survey, the research vessel did not anchor on the site. Live-boating allowed access to the site without impacting it in any way. A small buoy was deployed at each site's coordinates and was used to visually reference to the site's location on the surface, gauge the current's speed and direction, and act as a visual reference for the divers upon descent. The research vessel deployed divers as a group up current of the buoy and the divers would free-drift to the wreck site on the sea floor.

Current on the sites could be unpredictable, which complicated live boating. On occasion the research team encountered layered currents, where a surface current was going one direction, while the current on the bottom or in the middle of the water column moved in another. Upon reaching the bottom, divers were instructed to look for the site for no more than one minute. If the site could not be located in that time, a designated diver would deploy a lift bag which would be visible to the boat crew. The dive team could ascend safely on this line with the assurance that the boat was aware of their location. This procedure also allowed the redeployment of divers in the rare case of a missed descent.

After work was completed at the end of each dive, the team would begin their ascent as a group and inflate and deploy a lift bag attached to a line reel to indicate the divers' location to the research vessel and that the divers have begun their ascent. All divers left the bottom as a group and ascended as a group. When necessary, a buddy team occasionally left the bottom earlier than the planned bottom time, after communicating their intent to ascend to the rest of the dive team. In these instances, that buddy team would become their own independent dive team and inflate and deploy a lift bag to indicate their ascent and location to the research vessel, and begin their ascent.

The diving conditions were distinctly different at each site, and varied daily at each site. On the U-*352*, conditions were the most benign. Though some moderate current was occasionally present, it was negligible and did not interfere with underwater work. The maximum depth encountered was 115 fsw. Water temperature during the time we were present was ranged from 74-76ºF. Visibility was variable. On one day there was over 100 ft of horizontal visibility, while on other days it was as low as 30 ft.

On the U-*701*, diving conditions varied widely. Temperature was consistently in the 70+°F range, however current and visibility fluctuated greatly. Currents experienced on site were from a moderate flow which remained constant through the water column at approximately one-half knot, up to 3-4 knots and moving in alternate directions at different depths. The strength and direction of current could not be ascertained until the site was reached, and in some cases it was difficult to determine until divers were deployed. If the surface current was negligible there could still be a significant bottom current. The only indicator of subsurface current conditions was the use of a drop line. The general practice was to observe a shot-line to see the affect the current had. In some cases the buoy could be completely pulled under by the force of the current, in which case diving operations would be postponed. Visibility on site ranged from over 100 feet down to near zero.

Conditions at the U-*85* were very different. Being located North of Cape Hatteras, the site is influenced predominantly by the Labrador current. As such, the water is much cooler and ranged from the high 50s°F to low 60s°F. Current at this site was negligible during the duration of our project. However, visibility on this site was of much poorer quality. On average the visibility was less than 10 feet and approached near zero within a few feet off the bottom sediment. This made photographic and video documentation challenging, but did not hinder traditional survey techniques. Towards the end of the project, visibility cleared somewhat and the best visibility observed on site was approximately 40-50 ft.

Archaeological Methodology

The archaeological methodology consisted primarily of documenting the sites by generating detailed site plans, photo-mosaics, recording diagnostic hull features, intensive video and photo documentation, and documentation of ordnance and artifacts *in situ*. Due to the sites' dynamic environment and the nature of this non-invasive survey, permanent baselines were not established at the sites, though temporary tapes were carefully installed by non-invasive means. Most measurements were taken from known structural features on the U-boats' intact pressure hull, conning tower, deck gun, hatches, and exhaust systems and then compared to historic engineering plans from the U-boats' original construction. Given constraints of bottom time at depth and the duration of the project, a hybridization of methods was used to generate the site plans. A combination of video, scaled drawings, original design plans, and scale photographs were combined to generate a detailed exterior survey of each wreck site.

Divers were assigned specific sections along the hull aft and forward of the conning tower to document, which were then compiled to create an overall site plan. Simultaneous with the site mapping, a photographic/video survey was conducted to create photo-mosaics, document artifacts, ordnance, and diagnostic features of the site. The photographic/video documentation includes the outer hull structure, diagnostic structural features such as the conning tower, deck gun, hatches, and torpedo tubes, any damage or degradation to the hull structure, as well as artifacts and ordnance *in situ*. At no point during the survey was the hull structure or any feature of the wreck sites altered. The U-boat wreck sites were respected as war graves and survey team members did not penetrate the hull or disturb the sites in any way.

All survey goals were designed to recover data that will document the U-boat sites, augment their historical significance, and enhance their nomination to the National Register of Historic Places. The methodology followed on the project to accomplish these goals is outlined as follow:

In-Water Documentation

1. Document the U-boat sites by generating detailed site plans and recording diagnostic features:
   a) Identify and record diagnostic structural features such as deck machinery, hatches and torpedo tubes;
   b) Identify and record hull damage due to the sinking event;
   c) Identify and record hull damage caused to the U-boats post-sinking due to natural and/or man-made causes;
   d) Identify and record all exposed artifacts within the sites immediate vicinity;
   e) Identify, record and determine the extent of hazardous material and ordnance remaining on the site while maintaining all safety protocols.

2. Create scaled photo-mosaics of the U-boat sites by generating plan and profile photo-mosaics and supplement with hull measurements:
   a) Conduct plan view photo-mosaic survey by video documenting sites using the photo-mosaic sled as a platform coupled with digital sonar to maintain a minimum of 30 ft above the subject;
   b) Conduct profile and oblique photo-mosaics surveys by video documenting sites using the photo-mosaic sled as a platform coupled with digital sonar to hold a constant distance from the U-boats and depth gauge to hold a constant depth while moving from bow to stern;
   c) Combine photo-mosaic data with the diver generated site plans.

3. Intensive video and photo documentation of the hull and diagnostic features:
   a) Video/Photograph hull and diagnostic hull features from all angles;
   b) Video/Photograph diagnostic artifacts from all angles with scaling device.

4. Identify and document areas on the U-boats to monitor hull and structural degradation over time:
   a) Select features on the U-boat's bow, amidships, and stern that would best illustrate hull and structural degradation over time;
   b) Document the extent of the features degradation;
   c) Clearly identify the features on the site plans for future reference;
   d) Document the U-boat's list on the sea floor by calculating the degree of angle with a clinometer to determine the current pitch and roll of the hull.

5. Document artifacts, any hazardous material, and ordnance *in situ* showing their spatial relationships viz a viz the rest of the shipwreck:
   a) Video, measure and record exposed artifacts, hazardous material, and ordnance *in situ*, and their relation to the rest of the site;
   b) Identify artifacts with diagnostic features and makers' marks.

Assessment

1. Identify the U-boats and make recommendations for future management:
   a) Identify U-boat name and type;
   b) Assess if historical accounts coincide with archaeological interpretations;
   c) Assess whether additional fieldwork is needed;
   d) Nominate the site to the National Register of Historic Places;
   e) Make suggestions for public interpretation.

2. Determine if remaining artifacts are threatened and/or have historical significance:
   a) Identify artifacts of historical significance or unique type;
   b) Identify artifacts of duplicative objects;
   c) Evaluate danger to artifacts if left undisturbed.

3. Determine if there are environmental hazards or ordnance remaining at the sites and make recommendations for their possible removal or neutralization:
   a) Identify environmental hazards at the site and contact the appropriate federal government oversight agency (*i.e*. U.S. Coast Guard);
   b) Identify ordnance at the site and contact the U.S. Navy, German Consulate and NOAA General Consul;
   c) Make recommendations for the possible removal or neutralization of any environmental hazards or ordnance that balances public safety with preserving the historical significance and integrity of the site.

4. Determine the site stability and integrity of each U-boat and make recommendations for its long term preservation:
   a) Assess site damage and determine if it was caused by the sinking event or post-sinking;
   b) Evaluate post-sinking hull damage/alterations and determine causes based on environmental and cultural considerations;
   c) Evaluate long-term hull integrity and make recommendations for site preservation.

In planning for factors beyond control (*e.g.*, inclement weather, equipment breakdown, personal illness, poor visibility on the site, etc.) the task list was designed to provide flexibility and adaptability. Dive tasks could require a single dive or multiple dives, but each task related to a discrete objective. The tasks were prioritized, and some tasks could not be conducted until others had been completed.

Operating within the conditions outlined above the archaeological investigation of these sites was undertaken. These environmental parameters established the conditions that were encountered on site and had an impact on the work conducted. The diving procedure also governed the scope and practicality of each goal set forth. Ultimately the research questions and goals in tandem with these other limitations and conditions guided the project. These conditions are important to understand in order to be able to recreate these conditions if the same parameters are to be used for future projects. Having knowable conditions is essential for creating comparative products, and will aid in potential long term monitoring of the site.

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Habitat-Mediated Signal Reception by a Passive Acoustic Receiver Array as Determined by Scuba Surveys

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Abstract

The use of acoustic telemetry to monitor the movements of marine fishes is wide spread. Fixed acoustic receiver arrays, capable of recording the movements of fishes tagged with acoustic transmitters from minutes to years, have been deployed in all the world's oceans, collecting data on a wide variety of fishes and invertebrates. Increasingly, data from telemetry studies are being used to characterize the movement of individual animals relative to the boundaries of spatial management measures, such as marine protected areas. Regardless of the goals of particular studies, all acoustic arrays are constrained by the effective detection range of individual receivers. Monitoring the movements of many coastal marine fishes requires the deployment of acoustic receivers in topographically complex reef environments. In such habitats, the interaction of fish behavior and reef structure can inhibit the ability of receivers to record fish movement consistently, even in circumstances in which a fish is well within the estimated range of detection. Yet the effect of topographic relief on transmitter signal detection is rarely addressed in the published literature. In the present study, we combined presence and depth data from a coded-depth transmitter with geolocation data from a hand-held GPS unit to characterize the role of topographic relief in signal detection of an acoustic receiver array in the Florida Keys National Marine Sanctuary. The primary goal of the study was to test a methodology for identifying major acoustic shadows within an array comprised of topographically complex features which might influence the detection of tagged fishes.

Keywords: fish movements, seafloor topography, telemetry

Introduction

The use of acoustic telemetry to monitor the movements of marine fishes is wide spread (see Heupel *et al.*, 2006). Fixed acoustic receiver arrays, capable of recording the movements of fishes tagged with acoustic transmitters from minutes to years, have been deployed in all the world's oceans, collecting data on a wide variety of fishes and invertebrates. Increasingly, data from telemetry studies are being used to characterize the movement of individual animals relative to the boundaries of spatial management measures, such as marine protected areas (see Lindholm, 2005).

Acoustic receiver arrays are made up of multiple individual acoustic receivers that have been arranged in a manner designed to address specific research questions. The size and configuration of receiver arrays are as variable as the studies of which they are a part. Large arrays can span features from 100s to 1000s of km^2 in total area (Domeier, 2005), while comparatively small arrays may be sited at particular features less than 10 km^2 in total area (Topping *et al.*, 2006; Lindholm *et al.*, 2007). Multiple receivers may be deployed adjacent to one another in 'lines' or 'curtains' designed to capture the movement of salmon smolts downstream and along the coast (Welch, 2003) or they may be deployed in tighter grid formations such that the overlapping detection ranges with adjacent receivers permits some triangulation of signal detections (Simpfendorfer *et al.*, 2002; Starr *et al.*, 2002; Lindholm *et al.*, 2006a,b).

Regardless of the goals of particular studies, all acoustic arrays are constrained by the effective detection range of the individual receivers that make up the arrays. The range of individual acoustic receivers has been shown to vary significantly with local environmental conditions, including water temperature, current velocity, and ambient noise (Heupel *et al.*, 2006). Recorded detection range has been reported as low as 10 m and as high as 1000 m (M. Domeier and G. Skomal, pers. comm., 2003). In response to this potential variability, most studies include some form of receiver range testing prior to the collection of data (Heupel *et al.*, 2006). Range testing is commonly conducted using individual 'reference' transmitters that are either placed at fixed locations at established distances from a receiver, or are used in drift transects away from a receiver. The range of a given receiver is often estimated to occur where 80% of expected signal detections are recorded. Where arrays are small, it may be possible to conduct effective range testing for each receiver in the array. In larger arrays, where it is often not possible to range test each receiver, results from individual receivers may be extrapolated to other receivers throughout the array.

Monitoring the movements of many coastal marine fishes requires the deployment of acoustic receivers in topographically complex reef environments. In such habitats, the interaction of fish behavior and reef structure can inhibit the ability of receivers to record fish movement consistently, even in circumstances in which a fish is well within the estimated range of detection (Lindholm *et al.*, 2005a,b; 2006 a,b). Yet the effect of topographic relief on transmitter signal detection is rarely addressed in the published literature. In the present study, we combined presence and depth data from a coded-depth transmitter with geolocation data from a hand-held GPS unit to characterize the role of topographic relief in signal detection of an acoustic receiver array in the Florida Keys. The primary goal of the study was to test a methodology for identifying major acoustic shadows within an array comprised of topographically complex features which might influence the detection of tagged fishes.

Methods

This study was conducted within a larger project dedicated to the quantification of fish movement patterns among feeding guilds and relative to the boundaries of a no-take marine reserve located at Conch Reef in the Florida Keys National Marine Sanctuary (FKNMS; Figure 1). An array of 24 single channel (69 kHz), omni-directional VR2 acoustic receivers (VEMCO, Shad Bay, Nova Scotia) was deployed by scuba divers in November 2005 (Figure 1) as part of a mission to the *Aquarius* Undersea Laboratory (http://www.uncw.edu/aquarius). Twenty of the receivers were deployed at Conch Reef where *Aquarius* is located and four were deployed at the nearest named reefs to the north and south of the study area.

The placement of the individual receivers was based on preliminary range tests that indicated that the range of detection for the transmitter model (used in the larger study) at each receiver had a radius of approximately 300 m. This range was considered an estimate and was likely to change somewhat over the course of the study with fluctuating oceanographic conditions. At the scale of Conch Reef, a total of nine receivers were deployed within the no-take marine reserve. The reserve is actually a combination of the Sanctuary Preservation Area (SPA) designated by the FKNMS (U.S. Department of Commerce, 1996) and the contiguous Research Only Area (RO) surrounding *Aquarius*. These receivers were located such that the estimated detection range of an individual receiver overlapped approximately 40% of the area covered by adjacent receivers. An additional eleven receivers were deployed in a ring around the combined reserve, intended to capture the movement of a tagged fish should it leave the area encompassed by the inner array.

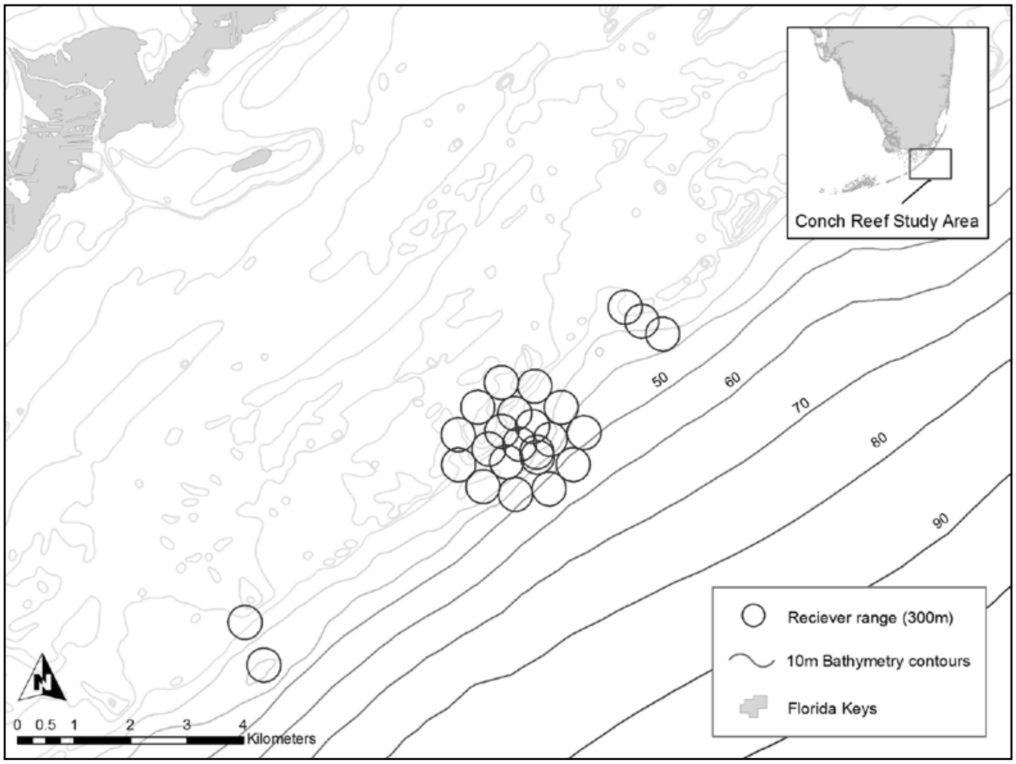

Figure 1. Map of the study area at Conch Reef, including the location of the acoustic receiver array.

Conch Reef is part of the reef tract found along the continental margin off the southeastern coast of Florida and the Florida Keys (Ginsburg and Shinn, 1994). Much of Conch Reef represents a thin veneer of Holocene accumulation on top of a Pleistocene foundation. Holocene accretions of note are represented by the named reefs you find on charts, which represent a small fraction of the total reef area. Extensive hard bottoms with low coral cover are the dominant habitat type, characterized by extensive spur and groove formations and a well-developed wall.

To characterize acoustic shadows resulting from topographic complexity within the range of individual receiver locations, we conducted 20-min scuba diver transects (Figure 2). Diver A swam along the seafloor with a compass in one hand and a wreck reel in the other (Figure 3). Diver A's geo-located position during a transect was recorded at 3 s intervals by a hand-held GPS unit (GARMIN eTrex) that was attached to the wreck reel at the surface. The GPS unit was enclosed within a waterproof PVC housing and supported by a life ring (Figure 4). The accuracy of the GPS unit is reported to be variable, between 5-12 m. Diver B was located in the water column mid-way between Diver A and the surface. Diver B ensured that the GPS unit remained directly above Diver A during each transect. Diver A's depth and position relative to the acoustic receivers was recorded by a single V13P coded acoustic pressure transmitter (VEMCO Limited, Shad Bay, Nova Scotia) which was attached to Diver A's tank valve and was supported approximately 20 cm above the diver by a small float. The V13P transmitter produced a unique ID code and water depth at 3 s intervals for the duration of a transect. Communication between divers A and B was accomplished through tugs on the reel line.

Each transect originated from a receiver and progressed away from the receiver along a pre-determined compass heading. We focused our sampling effort inside the reserve at Conch Reef, where the receiver coverage was comprehensive and the water depths accommodated sampling via scuba. As Diver A swam away from a receiver location, we expected that a detection would be recorded by that receiver within the estimated radius of detection of 300 m unless impeded by seafloor topography. When signal detections were recorded by a receiver, Diver A's depth was also reported by the transmitter. The GPS signal identified the precise location of the diver along the transect.

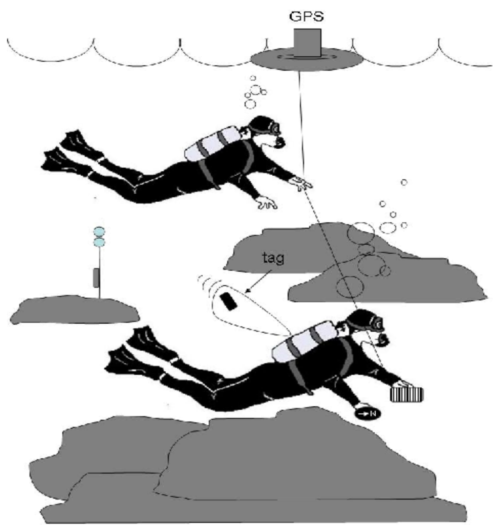

Figure 2. Diagram depicting approach to scuba diver transects.

A total of 49 transects were conducted (mean distance per transect = 300.5 m, SD = 80.5). Due to variable reception of both the GPS signal and the acoustic transmitter signal, all data for each transect were placed into 30-s time bins. Each bin was identified as either 'detection' or 'no detection' based on reception by acoustic receivers. The mean distance varied among transects primarily due to periodic encounters with the physical infrastructure located around *Aquarius* or with an adjacent receiver, diver swimming speed (*i.e.,* as influenced by current), as well as depth limitations at the deeper sites.

We plotted each transect as the accumulation of 30-s bins, noting whether a detection was recorded or not by any of the acoustic receivers in the array. We also calculated a measure of habitat-mediated receiver efficiency for each receiver. The number of detection bins per transect was divided by the total number of 30-s bins possible in a transect to correct for transects of variable length. This measure of efficiency was then averaged across all transects for a given receiver to produce a mean habitat-mediated efficiency for that receiver location.

The spatial distribution of acoustic shadows within the range of each receiver was quantified and plotted using the inverse distance weighted (IDW) function in the ArcGIS 9.2 Spatial Analyst extension (ESRI 2008). The inverse distance interpolation is a spatially-weighted average of sample values within a search area (see references in Babak and Deutsch, 2008).

Figure 3. Image of Diver A following a compass heading during a transect. A diver reel leads to the GPS unit at the surface.

Figure 4. Image of scuba diver at the surface with the GPS device supported by a surface float.

Results

A plot of all transects (Figure 5) revealed the broad patterns in signal detections throughout the array. In several instances signal detections were recorded along transects well beyond the estimated 300 m radius of detection (which was determined from traditional range testing). These extended transects were recorded at multiple receivers across the array and did not appear to be limited by water depth. In many of the deeper transects, once the detections dropped off the signal was not recorded again during that transect, suggesting that topographic features at that depth were significant impediments to acoustic signals. Whereas, in many of the transects conducted at shallow or moderate depths, detections were spotty along multiple transects, appearing or disappearing repeatedly as the diver swam away from the receiver. This suggests that many of the topographic features present in the area were lower-relief.

Habitat-mediated detection efficiency calculated at the scale of individual transects varied widely within receivers and across the array, ranging from a low of 12.5% efficiency to a high of 100% efficiency. At the scale of individual receivers (Table 1), detection efficiency varied from a low of 46.7% (CR-07) to a high of 91.7% (CR-02). The fact that these two receivers were adjacent to one another is indicative of the diverse topography on the reef. In general, the transects at the shallower receivers (CR-02, 06, and 07), where the topographic change was less severe, had the highest percentage of signal detections across transects. Whereas the transects conducted in the deeper water

(CR-04 and 08), where topographic change was more severe, had comparably fewer detections due to the presence of acoustic shadows in which detections were not recorded.

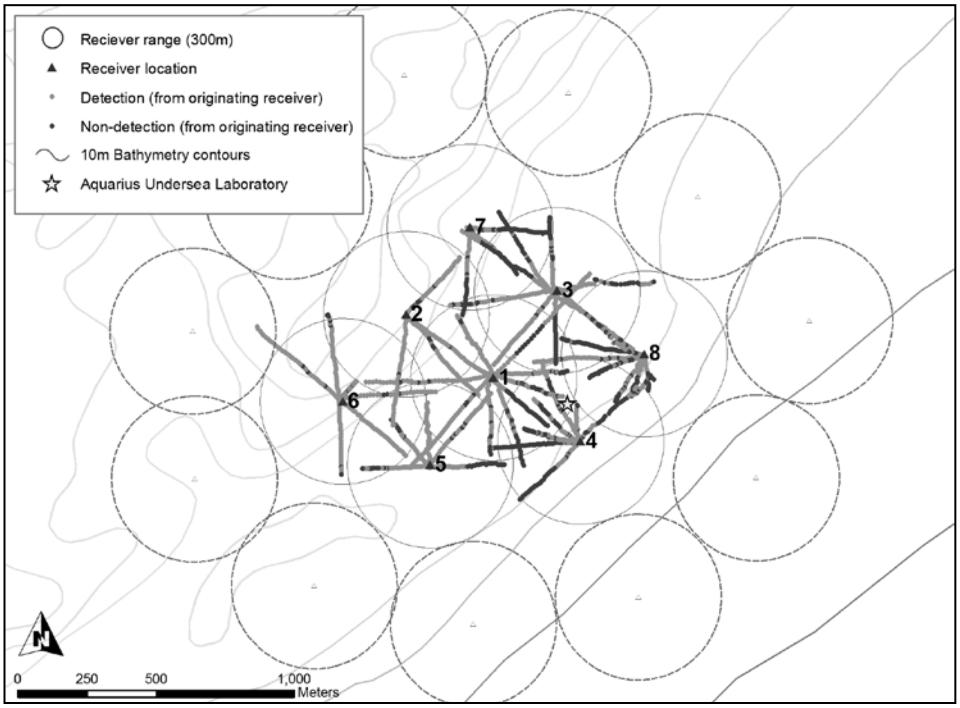

Figure 5. Map of scuba diver transects conducted in the central portion of the acoustic receiver array, including the estimate range of the acoustic receivers. Detections (light grey) and non-detections (dark grey) are reported for each transect.

Table 1. Mean detection efficiency for eight acoustic receivers deployed at Conch Reef.

Location	Receiver	Receiver Depth (m)	Mean % Detected	Standard Deviation
'Shallow'	CR-07	5.8	46.7	17.0
	CR-02	5.8	91.7	5.2
	CR-06	5.5	93.0	4.3
'Middle'	CR-03	14.3	63.4	20.1
	CR-01	14	74.4	21.3
	CR-05	11.9	78.5	19.7
'Deep'	CR-08	18	57.1	28.5
	CR-04	28	50.8	21.4

The IDW approach reported a probability of detection around each of the eight receivers in the main portion of the array. Results of the IDW analysis (Figure 6) depicted the presence of acoustic shadows at each of the receivers where the diver transects were conducted. Though other adjacent receivers are visible in each portion of Figure 6, the data on signal reception are reported here only relative to the receiver from which the divers initiated a transect. Our ability to characterize the shadows was obviously constrained to the areas in which transects were conducted (boxed areas in Figure 6). The white portions of the boxes depict interpolated areas that the receivers probably 'see,' or more appropriately hear, while the dark areas represent likely acoustic shadows. It is not surprising that the most detailed representations of the acoustic environment around the receivers come from areas where more transects were conducted in multiple directions away from the receiver (CR-01, 03 and 04).

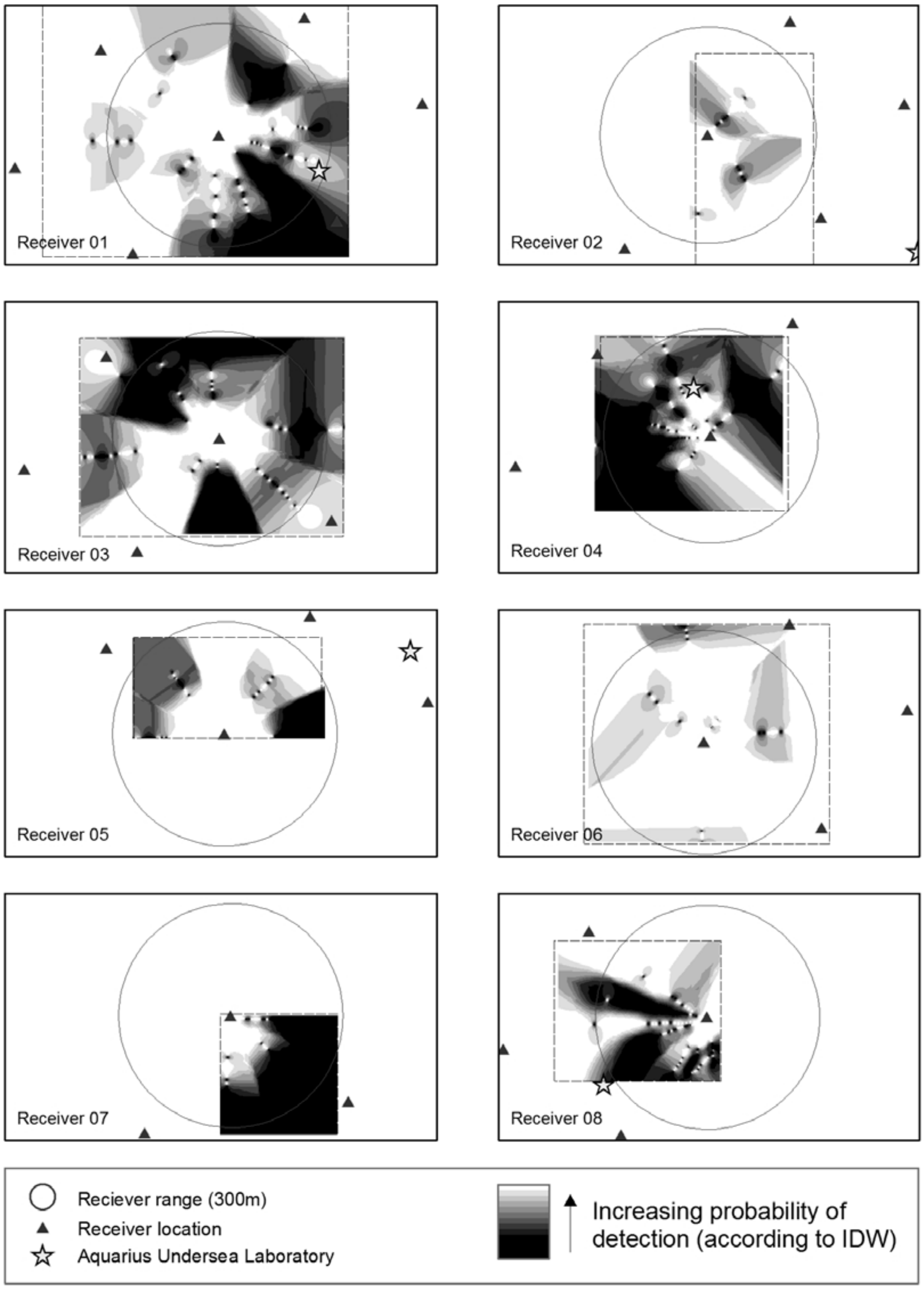

Figure 6. Results of the IDW approach to characterizing acoustic shadows. Results are depicted for each of the eight receivers in the central portion of the acoustic receiver array.

Discussion

Our results clearly indicate that signal detection by the passive acoustic receiver array deployed at Conch Reef was mediated by topographic features on the seafloor. These results have clear implications for acoustic studies of marine fishes, particularly reef fish species that dwell in habitats of high and/or variable topographic relief. For instance, at no time was the observed acoustic environment around any of our receivers shaped like a circle. However, this is how most studies (including many of our own) depict receiver coverage within an acoustic array. To our knowledge this is the first instance in which this phenomenon has been reported in the published literature.

The topography at the Conch Reef study site is diverse, including walls, pinnacles, and extensive spur and groove formations, creating a number of potential acoustic shadows. Previous studies using fixed acoustic receivers at the site (Lindholm *et al.*, 2005a; 2006a; 2006b) suggest that seafloor topography resulted in fewer detections for tagged fish than would have been expected *a priori*, given known fish behavior. This was confirmed by manual tracking of tagged fish within the array by divers (Lindholm *et al.*, 2005b), where individual tagged hogfish (*Lachnolaimus maximus*), blue parrotfish (*Scarus coeruleus*), and black grouper (*Mycteroperca bonaci*) were shown to be well-within the range of a given receiver during a period in which the fish was not recorded by that receiver. Further, analyses indicated that the vast majority of tagged fish 'departures' from a fixed receiver array lasted only 15-60 min in duration, suggesting that the departures were most likely fish moving into acoustic shadows within the array rather than leaving the array altogether (Lindholm *et al.*, 2006b). The results of the present study provide insight into how acoustic shadows can be identified within a fixed receiver array, and suggest directions for future research on this subject.

The diver-based transect approach to testing the detection range of acoustic receivers has a distinct advantage over other common approaches, that is the ability to place the acoustic transmitter in close proximity to the bottom, regardless of the topography. In this way this approach is better matched to the behavior of many of the fish species that are being studied. Where range testing is conducted from a surface vessel, a transmitter is lowered over the side into the water and towed a particular distance. This approach is robust for characterizing the effects of the water column on signal reception, but prevents accurate measurements of receiver range at-depth due to the risks of fouling the drifting transmitter on the seafloor. Another common approach is to place a reference transmitter at fixed locations relative to a receiver to track fluctuations in receiver range over time. This approach offers insight into the effect of environmental conditions on receiver range over time, but does not offer insight into the role of an organism's interaction with topography in signal reception. Whereas this transect approach, where transects are re-sampled at regular intervals over a study period, can provide both a means to understanding environmental influence on transmitter detection as well as the influence of seafloor topography.

We initiated this study to provide insight into the habitat-mediation of acoustic transmitter detection. Our approach will not be applicable to all acoustic receiver arrays, and may be too time-intensive for many studies. Diver-based transects are limited in the depth range in which they can be safely conducted, making the approach inappropriate for many deeper water receiver arrays. Transects also require a line connecting divers to the surface float which can be easily fouled by macro-algae or other obstructions in the water column. They are also time and personnel intensive, placing the approach beyond the scope and/or budget of many studies.

However, our approach to presenting the results provided here offers a variety of options. Where transects can be conducted, the very simple receiver efficiency provided in Table 1 can be easily calculated. The level of information it provides is negligible, but it is a start. We lacked detailed bathymetric coverage for much of the study area at Conch Reef, a challenge that is not unique to our study. Where transect coverage can be spread around one or more receivers the IDW approach provides an opportunity to map the acoustic environment whether detailed bathymetric maps are present or not.

Where detailed bathymetric maps are available, our evolving approach presents even greater opportunities. Our forthcoming model will provide opportunities to model the acoustic environment without placing divers in the water. Figure 7 depicts the results of a viewshed analysis conducted on a digital elevation model (DEM) for a portion of Conch Reef. It depicts the portion of the environment that the receiver would encompass based on the deployment of two receivers, each 3 m above the seafloor. The Spatial analyst extension (available for ArcGIS 9.2) has a built-in viewshed tool which creates a binary raster from a DEM based on an observation point. The viewshed analysis returns a binary raster with cell values of one where the observation point is visible and a value of zero where the line of sight between the observation location and destination cell is obscured. This approach can be used to model the acoustic environment independent of transects, or can be tested against transect data where they are available.

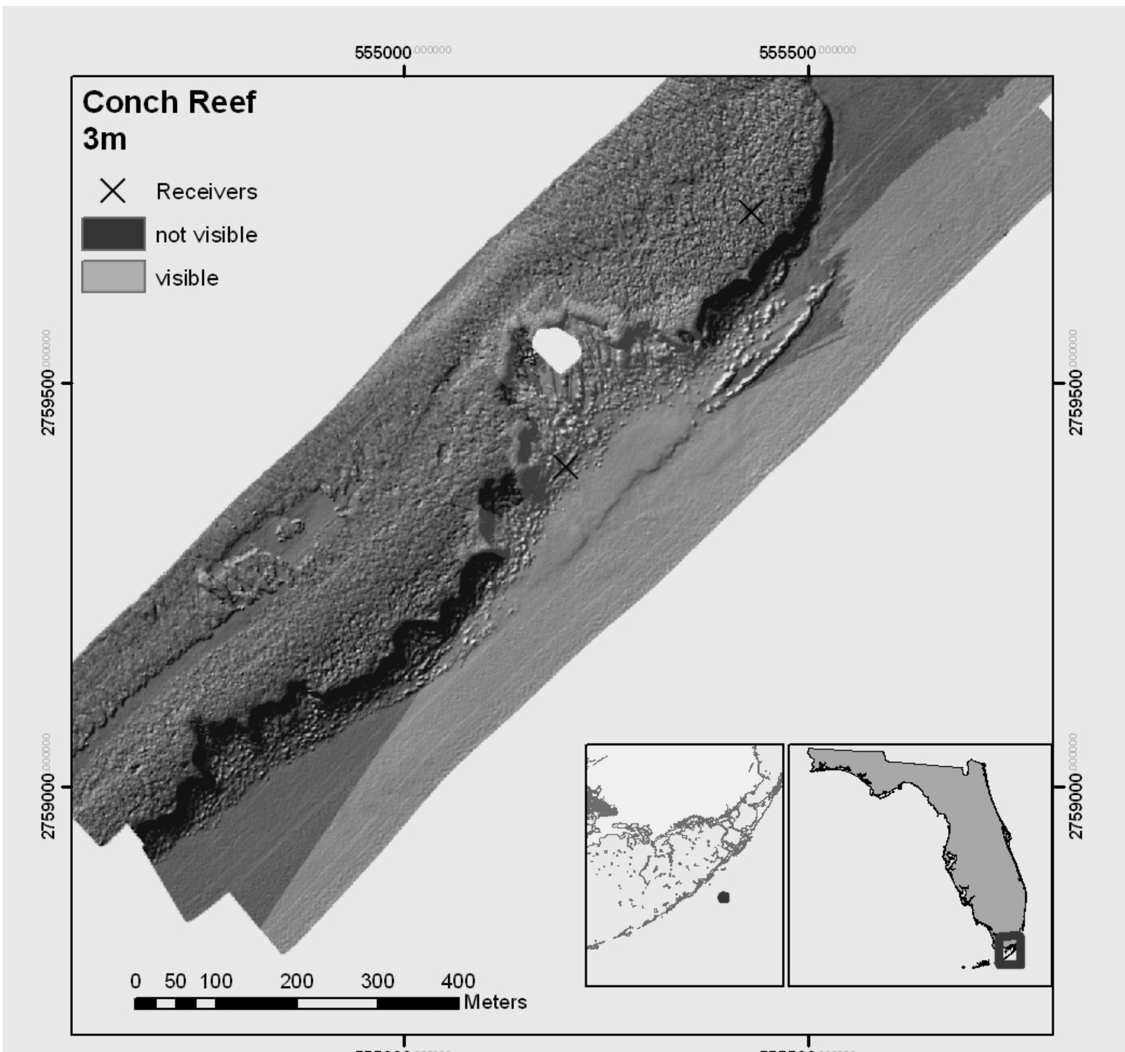

Figure 7. Results of a Viewshed analysis conducted on a digital elevation model of Conch Reef. The area that is visible from the receiver is light grey.

On-going efforts employing this diver-based transect approach will include the use of detailed bathymetry to quantify seafloor habitat rugosity within the range of a given receiver, and relate that rugosity measure to signal detection. An experimental design that is stratified by habitats of differing topographic complexity (*e.g.,* low topography vs. high topography) will allow us to predict the role of topography in mediating signal detection of receivers placed in those environments.

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Torrid Seas to Icebound Lakes: Shipwreck Investigations within NOAA's National Marine Sanctuaries

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Abstract

NOAA's National Marine Sanctuaries Maritime Heritage Program is committed to preserving historical, cultural and archaeological resources within the National Marine Sanctuaries. This paper will focus on the Maritime Heritage Program's efforts to protect, promote and explore our nation's maritime heritage through a national program embracing heritage resources in our evolving coastal, marine and Great Lakes stewardship. It will explore the diving technologies and methodologies utilized to document maritime heritage resources in the National Marine Sanctuaries unique and challenging environments from the historic whaling shipwrecks of the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands to the intact schooners of the Thunder Bay National Marine Sanctuary. The United States became a world power through its maritime commerce and naval strength. Documenting and protecting shipwreck material remains helps us rediscover that proud legacy by forming a physical connection with our past. Through the Maritime Heritage Program, NOAA's National Marine Sanctuaries confirm their commitment to preserve our rich maritime heritage not only for today, but also for future generations.

Keywords: archaeology, Maritime Heritage Program, Northwestern Hawaiian Islands, Papahānaumokuākea, shipwrecks, Thunder Bay, whalers

Introduction

Our nation's maritime heritage is a broad legacy that includes not only physical resources, such as historic shipwrecks and prehistoric archaeological sites, but also archival documents, oral histories, and traditional seafaring and ecological knowledge of indigenous cultures. NOAA's Office of National Marine Sanctuaries created the Maritime Heritage Program in 2004 to focus on these research challenges with a mission to protect, promote and explore our maritime heritage through a national program embracing heritage resources in our evolving coastal, marine and Great Lakes preservation efforts. When properly studied and interpreted, maritime heritage resources add an important dimension to understanding our nation's rich maritime legacy, and make us aware of the critical need for wise ocean stewardship.

Two projects highlight the success of the Maritime Heritage Program in accomplishing its goals of exploration and protection including the discovery and documentation of historic whalers in the Papahānaumokuākea Marine National Monument and the ongoing research and public outreach in the Thunder Bay National Marine Sanctuary.

Papahānaumokuākea Marine National Monument

Since 2003, the Maritime Heritage Program has been conducting annual research expeditions to the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands. In 2004, the British whalers *Pearl* and *Hermes* were discovered at Pearl and Hermes Atoll by NOAA divers from Coral Reef Ecosystem Division of NOAA's Pacific Island Fisheries Science Center. The Maritime Heritage Program began archaeological fieldwork at the wreck sites later that year. The *Pearl* and *Hermes,* lost in 1824, are the oldest shipwrecks yet discovered in the monument and their ongoing documentation have revealed insights into 19th century whaling and survival in one of the most remote areas of the world. In the following years several other historic shipwrecks have been discovered and documented by NOAA on the neighboring atolls including the American whaler *Parker* lost in 1842, the U.S. Navy side paddle-wheeler USS *Saginaw* lost in 1870, British iron hulled ship *Dunnottar Castle* lost in 1886, and the schooner *Churchill* lost in 1917.

On July 31, 2008, the NOAA ship *Hi'ialakai* departed from Pearl Harbor in Honolulu, Hawaii for a 30-day expedition to Papahānaumokuākea Marine National Monument. The multidisciplinary expedition set sail with approximately 20 scientists from various fields including a team of maritime archaeologists from the National Marine Sanctuaries, shark researchers, coral genetics researchers, Native Hawaiian cultural practitioners and a wilderness documentary filmmaker with stops planned at French Frigate Shoals, Pearl and Hermes Atoll, Midway Atoll, and Kure Atoll. The archaeologists' main objectives were to interpret the known archaeological sites through underwater mapping, video and photography, and in combination with historic research, search for new sites in high probability areas.

Building upon proven search techniques the team discovered the shipwreck remains of one of the earliest whalers lost in the Northwestern Hawaiian Islands, the British whaling ship *Gledstanes* sunk off Kure Atoll in 1837. Historic records made several references to the loss of the *Gledstanes*, but its exact location had remained a mystery for over 170 years until August 13, 2008, when the archaeologists discovered a pile of iron ballast and some chain on the ocean bottom. The ballast led to a trail into the dramatic topography of the reef where more artifacts were found scattered, including four massive anchors, iron ballast, a cannon and cannon balls, and a trypot.

Historic research tell us that after the loss of *Gledstanes* due to extremely rough seas, the crew launched the ship's small boats and made for the closest dry land — the small sandy island at Kure Atoll named Ocean Island. In a short time, the *Gledstanes* broke apart in the heavy surf. The crew salvaged what they could from their destroyed ship and set about fashioning a 38-foot vessel called the *Deliverance,* and then set out for help. Today the wreck site is located in an extremely dynamic environment where waves and strong currents have weathered the exposed artifacts. What remains are the heaviest iron pieces embedded into the coral reef and substrate, now a permanent part of this vibrant eco-system.

The *Gledstanes* is the fourth whaling ship, and one of the oldest ships, discovered thus far in the Papahānaumokuākea Marine National Monument, shedding further light on the major significance of 19th-century whaling heritage in this region.

Thunder Bay National Marine Sanctuary

For over 12,000 years, people have traveled on the Great Lakes. From Native American dugout canoes to wooden sailing craft and steel freighters, thousands of ships have made millions of voyages across the Great Lakes. The last 150 years have been particularly explosive, transforming the region into one of the world's busiest waterways. Yet, with extraordinary growth comes adversity. Over 200 pioneer steamboats, majestic schooners, and huge steel freighters wrecked in Lake Huron near the Thunder Bay National Marine Sanctuary alone. Today, just offshore of Alpena, Michigan, the sanctuary's shipwrecks capture dramatic moments from centuries that transformed America. As a collection, they illuminate an era of enormous growth and remind us of risks taken and tragedies endured.

Lake Huron's cold, fresh water ensures that Thunder Bay's shipwrecks are among the best preserved in the world. Many sites remain virtually unchanged for over 150 years. With masts still standing, deck hardware in place and the crews' personal possessions often surviving, sites located in deeper waters are true time capsules. Other shipwrecks lay well-preserved but broken up in shallower waters. Readily accessible by kayakers, snorkelers, and divers of all abilities, these sites often provide sanctuary users with their first shipwreck experience.

Thunder Bay's shipwrecks are magnificent, yet vulnerable. Natural processes and human impacts threaten the long-term sustainability of our underwater maritime heritage. Through research, education, and community involvement, the sanctuary works to protect our nation's historic shipwrecks for future generations. Protecting Thunder Bay's underwater treasures is a responsibility shared by the sanctuary, its many partners, and the public.

Thunder Bay National Marine Sanctuary protects a nationally significant collection of shipwrecks and related maritime heritage resources. By fostering an understanding that our past connections to the Great Lakes and oceans are critical to our future, the sanctuary works to ensure that future generations will continue to experience and value Thunder Bay's irreplaceable underwater treasures.

The Thunder Bay National Marine Sanctuary regulations protect these maritime heritage resources. To enforce these regulations, the sanctuary partners with local, state, and federal authorities. It also relies on observations from recreational divers and other members of the community. The sanctuary strongly encourages recreational divers, snorkelers, and kayakers to responsibly visit sanctuary shipwrecks. To facilitate recreational access, the sanctuary invests in mooring buoys designed to improve safety and access to resources, while reducing visitor impacts.

Ice, waves, and aquatic invasive species such as zebra and quagga mussels all have the potential for harming maritime heritage resources. The sanctuary is working with university and NOAA scientists to develop long-term monitoring programs to better understand how the chemical, biological, and physical conditions found around Thunder Bay's shipwrecks are affecting the corrosion and deterioration of these irreplaceable archaeological sites.

The sanctuary's education and outreach programs help people of all ages and backgrounds enrich their lives while learning about, physically experiencing, and working to preserve the Great Lakes and their maritime heritage. Because people preserve what they value, and value what they understand, Thunder Bay National Marine Sanctuary embraces education as the most powerful resource preservation tool. Sanctuary education comes in many forms, from programs for teachers and students to imaginative exhibits, to community boat-building, and remotely operated vehicle competitions. Although preservation is the central message, the sanctuary promotes learning across the curriculum.

Developing knowledge of the sanctuary's maritime heritage resources through research is a primary function of Thunder Bay National Marine Sanctuary. These resources include shipwrecks, docks, cribs and piers, prehistoric and historic Native American sites, and many other cultural remnants of the past. Thunder Bay National Marine Sanctuary staff conducts, supports, promotes, and coordinates all research with an aim toward sanctuary characterization. Characterization is the process through which sanctuary resources are inventoried, located, documented, and ultimately analyzed within a broader historical and archaeological context. Knowledge acquired through research is used to evaluate existing management practices, enhance future management decisions, and educate the public about the importance of the Great Lakes and their history.

Characterization of the sanctuary begins with a historical inventory of potential maritime heritage resources located in and around the sanctuary. Derived from historical and archival research of contemporary newspapers, lifesaving station and ship logs, vessel enrollments, insurance and court records, and other published and unpublished literature, Thunder Bay National Marine Sanctuary's maritime heritage site inventory is an ongoing project where new data is continually being added to the sanctuary's files and databases. Physically locating maritime heritage sites is the next step in sanctuary characterization, and to date, much of the sanctuary's research efforts have focused on locating shipwrecks and related maritime heritage resources. Several remote sensing surveys have been undertaken within the sanctuary and surrounding waters with assistance from various parts of NOAA and other partners. These surveys have included side-scan sonar, Light Detection and Ranging (LIDAR), and high-resolution aerial photogrammetry surveys.

Documentation is perhaps the most intense and important aspect of Thunder Bay's characterization efforts. Archaeological documentation provides baseline data to evaluate the current state of preservation, and can identify threats to sites, such as zebra mussels, ice and anchor damage, looting, and other intentional and unintentional human impacts.

Through documentation, archaeologists reveal the stories of the past that are preserved in Thunder Bay's nationally-significant collection of shipwrecks, and help sanctuary staff create products that allow recreational users - kayakers, snorkelers, and divers – to connect with the Great Lakes and their history. Equally important, the results from sanctuary documentation are used in exhibits, educational materials, and outreach products to allow non-divers to also explore these historic sites.

The majority of shipwreck documentation is done by divers manually mapping maritime heritage sites using tape measures, drawing slates, still photographs and videography. This method is particularly effective for shore-side and relatively shallow-water sites (0-100 feet deep). Using this method, shallow-water wrecks such at the *New Orleans*, *Shamrock*, *Maid of the Mist, Monohansett*, and dozens of other shipwreck sites near North Point, Isaacson Bay, and Black River have been documented by the sanctuary and its partners.

Diving is also an important way archaeologists access shipwrecks beyond the recreational diving depth limit of 130 ft (40 m). Using specialized diving equipment, sanctuary researchers have documented several "deep-water" shipwreck sites including an unidentified two mast schooner located in 2001, the 198-ft (60-m) wooden passenger steamer *Pewabic*, and the canal schooners *Cornelia B. Windiate, E.B. Allen,* and *Kyle Spangler*. Located in water depths ranging from 100 to 200 ft (30-60 m), these sites have been documented using a combination of techniques including photo-mosaics, archaeological site plans, artistic renderings, and video and still imagery. The sanctuary also uses remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV) to access deeper archaeological sites. The data is essential for evaluating and managing shipwreck sites that are becoming increasingly popular with divers.

All phases of characterization are greatly enhanced through access to historical records. The sanctuary manages the Thunder Bay Sanctuary Research Collection, one of the nation's largest archives of 19th-century Great Lakes maritime history documents. The collection is housed and jointly managed by the Alpena County George N. Fletcher Public Library. Established in 2003 after a major donation of archival material from C. Patrick Labadie, the collection has continued to grow through many other donations. Data produced from all phases of characterization and related research is being incorporated into the sanctuary's resource database and Geographic Information System (GIS). This allows researchers to better relate historical information with the actual disposition of shipwrecks and other maritime heritage sites. Satellite imagery, historic and modern charts, and other scientific data are also incorporated into the GIS program to enable better management, interpretation, and public understanding of the sanctuary's maritime landscape.

The sanctuary also works to enhance NOAA and other partners' abilities to observe, protect, and manage the Great Lakes. By working with various partners on interdisciplinary Great Lakes research, the sanctuary is working toward a better understanding of the physical, chemical, and biological processes that affect sanctuary resources, while contributing to efforts to better understand the Great Lakes, one of our nation's most precious natural resources. Finally, the sanctuary recognizes that global climate change has far reaching effects on the oceans and Great Lakes. Understanding and confronting climate change are increasingly important aspects of marine conservation. To that end, Thunder Bay National Marine Sanctuary is in the process of becoming one of the Office of National Marine Sanctuaries' Sentinel Sites. Sentinel sites are locations in the marine environment that support sustained observations of changes in the status of the marine environment. They allow investigators to track the status of key indicators of ecosystem integrity, serve as a means to provide early warning to resource managers, and offer opportunities for technology and protocol testing. They address NOAA activities in areas of mandated responsibility and help address questions about regional issues such as habitat degradation and invasive species impacts.

These ongoing preservation, education and research efforts would not have been possible without the sanctuary relying heavily on the work of its partners to carry out its mission. Partners in the form of private businesses, nongovernmental organizations, educational and cultural institutions, and local, state and federal agencies provide expertise for scientific research and exploration, resources and capacities for site monitoring and enforcement, and support for educational and outreach programs. Thunder Bay National Marine Sanctuary's many partnerships have been, and will continue to be, critical to the success of the sanctuary.

Conclusion

NOAA's thirteen national marine sanctuaries and one marine national monument contain a diverse collection of archaeological sites. The Maritime Heritage Program has become the nation's leader in the exploration, documentation, and stewardship of these resources. Since the first national marine sanctuary was created in 1975 with the newly discovered shipwreck of the Civil War ironclad USS *Monitor*, NOAA has taken a leadership role in the protection of these fragile sites. In addition to the *Monitor*, countless other archaeological sites have been discovered within the national marine sanctuaries. NOAA's dedication to being the principle federal agency in maritime archaeology was illustrated in 2000 with the establishment of the Thunder Bay National Marine Sanctuary in Alpena, Michigan, which maintains stewardship over one of the nation's most historically significant collections of shipwrecks. That same dedication continues today in the Papahānaumokuākea Marine National Monument. This monument is best known for its pristine natural resources, but it also contains the shipwrecks of early exploration vessels and whalers, which were a vital part of the United States and the world's economy in the seventeenth and eighteenth centuries.

The United States became a world power through its maritime commerce and naval strength. Using maritime archaeology to document these material remains helps us rediscover that proud legacy by bringing a physical connection to our past. Through the Maritime Heritage Program, NOAA's National Marine Sanctuaries confirm its commitment to preserve our rich maritime heritage not only for today, but also for future generations.

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Flower Garden Banks National Marine Sanctuary and Texas A&M University at Galveston: Building a Research and Learning Partnership

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Abstract

The Flower Garden Banks National Marine Sanctuary (Sanctuary), located off the coast of Texas, is one of the most pristine off-shore coral reefs in the United States. Visited by divers, fishermen, and commercial vessels every day, the relatively unimpacted areas of the Sanctuary offer unique challenges in management and conservation, as well as unique academic opportunities to study and explore the resources in and around the Sanctuary. To take advantage of this, the Sanctuary and Texas A&M University at Galveston are working to establish a formal relationship to bring the academic and diving capabilities of the university to the Sanctuary, while at the same time providing students and professors of the university with new opportunities to direct their studies and field work towards topics that directly promote the Sanctuary's mission of conservation, sustainable use, and resource protection. While the Sanctuary and university have a long and prosperous track record, a formalized relationship can root this partnership in established science for conservation purposes and serve as a working model for other AAUS organizational members and national marine sanctuaries. This paper explores the merit, opportunities, strengths and hurdles of this partnership, and highlights the success and challenges in bringing this to partnership to life.

Keywords: AAUS, National Marine Sanctuary Act, NOAA, reciprocity

Background

The reciprocity agreement in place with the National Oceanic and Atmospheric Administration (NOAA) and the American Academy of Underwater Sciences (AAUS) lays the foundation for scientific diving collaborations between AAUS organizational members (OM) and various NOAA entities. One division within NOAA where such collaborations are especially applicable is the Office of National Marine Sanctuaries (ONMS). Established as a provision of the National Marine Sanctuaries Act of 1972, the ONMS is charged with providing conservation and protection services for sustainable use of the unique ecological and cultural resources associated with the fourteen protected areas currently in the National Marine Sanctuary System.

As a result of the need for scientifically valid data upon which to base sound management decisions, National Marine Sanctuaries are typically active research sites, and regional universities are often involved with ongoing research associated with their local sanctuaries; research activities within a sanctuary are usually overseen by the sanctuary Research Coordinator. One such example of this type of involvement is the developing relationship between the Flower Garden Banks National Marine Sanctuary and Texas A&M University at Galveston.

Flower Garden Banks National Marine Sanctuary

Designated in 1992 and headquartered in Galveston, Texas, the Flower Garden Banks National Marine Sanctuary (FGBNMS) is located approximately 100 miles off the Texas/Louisiana coast in the Gulf of Mexico, and is home to the northernmost coral reefs in the continental United States, as well as populations of recreationally and commercially targeted reef and pelagic fishes. Mandated to monitor, conserve and protect these resources for sustainable use, the FGBNMS both conducts and facilitates research needed to help answer questions regarding the ecological condition of the Sanctuary and its resources. With a small NOAA Working/Scientific Diving Unit (six divers), the FGBNMS relies heavily on reciprocity and volunteer divers, currently using approximately 50 divers and logging approximately 1,000 dives per year. The lack of a dedicated research vessel has somewhat limited the Sanctuary's research opportunities in the past, a situation which was remedied with the arrival of the R/V *Manta* in 2008, a vessel purpose-built for research and scuba (including nitrox) operations in the Gulf of Mexico. The presence of the *Manta*, and the potential for boundary expansion to include nine additional sites within the FGBNMS (recommended through the Sanctuary's current management plan review process), has dramatically increased the Sanctuary's need for consistent access to a larger pool of trained individuals with scientific diving reciprocity, a need that can potentially be met through the resources available at Texas A&M University at Galveston.

Texas A&M University at Galveston

Texas A&M University at Galveston (TAMUG), a branch campus of Texas A&M University specializing in marine and maritime sciences, has a well-established scientific diving program. TAMUG is an OM of AAUS; faculty and staff have been conducting research underwater at TAMUG since the late 1970s, and TAMUG has had a formal scientific diver training program in place since the late 1980s. In addition, the current TAMUG diving safety officer (DSO) has extensive scientific diving experience in the Gulf of Mexico, and was previously on the research staff at the FGBNMS.

Scientific diving courses are available at the graduate and undergraduate level as a formal part of the Marine Biology curriculum, and TAMUG also offers a full range of recreational diving courses including leadership-level training (Divemaster, Instructor). This combination of course offerings produces not only scientific divers, but also smaller numbers of scientific divers with the basic qualifications and training needed to support the supervision of diving operations. TAMUG is currently experiencing growth across all of its diving programs. In addition to working with NOAA, TAMUG also has ongoing research collaborations with the Texas Parks and Wildlife Department and other Texas universities.

A Partnership Evolves

The needs of these two institutions, the FGBNMS and TAMUG, create a situation that lends itself to a mutually beneficial collaboration. With the acquisition of their research vessel, the Sanctuary has enhanced their monitoring and research capabilities, now needing more qualified divers more often to reach scientific objectives, with a more frequent and wider variety of field activities. TAMUG has a need to supplement the education of its students with real-world opportunities, providing them with practical experience that will improve their competitiveness upon graduation, and TAMUG also seeks to provide ongoing opportunities for its research faculty. In an effort to work together to meet these respective needs TAMUG initially provided small numbers of trained divers qualified to conduct the specific work needed by the Sanctuary over several field expeditions. The success of this initial collaboration prompted TAMUG to begin development of programs to train more divers to meet specific Sanctuary needs underwater (benthic/fish monitoring protocols, field identification and taxonomy, photo/video skills, etc.). The two institutions also initiated the creation of an agreement formalizing their collaboration, including a monetary commitment from the Sanctuary to help support the TAMUG Dive Program, with funds to be used for the development of training programs and for supplemental equipment needs.

Initial Successes

Collaborative diving projects began in the spring of 2007, and by the end of 2007, 56 dives by TAMUG divers had been made supporting various FGBNMS activities. During calendar year 2008 opportunities and scope of work expanded, and a total of 114 TAMUG/FGBNMS dives were made; the majority of the TAMUG AAUS divers were undergraduate students. All dives were made on nitrox in depths between 70-100 fsw, and to date, all TAMUG/FGBNMS dives have been incident-free.

Tasks accomplished underwater mainly involved activities associated with monitoring and assessment projects: locating and mapping long-term photographic stations, laying/retrieving transect lines, assisting with random video and photo quadrats, transect-based invertebrate surveys and roving diver fish surveys. Other tasks included post-hurricane Ike damage assessments, and retrieval and deployment of remote water quality instrumentation, acoustic telemetry receivers and remote cameras. TAMUG divers also provide deck support (dive roster, tank fills, line setting/handling) and data entry support.

Mutual Benefits

As this collaboration develops the FGBNMS will be gaining access to a large pool of AAUS-compliant, mission-trained divers available on a consistent basis (who have been prepared and vetted by a DSO with project and site familiarity) helping the Sanctuary better meet its current research needs. As the collaboration matures, the FGBNMS will be able to expand its research and monitoring work, taking advantage of increased diver numbers and capabilities.

TAMUG divers now have opportunities to participate in ongoing, long-term research and monitoring projects on a state of the art research vessel, ultimately gaining marketable experience. The partnership with the Sanctuary, including more regular access to the environment, also creates new opportunities for directed research by TAMUG faculty and students. The funding arising from the collaboration will allow for the development of new classes and educational opportunities for graduate and undergraduate students.

Recommendations

Several points bear mentioning for AAUS OMs considering a general scientific diving collaboration within the National Marine Sanctuary System.

Early and thorough communication between the sanctuary Research Coordinator and the institutional DSO are needed to identify specific skill needs and training requirements, and to avoid any misconceptions or assumptions regarding resources and abilities. The institutional DSO should have or acquire on-site experience, as this will allow for a more complete and accurate assessment of the training and experience needed for the divers to safely conduct the work required. A formal arrangement such as a memorandum of understanding/agreement will ensure that necessary resources in training and staff time are provided to the institution (and DSO), and that the sanctuary is given a reliable base on which to plan activities and projects. Initial scope of work should be limited, realizing that if the collaborating AAUS OM is a university, the majority of divers provided will be students. While trained and capable, student divers may lack the benefit of practical experience gained through time spent in a professional career. A small-scale start will give the research coordinator and DSO a better perspective and help them to formulate realistic expectations.

Summary

There are many successful examples of scientists and students from AAUS OMs conducting research in the country's various National Marine Sanctuaries. While specific, focused research will continue to be an important source of collaboration, there are many mutual benefits to be derived from a more general partnership between a National Marine Sanctuary and a local AAUS OM, especially universities with scientific diving programs. University benefits may include new educational and hands-on opportunities for students, new research opportunities for faculty, and potential sources of funding for new programs and equipment. The involved Sanctuary gains additional trained "staff" helping them to better meet their resource management mandates, and the potential for expanded research activities.

Entering into a broad-scale scientific diving partnership such as the one described here presents challenges to both organizations; these may be generally applicable to similar collaborations. Considerations include thorough early communication between the sanctuary research coordinator and institutional DSO, a DSO familiar and experienced with the site(s), small-scale projects - at least initially, and the framing of a formal agreement clearly defining what is to be expected and provided by both parties.

While the collaborations between individual National Marine Sanctuaries and AAUS OMs will present a unique set of circumstances, it is hoped that the generalities described here, with the successful partnership between the Flower Garden Banks National Marine Sanctuary and the scientific diving program at Texas A&M University at Galveston as a model, will prove beneficial and encourage future collaborations between the Office of National Marine Sanctuaries and the AAUS.

Acknowledgments

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Exceptional Areas, Significant Challenges, a Perfect Opportunity: The National Marine Sanctuary University Partnership Program

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Abstract

The Office of National Marine Sanctuaries is developing a new program to coordinate and foster collaboration between the US National Marine Sanctuaries and Universities around the country. The goal of this partnership is to build and sustain a community of university faculty and students with an interest in working with sanctuary staff to improve stewardship of the resources and values of the national marine sanctuaries. The partnership provides opportunities for collaboration on a wide variety of disciplines, from the arts and film to ecological research and management. Recent successful collaborations include a Keystone Project at the University of Washington on Identifying compatible uses in the Olympic Coast National Marine Sanctuary, and a Distributed Graduate Seminar, funded by the National Center for Ecological Assessment and Synthesis in Santa Barbara, CA, held in Fall 2008 at eight universities around the US.

Keywords: national marine sanctuaries, marine protected areas, partnerships, universities

Exceptional Areas, Significant Challenges

The Nation's Marine Sanctuaries are America's ocean treasures, areas of special national significance managed by NOAA for the benefit of this and future generations. The National Marine Sanctuary System includes some of the most outstanding areas of ocean and coastal waters of the United States, complex and diverse ecosystems and maritime heritage seascapes that demand rigorous and cutting-edge science to support sound management decisions. The highest caliber of research is required to address the many questions that must be answered to effectively preserve and protect these critically important areas of the ocean. The Office of National Marine Sanctuaries believes that a stronger partnership with universities can help to address this requirement, and make an investment in training the next generation of researchers and ocean stewards to preserve sanctuary resources for the benefit of this and future generations. As centers for creativity and innovation, universities offer the right kind of support for enhancing stewardship for these areas of special national significance, and offer students and faculty opportunities for practical application of what they are learning and contributing to their various disciplines.

University Partnership Goal: *Create and sustain a community that cultivates opportunities for collaboration among university faculty, students, and National Marine Sanctuary System in research, education, outreach, arts, culture, and professional development.*

The National Marine Sanctuary University Partnership

The National Marine Sanctuary System is building a voluntary partnership with willing universities, particularly minority-serving institutions, to provide their advanced undergraduate and graduate students with the opportunity to focus their study and research on issues relevant to the effective stewardship of the National marine sanctuaries. Participation will offer University Partnership students practical experience, opportunities for enhancing their potential value in the job market, the satisfaction of engaging in research that has direct management application, and and the ability to be part of an international community of researchers with common interests and similar professional focus. Biennial national conferences will foster community interaction, recognize the results of Partnership-sponsored research, and highlight how the National Marine Sanctuary System is applying this research, on the ground, to improve management effectiveness. A virtual network (building on the "Facebook" website popular on University campuses worldwide) is planned to foster community interaction among the Partnership participants. This web-based information exchange will: 1) offer a forum for linking students who are involved with research in different sanctuaries, to share ideas and encourage collaboration; 2) provide information on scholarship and fellowships to support Partnership research and related projects; 3) announce opportunities to work on other short-term commitment projects in sanctuaries like participating as part of the science team for research cruises on NOAA ships; and 4) establish a virtual bulletin board where announcements or information of interest to the community can be posted. While scientific research and natural resources policy are the initial focus, universities offer considerably more opportunities for mutually beneficial collaboration. It is hoped that eventually the partnership will be expanded in to environmental education, maritime history and archaeology, media, marketing and public relations, and even to the fine and performing arts. All these disciplines are part of the effective management of national marine sanctuaries, and such collaborations can contribute significantly to improving sanctuary stewardship.

Place-Based Collaborative Research

Initially, projects will be encouraged that address a suite of highest priority research questions developed from input provided by Sanctuary researchers, educators, maritime historians and archaeologists, policy analysts, communications specialists, social scientists, and planners. Over time, it is anticipated that Partnership community will play a larger role in collaborating with NMS staff to identify priority topics and projects, and to help us identify emerging questions and issues that require essential research to support effective management. Participation in the University Partnership is entirely voluntary and will be guided a collaborative body of university faculty and NMS staff who will help effectively match students to research of relevance, ONMS partners/mentors, and possible funding. The Partnership will also offer opportunities to develop exchanges among professional staff and participating universities. University researchers might be afforded opportunities to spend sabbaticals at Sanctuaries and sanctuary staff might seek temporary or adjunct teaching and research appointments, which will help to strengthen connection between the university and Sanctuary communities. Collaboration can also provide an opportunity to develop joint research proposals that leverage sanctuary contributions such as research vessel time with funding for university support.

Implementing the University Partnership

It will take time to develop and implement the various organizational elements, develop the priority topics, and seek some minimal funding for start-up activities. It is important to recognize that this is a true partnership program, and not simply a funding mechanism for supporting student and faculty research. While small amounts of funding may be found to enhance work being done as part of the Partnership, and some in-kind services may be available such as vessel time and lodging, it is expected that universities will bring both students and funding to help support their work. NOAA will also offer information and support for students seeking funding for internships and fellowships from relevant NOAA programs, such as Nancy Foster (graduate) and Ernest Hollings (undergraduate) Scholarships.

During the first year, ONMS and university partners will: 1) continue to distribute materials describing the Partnership to universities and colleges throughout the US; 2) develop a suite of illustrative priority research requirements that link to management applications; 3) identify existing fellowship and grant programs that are relevant to objectives; 4) identify funds inside NOAA, and Partnership members will help identify funds outside of NOAA to support start-up activities, and in the longer-term, future operations; 6) develop three to four pilot projects with willing universities, distributed geographically and targeted to a range of research topic areas (ecological research, maritime heritage research, marine policy research and analysis, education research, and communications-related research and projects).

Recent Successful Collaborations

Two projects have been successfully completed that help to demonstrate the concept behind the University Partnership, and the kind of projects envisioned when the Partnership was created.

Students from the University of Washington have recently completed a project developed and conducted in partnership between the Olympic Coast NMS, NOAA, and the University of Washington Environmental Management Certificate Program. The project used the Olympic Coast National Marine Sanctuary management plan as a framework for comparing the compatibility of commercial activities with the priorities of the sanctuary. According to the Executive Summary of that report (Personal Communication, Claudia Capitini, 17 March, 2007), "In this report a team of interdisciplinary graduate and professional students apply an innovative approach to further explain the benefits and impacts of potential and current commercial activities in the Olympic Coast National Marine Sanctuary (OCNMS). The purpose of this analysis is to provide a tool to assist the OCNMS management plan. Understanding that a compatibility analysis of commercial activities is complicated and contains various levels of uncertainty, the analysis applies a framework that allows for a concise comparison of commercial activities to both national and OCNMS objectives. The report provides an introduction to the National Marine Sanctuaries (NMS), and a review of the sanctuaries primary purpose, permitting process, and currently regulated activities. A stakeholder analysis was conducted to identify the following stakeholders that are important in making compatibility decisions in the OCNMS including: the Olympic Coast Tribes, federal agencies, state agencies and the general public. The report also reviews the activity analysis methodology that was used to determine the level of compatibility of each activity. At the outset, the team developed a list of compatible commercial activities with the assistance of staff and the use of internal documents and existing management plans from other Sanctuaries to develop a context for this analysis. After identifying commercial activities for analysis, the team developed criteria to measure the compatibility of each activity with OCNMS goals. The national level criteria were based on the National Marine Sanctuary Organic Act, and Section 301(b) of the Act that identifies the purposes and policies of the ONMS. The local level criteria were based on the OCNMS designation document and the existing management plan. To measure the level of compatibility of an activity with the criteria outlined, a scale was developed to evaluate how well each activity aligned with an individual criterion. Each activity was evaluated and ratings were determined based on that activity's alignment with the goal. Finally, individual members of the team prepared an Activity Report for each commercial activity that provides an overview of the activity and a review of its ecological, socio-economic, and educational or outreach impacts. Each activity was independently evaluated against the criteria above using the compatibility scale. Following these independent assessments, each analysis was normalized to attain consensus regarding our final evaluation of its compatibility. The commercial activities evaluated included the following: wave energy, wind energy, liquefied natural gas port development, desalination, vessel traffic, tourism, treasure hunting, marine salvage, bio-prospecting, and coastal and offshore aquaculture. The activity analysis for each activity included an activity description, relevance to the OCNMS, a review of the impacts of the activity and a compatibility analysis." The Olympic Coast Sanctuary is using the report in support of their management plan review.

With funding from the National Center for Ecosystem Assessment and Synthesis (NCEAS) in Santa Barbara, CA, eight universities (California State University at Monterey Bay, University of Hawaii, University of Washington, University of Michigan, University of California at Santa Barbara, University of Connecticut, University of New Hampshire and the University of South Florida) simultaneously conducted graduate seminars addressing the topic "The Role of MPAs in Ecosystem-Based Management: Examining the Science and Politics of an Ocean Conservation Strategy." The university participants were chosen to bring a range of geographic, technical, and cultural perspectives to seminar participants. The distributed graduate seminar was also structured to pair university students and faculty with sanctuary staff members having direct experience in managing MPAs. Sanctuary staff represent specific sanctuaries or regional and national program management perspectives. Students investigated one or more of five questions depending on student and faculty interest and the relevance to local issues. Sanctuary staff will bring real-world examples to the discussions, including members of the local community involved in the issue.

Specific questions addressed by the seminar participants include:

- Can successful ecosystem-based management approaches be implemented in the marine environment without MPAs as part of the approach?
- How can MPAs meet local management objectives and simultaneously contribute to broader regional objectives for ecosystem-based management?
- Are existing legal and jurisdictional authorities sufficient to integrate MPAs into ecosystem-based management efforts at local and regional scales?
- Can National Marine Sanctuaries effectively implement ecosystem-based management approaches within their boundaries and contribute to broader ecosystem-based management efforts in the regions in which they occur?
- To what extent can insights derived from an evaluation of National Marine Sanctuaries and ecosystem-based management be extrapolated to the broader global discussion of MPAs?

The students, faculty and sanctuary staff who participated in this collaboration are meeting in April of 2009 to synthesize the information developed in case studies generated during the seminars, and a final "grand synthesis" report will be published.

While these are but two of the many successful collaborations between Universities and national marine sanctuaries around the country, the NMS University Partnership provides an NMS System-wide mechanism to coordinate, promote, sustain and enhance these critical partnerships. While it may take some time to fully realize all the goals set forth for the University Partnership, if the initial collaborations are any indication, the future appears to be promising.

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The Office of National Marine Sanctuaries Science Needs Assessment: A To Do List for Ocean Conservation

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Abstract

In 2008, the National Oceanic and Atmospheric Administration's Office of National Marine Sanctuaries (ONMS) initiated a process to identify its scientific requirements across the system of sanctuaries. Based on priorities identified in the management plan for each national marine sanctuary and the scientific findings in each sanctuary condition report, the ONMS drafted a national assessment of science and information needs required by the ONMS to meets its mandate under the National Marine Sanctuaries Act to manage and protect resources these national treasures. All framed within the context of specific management issues facing our nation's marine sanctuaries (invasive species, declining water quality, marine reserves, over harvesting, etc.), these scientific needs are the fundamental requirements in either capability or knowledge, and represent areas of support for which the ONMS looks to partnerships to address. Partnerships with the American Association of Underwater Sciences and its member institutions across the country can play an integral role in addressing these priority scientific requirements. This paper explores the requirements and opportunities defined in the assessments and presents opportunities for partnerships in marine protected area management and ocean conservation for the United States.

Keywords: condition report, management plan, NOAA, ONMS, ocean, science requirements

Introduction

The Office of National Marine Sanctuaries

The Office of National Marine Sanctuaries (ONMS) serves as the trustee for a system of 14 marine protected areas encompassing more than 150,000 square miles of ocean and Great Lakes waters from Washington State to the Florida Keys, and from Lake Huron to American Samoa (Figure 1 and Appendix 1). The sanctuary system includes 13 national marine sanctuaries and the Papahānaumokuākea Marine National Monument. The ONMS, part of the National Oceanic and Atmospheric Administration (NOAA), manages the sanctuary system by working cooperatively with its partners and the public to protect these special places while allowing compatible recreation and commercial activities. ONMS staff works to enhance public awareness of our marine resources and marine heritage through scientific research, monitoring, exploration, educational programs and outreach. To manage and protect these special places, the ONMS relies on sound science to support and guide its investment of resources, development of policy and regulations, and management decisions. This scientific support is provided through the Conservation Science Program at the site, regional and national levels of the sanctuary system.

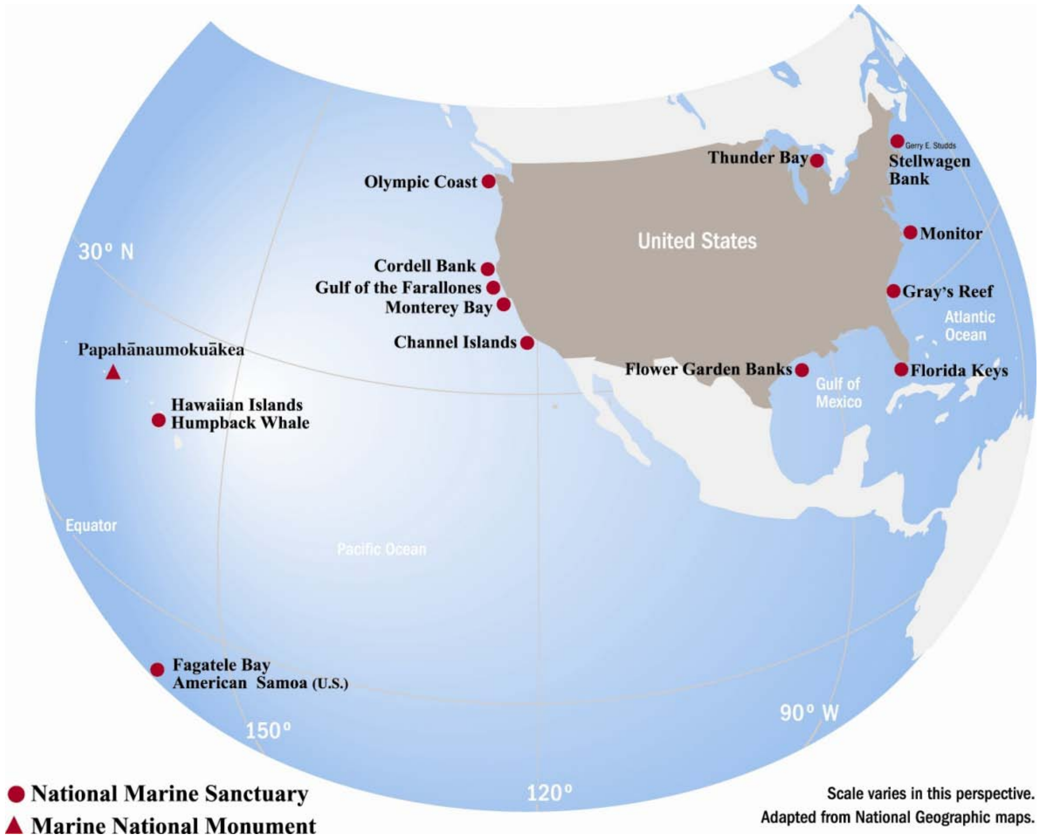

Figure 1. Global view of the United States National Marine Sanctuary System.

Conservation Science and National Marine Sanctuary Management

The Conservation Science Program of the ONMS conducts, sponsors, and facilitates research that is fundamental to understanding the nature and uses of natural and cultural resources in national marine sanctuaries. The ONMS defines conservation science as areas of scientific investigation concerned with the preservation of natural and cultural resources. For the ONMS, this includes activities related to three primary scientific activities: characterization, monitoring, and research, each of which is designed to improve understanding through assessing, evaluating, and investigating its trust resources. Conservation science plays a fundamental role in ONMS management by providing information on the state of resources in sanctuaries and supports reasoned management decisions on the sanctuary, regional, and national scales. Knowledge of the state of resources is vital to effective mitigation of the pressures on ONMS resources and informs specific management actions in response to those pressures. Further, application of this knowledge and approach to management at multiple scales is the root of ONMS ecosystem approaches to management (EAM) in addressing specific management issues across the system both within and outside of sanctuary boundaries. In this management driven process, the requirements of the conservation science program will change over time as the capabilities and management goals continue to evolve.

The driving documents in the management of national marine sanctuaries are the sanctuary management plans, a five year planning document. These documents are products of an intensive public process, and are intended to define, in as much detail as possible, the priority actions to be taken by the ONMS. Second to management plans are the sanctuary condition reports. These reports provide an assessment of the status and trends of the condition of resources in a sanctuary in a consistent and uniform format and are designed to set the stage for the initiation of a management plan review by providing using the best available information. With the information provided in the reports, the ONMS and its constituents work to design the sanctuary management plan such that key issues, such as those identified in the condition reports are addressed (Figure 2).

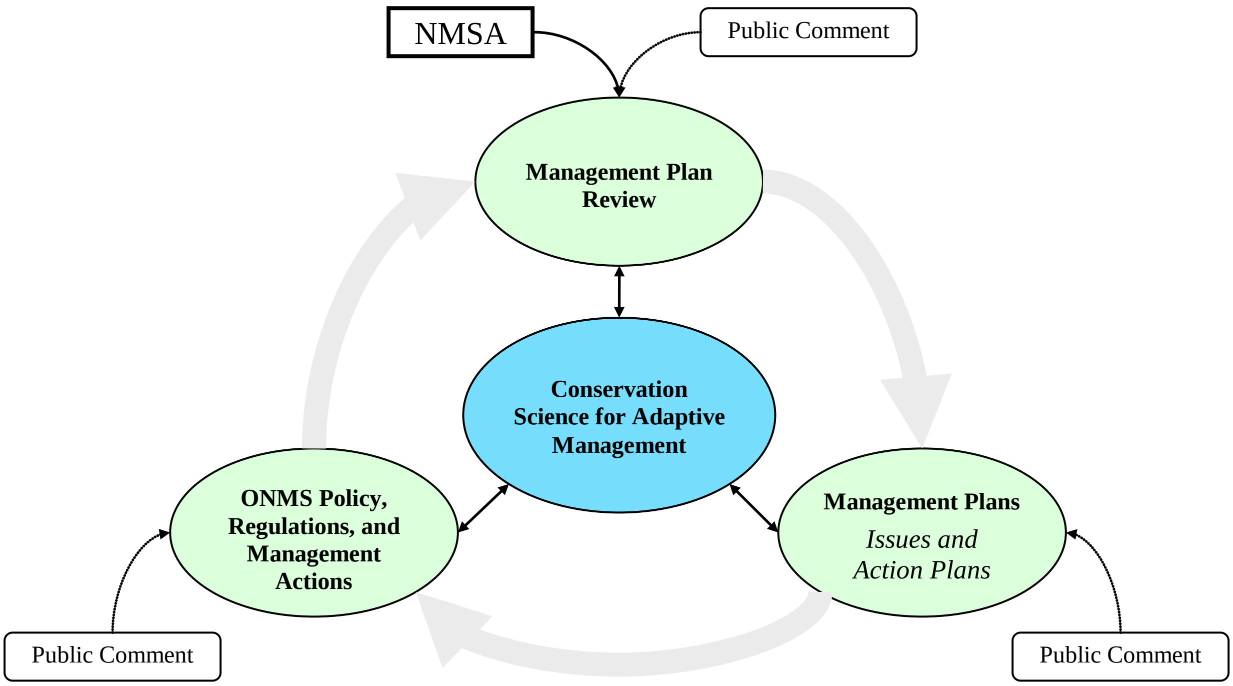

Figure 2. Conservation science for adaptive management. In a sanctuary operating under adaptive management principle, conservation science activities are driven and prioritized by the management plan review process and resulting sanctuary management plans and directly supports ONMS management decisions and actions.

The ONMS Science Needs Assessment

In the ONMS, the scientific requirements to support the wide array of management efforts underway are expansive. While issues addressed in various areas of the system can differ completely in topic and or approach, in many cases there is overlap and similarities. The sanctuary management plans and condition reports provide guidance on what the scientific requirements are for each sanctuary and the system. These documents are essential planning documents for each sanctuary office and the system as a whole. However, they do not present information with which the science community can work to assemble both annual and out year program planning in support of the management requirements. In 2008, the ONMS initiated a process to assess the management issues the sanctuary system at the site, regional and national levels. This science needs assessment is designed to identify the priority management issues across the sanctuary system and define the science support and information required to successfully address that management issue. As part of this assessment, the priority management issues to be addressed are extracted from these guiding documents and an evaluation of what science is required to address that issue is conducted.

The results of the evaluation of the management plans and condition reports are presented in a unique format. In an effort to keep the presentation clear, direct, and focused, while at the same time provide the essential information necessary to understand the issue and the associated science requirements, a short standard template is used to codify the information and present it in a short summary fashion. The format of the template puts the science requirements in the context of a management, beginning with the management issue and ending with the anticipated management response. This "end to end" approach, management issue to management response, is used to consistently present the scientific requirements across the program. Connecting the ends of the model is the information on the scientific questions that need to be answered, the methodologies to be used, data sources, and products needed to support the planned management actions. The specific components of each science needs template are as follows.

1. *Management Issue* – A simple statement describing the management issue.

2. *Description of the Issue* **–** Provides brief background and quick summary of the issue.

3. *Questions* – Lists key questions pertaining to the management issue. These questions address the specific scientific needs/questions relative to the issue.

4. *Scientific Approach and Actions* – Identifies possible methods or steps to take in addressing the issue/questions.

5. *Key Partners and Information Sources* **–** Highlights key players, potential partners, and information sources. This section provides guidance on who should be included in any work on this issue due to their current involvement, potential contribution, or political relevance.

6. *Management Support Products* – Describes desired final products (data sets, analytical results, papers, decision support tools, etc.) needed to support planned management action.

7. *Planned Use of Products and Anticipated Management Response* – Describes anticipated use of the decision support products.

8. *Program References* – Defines connections to ONMS planning documents, *i.e.*, management plans, sanctuary condition report, and sanctuary research plans.

The information is presented for each management issue in a one page summary format under the above headings. This information is not intended to be exhaustive and define in details the science requirements for a given management issue. Instead, these one page documents are designed to present a general overview of the management issue and some fundamental information on the science requirements such that potential partners can assess their interest in and ability to address certain needs. Then, if interested, potential partners can engage the ONMS on developing a partnership to address a given management issue and associated science needs.

Overview of the Assessment

System-Wide Requirements and Trends

Connected by the common thread of the guiding principles of the National Marine Sanctuaries Act, national marine sanctuaries from very different geographic, ecological and even political realms in many cases identified similar pressures and threats to resources. Across the system of sanctuaries several common areas of focus emerged as thematic management issues. Ranging from loss of biodiversity and global climate change to unexplored deep water communities and introduced species, these thematic areas are shaping the management actions of the ONMS. Both complex and expansive in scope, these issues represent high impact threats to the resources found in national marine sanctuaries. When examined as a collective requirement across the sanctuary system, these major thematic areas are significant and pressing issue facing the sanctuary system today. For examples of the major thematic areas and the sanctuaries that identified management issues relating to these issues, see Table 1.

Table 1. Summary of major thematic areas of management issues.

Sanctuary[1] / Thematic Areas	TB	SB	M	GR	FK	FGB	HIHW	PMNM	FB	CI	MB	GF	CB	OC
Biodiversity				✓	✓			✓	✓					
Global Climate Change					✓		✓	✓	✓	✓		✓		✓
Extraction (*e.g.*, fishing)	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			
Socioeconomics and Use	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
Ecosystem Connectivity					✓	✓	✓		✓					
Marine Zoning	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	
Introduced Species	✓			✓	✓			✓	✓		✓	✓		✓
Water Quality		✓			✓	✓	✓	✓		✓	✓		✓	
Maritime Heritage	✓	✓	✓					✓						
Deep Communities	✓		✓		✓	✓		✓			✓		✓	✓
Habitat Characterization	✓			✓	✓	✓		✓		✓		✓		✓
Historical Ecology		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[1] Many areas of study were consistently identified by individual sanctuaries in the science needs assessment and represent thematic areas of requirements. At individual sanctuaries, these needs may differ slightly in topic and questions that need to be answered, the over arching issues they represent were found to be relevant across the sanctuary system. Definitions of acronyms are found in Appendix 1.

Specific Highlights From Across the System

From the diversity of ecosystems and resources included in the sanctuary system also stem unique management issues and associated science needs. While collectively a system of protected areas, most national marine sanctuaries have specific attributes that set them apart from each other as special places. New discoveries of the spawning grounds for the marbled grouper, a very rare species at the Flower Garden Banks National Marine Sanctuary in the Gulf of Mexico, present unique opportunities to study these animals to understand their biological and ecological reproductive requirements. Also in the FGBNMS, as well as other sanctuaries, is the issue of toxins in the water column that affect not only the resident species, but the local human populations as well. The presence of high levels of mercury in fish has been documented but not fully understood. Ciguatera and harmful algal blooms are also common threats to the resources and local human populations of several sanctuaries that warrant concerted research. Vessel strikes on marine mammals is a high profile management issue that captures the attention of the public at local and national levels and is significant issue at two sanctuaries. This issue coupled with the impacts of noise in the ocean on marine mammals represent a significant area of research required focusing primarily on the marine mammals. Examples of other key issues that are documented in the assessment that are specific to only a few sanctuaries but represent many important areas of research opportunities are presented in Table 2.

Table 2. Summary of unique management issues from across the system[1].

Management Issue	Relevant Sanctuaries
Protection of Fish Spawning Grounds	Gray's Reef, Flower Garden Banks
Impacts of Acoustic Signals on Mammals	Stellwagen Bank, Hawaiian Islands Humpback Whale
Implications of Ecosystem Connectivity	Florida Keys, Flower Garden Banks
Vessel Strikes of Marine Mammals	Stellwagen Bank, Channel Islands, Hawaiian Islands Humpback Whale
Alternative Energy	Stellwagen Bank, Hawaiian Islands Humpback Whale
Human Health – Toxins and HABs	Flower Garden Banks, Olympic Coast, Monterey Bay
Marine Debris	Stellwagen Bank, Papahānaumokuākea, Florida Keys, Flower Garden Banks

[1] Across the system, specific needs are identified at each site. This table highlights some of the high profile issues that represent significant issues and unique research opportunities.

Getting the Job Done

For the past few years, the operating budget for the ONMS has declined. For the 2010 fiscal year a similar reduction is anticipated. While the ONMS does have staffing resources and infrastructure both on land and on water (*e.g.*, vessels, divers, ROVs, etc.), the work load requirements defined in this assessment far exceeds the resources available through direct federal funding. For the past few years the ONMS investment in conservation science fluctuates around $6.0 million, approximately 8% of the total budget. These funds are directed proportionally to characterization and research with a slightly larger portion directed towards short and long term monitoring related activities. Within these general categories, most of the funding goes towards staff and infrastructure costs, with only a small percentage available for program support.

The success of the ONMS management and protection of these special places relies heavily on the success of partnerships and leveraging resources. Annually, the ONMS leverages its 'science dollars' to generate over $11 million in additional support across the system. These contributions typically stem from critical partnerships with other federal and state governmental agencies, non-government organizations, academic institutions, and private sector entities, including volunteer programs.

Successful collaborations and partnerships are based on a relationship where each party benefits from the accomplishments attained, and each party identifies the work being completed to be in line with the programmatic requirements and priorities of each partner. By identifying the science required for the ONMS to address its priority management issues across the system, partners interested in collaborating with the ONMS and leveraging their resources with ONMS resources to address topics and issues of mutual interest is facilitated with the ultimate goal of managing and protecting our nations national marine sanctuaries and promoting ocean conservation around the country.

For More Information

The ONMS Science Needs Assessment is an evaluation process that will be continually updated and modified. All information produced from the assessment will be accessible on the internet at www.sanctuaries.noaa.gov/science/welcome.html.

Appendix 1. The National Marine Sanctuary System

CI - Channel Islands National Marine Sanctuary; *Santa Barbara, California*
CB - Cordell Bank National Marine Sanctuary; *Olema, California*
FB - Fagatele Bay National Marine Sanctuary; *Pago Pago, American Samoa*
FK - Florida Keys National Marine Sanctuary; *Key West, Florida*
FGB - Flower Garden Banks National Marine Sanctuary; *Galveston, Texas*
GR - Gray's Reef National Marine Sanctuary; *Savannah, Georgia*
GF - Gulf of the Farallones National Marine Sanctuary; *San Francisco, California*
HIHW - Hawaiian Islands Humpback Whale National Marine Sanctuary; *Oahu, Hawaii*
MB - Monterey Bay National Marine Sanctuary; *Monterey, California*
M - Monitor National Marine Sanctuary; *Newport News, Virginia*
OC - Olympic Coast National Marine Sanctuary; *Port Angeles, Washington*
PMNM - Papahānaumokuākea National Marine Sanctuary; *Oahu, Hawaii*
SB - Stellwagen Bank National Marine Sanctuary; *Scituate, Massachusetts*
TB - Thunder Bay National Marine Sanctuary; *Alpena, Michigan*

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The Etiology of Spinal Cord Decompression Sickness: a Literature Review

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Abstract

Spinal cord decompression sickness (SCDCS) is one of the most serious forms of diving-related injury; however, the exact pathophysiology is still unknown. Past and recent literature relevant to SCDCS is reviewed, including animal and human studies, and medical case histories. Three principal mechanisms are hypothesized in the literature. Shunting of gas emboli to the arterial circulation by venous bubbles overwhelming the pulmonary filter, or through a cardiac or intrapulmonary shunt, could result in blockage of vessels and eventual spinal cord ischemia. The formation of an excessive amount of venous gas emboli could lead to venous cord infarction. Autochthonous bubbles could also form in the spinal cord tissue itself, leading to disruption of blood flow and damage to surrounding cells. Ultimately, the pathogenesis underlying individual cases of SCDCS could differ depending on latency of symptom onset, dive profile preceding symptom onset, and clinical presentation.

Keywords: arterial gas embolism, autochthonous bubble, decompression sickness, spinal cord

Introduction

After incurring an inert gas load under hyperbaric conditions, divers decompress as they ascend to the surface. During decompression, inert gas bubbles may form in the blood and tissues when the inert gas tension (concentration/solubility) exceeds ambient pressure and a state of supersaturation is achieved. The presence of bubbles in the blood vessels can lead to the development of decompression sickness (DCS), although it does not correlate directly with clinical manifestation (Nishi, 1993; Dunford, 2000).

The symptoms of DCS range in severity. Mild forms of DCS involve general malaise, fatigue, localized skin rash and joint pain. More severe manifestations involve the lungs and central nervous system (CNS). Pulmonary obstruction by a large quantity of gas emboli leads to respiratory difficulties, while bubbles present in the CNS can lead to cerebral dysfunction, paralysis and death.

Spinal cord DCS (SCDCS), a subtype of CNS-related DCS, is one of the most serious forms of diving-related injury. Symptoms include paresthesia (abnormal sensations) in the lower back and chest; ascending muscle weakness; chest or abdominal girdle pain; urinary or bowel incontinence; and paralysis (Francis and Mitchell, 2002). Like most forms of DCS, the pathophysiology of SCDCS is not completely understood. Differences in clinical presentation, diving exposure preceding symptom onset, latency of manifestation, and individual anatomy have led to several plausible hypotheses of SCDCS etiology.

In this review paper, past and current literature relevant to SCDCS is examined. Human and animal research studies have investigated potential underlying causes, both on an anatomical and pathophysiological level. Similarly, published case histories have provided insight into possible relationships between diving exposure, individual physiology, and clinical presentation. Throughout the reviewed literature, three principle hypotheses of SCDCS etiology are consistently considered and evaluated: arterial gas embolism, venous cord obstruction, and autochthonous bubble formation.

Arterial Gas Embolism

Intravascular and tissue bubble formation requires inert gas supersaturation, which is achieved when the tension of dissolved inert gas (*e.g.*, helium or nitrogen) exceeds the ambient pressure. Consequently, the arterial systemic circulation is an unlikely environment for bubble formation. When the arterial blood supply passes by the lungs, it rapidly equilibrates to alveolar (ambient) pressure, thus minimizing the probability of reaching a supersaturated state. Even when there is not enough time for arterial blood to equilibrate (*e.g.*, during a rapid ascent), there is limited evidence of arterial bubble formation (Powell et al, 1982).

Bubble formation in the venous systemic circulation is more likely, however. As inert gas diffuses from the tissues to the blood in the venous end of capillary beds, a favorable environment of relatively low pressure and high gas tension is created. In contrast to arterial bubbles, venous bubbles have been measured in field divers, human decompression subjects, and animals during decompression studies. Typically, bubbles that form in the venous side of the systemic circulation pass through the right heart to the pulmonary artery, where they are subsequently filtered out of the circulation by the lungs.

There are several mechanisms for bubbles to move from the venous side to the arterial side of the systemic circulation, or embolize. Excessive levels of venous gas emboli (VGE) can overwhelm the pulmonary filter and lead to passage of bubbles into the arterial circulation (Butler and Hills, 1979). Likewise, venous bubbles may also pass through a cardiac shunt such as a patent foramen ovale (PFO). It has been estimated that 20-34% of the adult human population have a PFO (Hagen et al, 1984), and the flow through the PFO is often from the left side of the heart to the right side of the heart. Flow must be reversed in order for venous bubbles to move from the right side of the heart to the left. Induction of flow reversal has been demonstrated in decompressed animals with high levels of VGE (Vik et al, 1993), while other factors such as straining, lifting or coughing are thought to increase right to left shunting (Dear et al, 1993).

In terms of SCDCS, it has been hypothesized that bubbles entering the spinal cord arterial circulation would enter an area of lipid-rich tissue where they would grow (Boycott et al, 1908). These bubbles would block spinal cord vessels, leading to a decrease or cessation in blood flow to the surrounding tissues (ischemia) and subsequent oxygen deprivation (hypoxia) which could eventually lead to cell and tissue death (necrosis). Observations of tissue following induction of SCDCS have shown distinct areas of internal bleeding (hemorrhaging) in the white matter of the spinal cord, which has been compared to pathology seen in other conditions of spinal cord necrosis following ischemic injury (Slager, 1968).

Further evidence supporting the arterial gas embolism hypothesis comes from studies investigating a possible correlation between presence of a right-to-left shunt (RLS) and SCDCS. Gempp et al (2008) conducted a study assessing the prevalence of RLS in 49 divers who had been previously diagnosed with SCDCS in comparison to 49 diving controls. Their study determined that the proportion of divers with a large RLS was greater in the SCDCS group versus the control group. They also determined that while there was not a significant association between RLS and cervical SCDCS, there was a significant relationship between large RLS and SCDCS of the lower spinal cord (thoracolumbar) region. Similarly, Wilmherst and Bryson (2000) found a correlation between the presence of a large RLS and SCDCS development in divers.

The primary argument against the arterial gas embolization hypothesis of SCDCS is focused on the dispersal of bubbles once they move into the arterial systemic circulation. The brain receives 75-85 times the blood flow of the spinal cord, so the brain would most likely be embolized before the spinal cord; however, cerebral symptoms rarely appear with clinical presentation of SCDCS (Francis and Mitchell, 2002). In the clinical setting, the brain is the primary organ affected in other embolic conditions, such as pieces of fat or blood clots passing into the arterial circulation. Likewise, during cardiac surgery bubbles can form from gas left in the heart and pass into the arterial circulation (Milsom and Mitchell, 1998) and exposure to these bubbles frequently leads to post-operative cerebral injury and decreased cognitive function. However, post-operative spinal cord injury is extremely rare.

The pathology of an ischemic injury to the spinal cord is also a matter of debate. Spinal cord gray matter may be targeted over white matter in conditions of ischemia (DeBirolami and Zivin, 1982; Francis et al, 1989). There is also evidence that blood flow to the spinal cord actually increases during SCDCS onset (Marzella and Yin, 1995), contesting the role of ischemia in the development of SCDCS.

Venous Cord Obstruction

The venous cord obstruction hypothesis was first suggested in 1955 by Haymaker and Johnston. They proposed that a large amount of venous bubbles in the epidural vertebral venous plexus (EVVP), a large, valveless vein in the spinal cord, could lead to congestion and swelling of the spinal cord. In addition to the large bubble load in the spine itself, lungs filled with gas emboli would lead to a high amount of back pressure on the venous system, further exacerbating the problem. In 1973, Hallenbeck *et al.* suggested that the surface of the bubbles are triggering sites for a number of biochemical pathways in the body, and demonstrated that the coagulation cascade was activated by the presence of bubbles. Further studies involving observation of the spinal cord in animals during DCS confirmed an accumulation of bubbles and blood clotting in the spinal cord, leading to a decrease and eventual cessation of venous outflow leading to tissue death in the spinal cord (Bove et al, 1974; Hallenbeck et al, 1975).

While it has been suggested that the distinct white matter hemorrhages observed in SCDCS were compatible with pathology seen in other cases of spinal cord venous infarction (Henson and Parsons, 1967), there is disagreement in regards to the exact pathology seen in venous cord infarction. Animal models have demonstrated that destruction of the EVVP leads to white matter edema without permanent damage (Kato et al, 1985) or gray matter involvement (Taylor and Byrnes, 1974). In clinical cases of human venous cord infarction, the grey and white matters are both significantly involved (Hughes, 1971).

In addition to conflicting pathological evidence, the other question for the venous cord obstruction hypothesis involves the presence of excessive VGE (Francis and Mitchell, 2002). While large counts of VGE have been observed in asymptomatic divers, the amount of bubbling required for venous cord obstruction to occur would be significant. If bubbles initiate a series of cascades, then there is a gap between large bubble loads in asymptomatic divers and large bubble loads leading to venous cord obstruction. Similarly, large bubble loads can lead to pulmonary DCS; however, pulmonary DCS does not present with spinal cord symptoms.

Autochthonous Bubble Formation

Autochthonous bubble formation involves the development of bubbles in the tissue itself. The distinct lesions seen in SCDCS are predominantly in the white matter (Dick et al, 1997). The spinal cord white matter is lipid-rich, and fat can absorb five times the amount of inert gas compared to water. The white matter's high inert gas solubility, combined with a relatively low blood flow, make it a favorable environment for bubble formation. Keyser (1916) first suggested that inert gas bubbles may form within the tissues during decompression, and bubbles forming in the neurological tissues would be more symptomatic than those forming elsewhere in the body.

Bubbles forming in the spinal cord tissue could then have a number of effects on the function of surrounding cells and blood vessels. Francis et al (1990) proposed the autochthonous bubble formation in the spinal cord white matter could lead to destruction of the axons at the site of formation, stretching and compression of surrounding axons, and a biochemical insult that is initiated by the surface of the bubble. Surrounding vessels could also be damaged by an expanding bubble (Broome, 1995), leading to distinct areas of hemorrhage similar to those seen in tissue specimens from SCDCS cases.

The primary challenge for the autochthonous bubble formation hypothesis is the lack of evidence. It has been suggested that this lack of evidence could be due to the transitory nature of extravascular bubbles (Francis and Mitchell, 2002). Animal studies have shown evidence of localized bubble formation and subsequent tissue damage (Clay, 1963; Sykes and Yaffe, 1985; Hyldegaard et al, 1994), but bubbles were not detectable in the fixed tissue. In 1988, Francis et al conducted decompression studies on dogs where the spinal cords were fixed with epoxy resin within 20 minutes of SCDCS diagnosis. They observed non-staining, space-occupying lesions (NSSOL) in the spinal cord tissue sections from those animals who demonstrated a loss of function. The tissue surrounding these lesions was compressed, indicating the lesions likely contained gas before they were fixed. Palmer (1997) conducted a histological study on NSSOL and argued that instead of initiating from bubbles forming in the tissues, these lesions are more likely formed by local blood vessels that have been distended by bubbles. The other major limitation to the autochthonous bubble formation hypothesis is based on the degree of supersaturation required for bubble formation in the tissues. It has been shown that bubbles form at a saturation pressure of less than 85 fsw (Francis et al, 1990); thus, bounce dives to depths shallower than this will unlikely result in tissue bubble formation.

Summary

There is support for, and challenges against, each of the three primary hypotheses of SCDCS pathophysiology. It is probable that more than one of these mechanisms, if not all, account for SCDCS across its range of latency and symptoms. Cases with a short latency are more likely to occur by a mechanism such as autochthonous bubble formation, while cases with a late onset of symptoms would more likely occur due to venous infarction (Francis and Mitchell, 2002). It is also possible that there is an interaction between mechanisms. Similarly, as suggested by Gempp et al (2008), arterial bubble embolism may account for SCDCS cases involving the lower spine, while another mechanism may be predominantly associated with symptoms of the upper spine.

Future studies will provide an improved understanding of mechanisms responsible for SCDCS. Extravascular bubble detection technology, which is currently in development, will clarify the origin of bubbles in the spinal cord tissue. Improved scanning technology will also allow researchers to investigate bubble formation, movement, and resulting tissue damage in SCDCS. Ultimately, development of a mechanistic model will provide a starting point for determining adjunctive, non-recompressive therapeutic approaches for SCDCS.

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The Haldane Effect

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Abstract

John Scott Haldane, British physiologist and philosopher, was born in 1860 in Edinburgh, Scotland. Haldane investigated poisonous gases occurring in coal mines and wells, sunstroke, the physiological action of carbon monoxide and the use of a caged canary for early carbon monoxide detection, the regulation of lung ventilation (with J.G. Priestley), and devised the haemoglobinometer, the apparatus for blood-gas analysis. He also described the effects of oxygen deficiency and exercise on breathing. During the First World War he worked on effects of poisonous gases and designed a portable oxygen administration apparatus. His work on hypoxia and the acclimatization of the human body to high altitude revolutionized concepts in respiratory physiology. Haldane published some landmark books on his philosophical ideas about the true significance of biology. Most importantly, however, Haldane investigated the problems of deep diving for the British Admiralty, developing the 'stage decompression' method, a lasting contribution to the diving world. This elaborate experimental investigation was conducted in part in a steel pressure chamber at the Lister Institute and with divers in Scottish deep-water lochs. In 1908, J.S. Haldane published those results in his seminal paper "Prevention of Compressed-Air Illness" in the Journal of Hygiene with A.E. Boycott and G.C.C. Damant. Stage decompression allowed divers to be safely brought to the surface and made it possible to conduct 120 fsw (37 m) salvage operations on the *Laurentic* to recover over £5,000,000 of gold ingots without recordable incident. One hundred years later, the Norwegian University of Science and Technology in Trondheim convened the Haldane Symposium, December 18-19, 2008, celebrating the past, present, and future directions of environmental physiology research in decompression.

Keywords: decompression, decompression tables, environmental physiology, John Scott Haldane

Introduction

The Haldane Effect

Deoxygenated hemoglobin (Hb) has a greater affinity for carbon dioxide (CO_2) than does oxygenated hemoglobin (HbO_2). Thus, oxygen (O_2) release at the tissues facilitates CO_2 pickup, while O_2 pickup at the lungs promotes CO_2 dissociation from Hb. In reality, the exchange of O_2 and CO_2 is occurring at the same time. In the oxygen-rich capillaries of the lung, this property causes the displacement of CO_2 to plasma as venous blood enters the alveolus and is vital for alveolar gas exchange.

Reduced (deoxygenated) hemoglobin is a better proton acceptor than the oxygenated form ($H^+ + HbO_2 \longleftrightarrow H^+.Hb + O_2$). In red blood cells, carbonic anhydrase catalyzes the conversion of dissolved carbon dioxide to carbonic acid, which rapidly dissociates to bicarbonate and a free proton ($CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$). The majority of CO_2 in the blood is in the form of bicarbonate. Only a very small amount is actually dissolved as CO_2, with the remaining amount bound to hemoglobin. The Haldane effect is not the subject of this paper; the enduring effect of the Haldanes is, of John Scott in particular, as the first environmental physiologist.

Haldane Family History

Haldane Places

Gleneagles in Perthshire, Scotland, was the Haldane family estate since the 13th century, where John Scott was raised. There are named extraterrestrial sites such as the Haldane lunar crater, located in Mare Smythii, near the eastern limb of the Moon, and the Haldane Martian crater. Haldane, Illinois, USA is an unincorporated county. There also exists the small town of Haldane, Southland, New Zealand and a Haldane Ducati motorcycle dealership in Auckland. The Glasgow School of Art, Department of Ceramics is housed in the Haldane Building on Hill Street, Glasgow, Scotland.

The Haldanes' Ancestry

Bernard, son of Brien, during the reign of King William the Lion (1165-1214) was the presumed founder of the Haldane family in Scotland. Almer de Haldane fought with King Robert de Bruce in the 14th century. Sir John Haldane was the third Lord of Gleneagles in the 15th century. Sir James Haldane presided as Governor of Dunbar Castle in the 16th century. The 11th Laird, Chief Sir John Haldane, was knighted by King Charles I in the 17th century. General George Haldane led troops in the Battle of Fontenoy in the 18th century. There is no record of Archibald Haldane, who settled in Virginia in 1655, regarding his relationship to the Haldane family forefathers of John Scott Haldane.

The Haldane Family Tree

John Scott Haldane is of the third generation of this Wikipedia excerpt of the Haldane family tree (Figure 1). Of note is the high level of influential accomplishments of members of this aristocratic Scottish family, in particular, the first through fourth generations.

Robert Haldane (1764-1842) was the brother of J.S. Haldane's grandfather, a Scottish churchman, and Royal Navy mariner.

James Alexander Haldane (1768-1851) was J.S. Haldane's grandfather, brother of Robert Haldane, who married twice and fathered a total of 13 children (obviously not all depicted above). He was an independent Scottish Church leader.

Daniel Rutherford Haldane (1824-1887) was J.S. Haldane's uncle and President of the Royal College of Physicians in Edinburgh.

Richard Burdon Sanderson Haldane (1856-1928) was The Right Honourable Lord Richard Burdon Haldane, 1st Viscount Haldane**,** John Scott Haldane's brother. He was a British politician, lawyer, philosopher and Secretary of State for War in 1909 (Maurice, 1937).

Elizabeth Sanderson Haldane (1862-1937) was J.S. Haldane's sister and the first female Justice of the Peace in Scotland in 1920.

John Burdon Sanderson Haldane (1892-1964), also known as 'Jack,' was J.S. Haldane's son, a prominent scientist in his own right who, with Ronald Fisher and Sewall Wright, was the founder of population genetics. Quite the philosopher, in his essay "When I am Dead" Haldane (1927) opined "If my mental processes are determined wholly by the motions of the atoms in my brain, I have no reason to suppose that my beliefs are true...and hence I have no reason for supposing my brain to be composed of atoms." J.B.S. Haldane also offered a cautionary note on the four stages of the acceptance of a scientific theory: 1) This is worthless nonsense; 2) This is an interesting, but perverse, point of view; 3) This is true, but quite unimportant; and, 4) I always said so**.** The Cambridge Dictionary of Scientists (2nd ed., 2002) characterizes J.B.S. Haldane as "One of the most eccentric figures in modern science. If his life has a theme, it is of bringing talents in one field of work to the solution of problems in quite a different area. He was self-confident, unpredictable and difficult to work with. His family was wealthy and talented, and his father was Britain's leading physiologist." In addition to his achievements in science and as an author, during much of his life J.B.S. Haldane was a noted atheist, materialist, socialist, and communist. In the field of genetics he was the first to discover linkage in mammals, to map a human chromosome, and to measure the mutation rate of a human gene. Haldane (1924) was also a famous science popularizer and remarkable in predicting many scientific advances, but has been criticized for presenting a too idealistic view of scientific progress. He also coined the term "clone" (Clark, 1969).

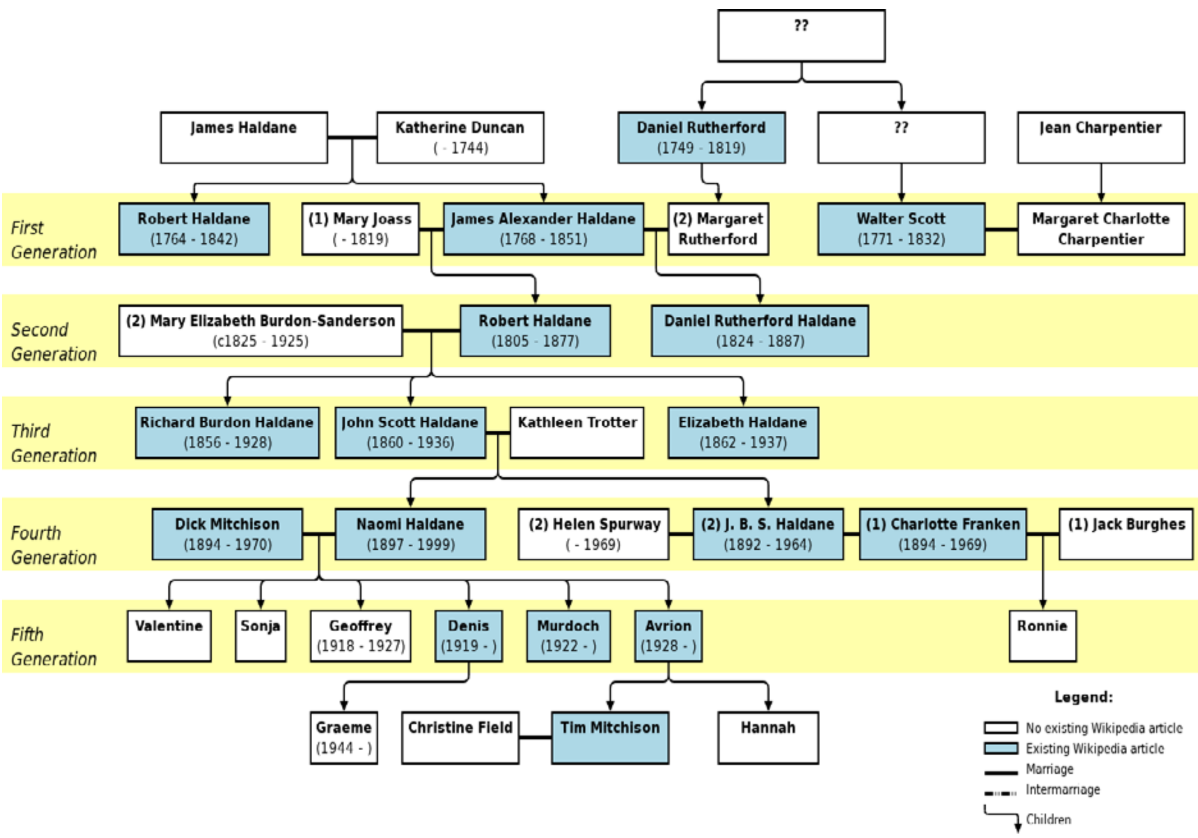

Figure 1. Haldane family tree.

Like his father, Jack Haldane was an enthusiastic experimenter, willing to expose himself to danger to obtain data. One experiment, involving elevated levels of oxygen saturation, triggered a fit which resulted in him suffering crushed vertebrae. In his decompression chamber experiments, he and his volunteers suffered perforated eardrums but Haldane stated that "the drum generally heals up; and if a hole remains in it, although one is somewhat deaf, one can blow tobacco smoke out of the ear in question, which is a social accomplishment."

In a 1923 talk given in Cambridge, Haldane, foreseeing the exhaustion of coal for power generation in Britain, proposed a network of hydrogen-generating windmills. This was the first proposal of the hydrogen-based renewable energy economy.

J.B.S. Haldane became a member of the prestigious Royal Society in 1932. Among the awards he received was the Royal Society's Darwin Medal (1953), the French Government's Legion of Honour (1937), the Academia Nazionale dei Lincei's Feltrinelli Prize (1961), the Weldon Memorial Prize from Oxford University, the Linnean Society's Darwin Wallace Medal, and the U.S. National Academy of Sciences Kimbler Genetics Award (Mahanti, 2006). He served as President of the Genetical Society from 1932 to 1936. Haldane was a friend of the author Aldous Huxley. Jack died on December 1, 1964 and had willed that his body be used for study at the Rangaraya Medical College, Kakinada (Mahanti, 2006). During his life, Jack Haldane wrote 24 books, more than 400 scientific papers, and numerous popular articles.

Naomi Margaret Haldane Mitchison (1897-1999) was J.S. Haldane's daughter, the sister of Jack**.** Naomi was a Scottish novelist and poet with over 90 works to her credit (Calder, 1997). "She was Bohemian, a child of the twenties, she had an open marriage and sexual freedom, taking off corsets, not wearing brassieres long before the 1960s. She believed herself to be part of an intellectual elite and felt empowered to do and be any way she felt" (Benton, 1990). In 1981, she was appointed Commander of the Order of the British Empire (CBE). In 1990, at age 92, Mitchison received an Honorary Doctorate of Letters from Heriot-Watt University, Edinburgh**.** Naomi was also a good friend of the writer J.R.R. Tolkien, serving as was one of the proofreaders of *The Lord of the Rings*.

John Scott Haldane

The Person
John Scott Haldane (1860-1936) is the main focus and anchor of the Haldane effect and arguably the first environmental physiologist. He was born in Edinburgh on 3 May, 1860, the fourth son of Robert Haldane by his second wife Mary Elizabeth, and died March 16, 1936, of pneumonia. Haldane believed that "the aim of the science of physiology is to deliver general principles which shall enable us to predict behaviour of the living body under various physiological conditions." He was considered the father of oxygen therapy: "The first step in good practice is to know what the oxygen is aiming at, where it is going, and in what quantities."

We know about Haldane from his work in developing decompression tables, but his contribution can only be understood if one considers his previous work and interests. First of all, Haldane was an observer and an experimentalist, who always pointed out that careful observation and experiments had to be the basis of any theoretical analysis. "Why think when you can experiment" and "Exhaust experiments and then think." His passion for obtaining data was demonstrated by the fact that during his medical studies in Jena he carefully observed the amount of beer being drunk, noting that the students on the average drank about 20 pints per evening.

Haldane received his education at the Edinburgh Academy, University of Edinburgh (1884), and University of Jena in central Germany, after which he was a Demonstrator at University College, Dundee, and from 1907-1913 a Reader in Physiology at Oxford University where his uncle, John Burdon-Sanderson, was Waynflete Professor of Physiology. J.S. Haldane became a member of the Royal Society in 1897 but had issues such as "The Royal Society system of selecting papers and excluding 'speculative' ones makes the meetings, Proceedings and Transactions as dull as ditch water and quite unrepresentative of the progress of British Science" (Goodman, 2007). Regardless, he was awarded Royal Medallist of the Society in 1916, Copley Medallist in 1934, and in 1928 he was appointed Companion of Honour for his scientific work in connection with industrial disease.

J.S. Haldane was personally gifted with a unique power of encouraging the faculty for research and his teaching was characterized by his efforts to make the students observe and think for themselves**.** He had the great ability to add both force and charm or character, the effect of which was securing the attachment of his pupils. Haldane had a profound sense of public service and he believed passionately that the world could be made a better place through the appliance of science. From miners dying of carbon monoxide poisoning and soldiers being gassed like rats in the trenches, to mountaineers and aviators coping with high altitudes, Haldane showed that science could bring light into the darkness. A friend described him as "almost quixotically anxious to do good to all mankind – and to teach them all a thing or two" (Goodman, 2007).

Haldane was also a philosopher of science and many of his lectures were published in books, including *The Sciences and Philosophy* in 1929, *The Philosophical Basis of Biology* in 1931, and *The Philosophy of a Biologist* in 1935.

The Self-Experimenter

Haldane was "himself such a coalmine canary, putting his own health and life on the line to protect others" (Goodman, 2007). Haldane's own philosophy was "All life is a physiological self experiment." Once, on his way home from his laboratory after such an experiment, he was stopped by an Oxford policeman who had observed the scientist's stumbling progress. Haldane explained that it was not due to alcohol, but gas. His housekeeper offered her sympathies to his wife, Kathleen: "I know how you feel, ma'am. My husband's just the same on a Friday night."

Haldane liked nothing better than to explore dangerous mine shafts and sewers. But it was in the specially constructed, air-tight chamber in his lab that the effects of gases on people were revealed. In an age before risk assessments, institutional review boards and human subject ethics committees, Haldane was a serial self-experimenter. He also thought nothing of exposing his own son Jack to dangerous doses of chlorine and other noxious gases. His young daughter Naomi once told a six-year-old friend outside their house: "You come in. My father wants your blood." Her friend screamed and ran away.

J.S. Haldane's Research

First Paper

Haldane's first essay in 1883, with his brother Lord Haldane, contributed to "Essays in Philosophical Criticism" by examining the relationship of philosophy to science and attempted to answer the questions: "What is man; discover man's relationship to his environment; and, knowing man's relationship to his environment, determine his function, what is he most suited to do in the world?" His real interest was the study of the relationship between the organism and the environment. This, as well as his deep feeling for social issues, would determine the focus of his professional life.

First Study

Haldane as Sherlock Holmes, environmental investigator, asked a) What is bad air? b) What makes air dangerous to breathe? and c) How can its bad effects be prevented? He proceeded by studying the air in overcrowded Dundee slums, turning up without warning in the middle of the night to collect air in bedrooms where eight people were sleeping. His results indicated that rooms of 180 ft^3 (5,097 L) had 65% more carbon dioxide, twice as many molds, 254% more organic matter, including hydrogen sulfide (0.07% can be fatal), and 1000% more bacteria than normal.

Self-Experiments

Some of Haldane's rebreathing experiments revolved around the concept of the good air being used up. His findings included: that oxygen was a gas that supported life longer than an equal amount of air; that carbon dioxide spoils pure air once it was breathed; and that after seven hours, O_2 was down to 13% and CO_2 was up to 6.5% accompanied by symptoms of heavy panting, severe headache, and vomiting; and, that after breathing O_2 of 2%, he went unconscious after 40 seconds. Word of his propensity for experimentation got out prompting one neighbor to knock on his door asking "My wife's cat has been lost and we thought that possibly… it might be here."

The Haldane Apparatus

Haldane invented the haemoglobinometer, the apparatus for blood-gas analysis, and also designed an apparatus for the accurate and fast analysis of air or mixtures of gases (Figure 2).

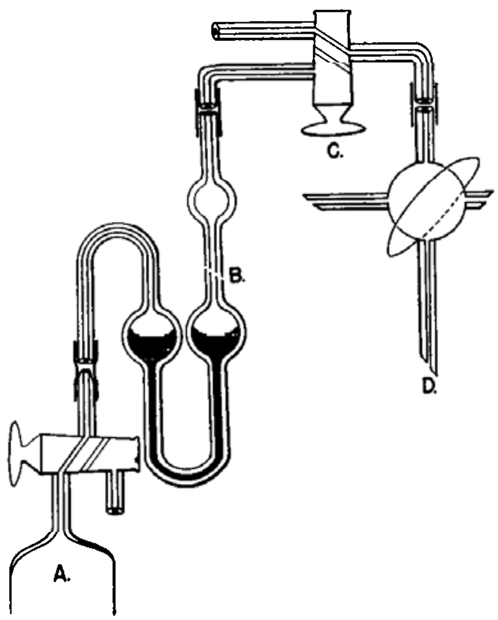

Figure 2. Haldane apparatus (Snyder, 1937): A is the gas-sampling tube; B is made of capillary tubing of 1 mm bore, with two lower bulbs to contain approximately 0.75 cc and an upper bulb to contain about 0.25 cc; C is a two-way stopcock; and, D is the upper part of the Haldane apparatus (Henderson type stopcock).

The Stink

When a Select Committee called upon him to "delve inside the lower depths of government and analyse the stink that flowed beneath," Haldane ventured into the sewers below Westminster Palace. A born iconoclast, he successfully challenged the idea that "sewer air" was a cause of typhoid and other diseases.

Coal Mine Canaries

Serinus canaria is affected by gas 20 times faster than man. Haldane held canaries in the mines in cages not unlike the one in Figure 3. Haldane, being fundamentally a kind man and concerned about the animal's well being, modified the cage so that only the front was open and could be o-ring sealed when closed. He had mounted a small oxygen bottle on top of the cage. When the canary fell off its perch from breathing toxic gas, he would shut the front door and open the oxygen bottle, ensuring the canary's survival.

Figure 3. Antique 19th century coal mine canary cage.

Mine Accident Experiments

In 1896, a mine explosion occurred in Tylorstown Colliery, Rhondda Valley, South Wales, with over 100 men inside. Enter J.S. Haldane, 'medical detective.' The toxic gas after the explosion (afterdamp) had not extinguished miners' lamps, leading Haldane to believe that oxygen was present and suffocation needed to be ruled out. His diagnosis was accurate: 75% of the deaths were attributed not to blast injuries, but to carbon monoxide (CO) poisoning as evidenced by pink and red skin coloration and carmine-red blood samples.

Haldane's continued curiosity about why the miners died led to more self-experimentation. Breathing 0.2% CO for 71.5 min, Haldane's vision became dim, his limbs weak, he had some difficulties in waking up or walking without assistance, and his movements were very uncertain. Afterwards he confessed to feeling confused, making spelling mistakes, experiencing indistinct vision, and not recognizing what he saw. Breathing oxygen produced dramatic improvements. On another occasion, after 29 min of breathing CO, Haldane calmly noted that he felt distinctly abnormal: he was panting, breathing 18 times per minute, his limbs shook and his pulse was racing. Soon, he began to feel unsteady on his feet.

Respiration Studies

Haldane and Priestly (1905) showed that the regulation of breathing is normally determined by the tension of CO_2 in the respiratory center of the brain, and that this nervous center is sensitive to variations in the tension of CO_2 in arterial blood. Since CO_2 is one of the principal products of tissue metabolism, an explanation was afforded of the automatic changes in breathing which occur with alteration in bodily activity.

More Environmental Studies

Haldane conducted other environmental studies on the effects of hyperthermia, nutrition, and in particular, lung disease mechanisms (lack of sunlight, poor ventilation, ladder climbing, infections, smoke inhalation, high and low temperatures, unsanitary conditions and breathing of stone dust - silicosis). Acott (1999) referred to Haldane as "the father of the salt tablet" for his recommendation of salt replacement during excessive sweating.

Haldane's altitude studies consisted of work at Pikes Peak (1911) and Mount Everest of which he said "the highest points of the Earth could be reached without the help of oxygen, providing they had the right men and the right weather." He was further involved with the design of the first prototype space suit (1921) and balloon flights to 90,000 ft (27,430 m) in 1933.

Also, the identification of nitrite (NO_2^-) as the active ingredient in red meat curing procedures dates back to the late 19th century. J.S. Haldane was the first to demonstrate that the addition of nitrite to hemoglobin produced a nitric oxide (NO)-heme bond, called iron-nitrosyl-hemoglobin ($HbFe^{II}NO$). The reduction of nitrite to NO by bacteria or enzymatic reactions in the presence of muscle myoglobin forms iron-nitrosyl-myoglobin. It is nitrosylated myoglobin that gives cured meat, including hot dogs, their distinctive red color and protects the meat from oxidation and spoiling (Gladwin, 2004).

Decompression Studies and Diving Tables

Haldane found that it was not pressure that damaged the body, but differences in pressure. Paul Bert (1878) dived 24 dogs to 290 fsw (88 msw) with rapid decompression, resulting in death by nitrogen bubbles. In his studies using goats at the Lister Institute of Preventive Medicine, Haldane used slow ascent rates of 5.0 $ft \cdot min^{-1}$ (1.5 $m \cdot min^{-1}$). The results were published in the seminal paper by Boycott, Damant, and Haldane (1908), 100 years ago.

Haldane made the important observation that no diver had "the bends" after rapid decompression from 42 ft (13 m) to the surface leading to the general principle that a 2:1 pressure difference could be tolerated. A staged-decompression technique was developed and tables describing uptake and elimination of nitrogen were developed by his son Jack Haldane at age 13. The body was divided into six compartments with different half times and the deepest dive tested to 210 fsw (64 msw).

Haldane also suggested that oxygen should be used to shorten decompression time provided that the pressure was kept less than 2.0 bar because of the fear of oxygen toxicity. However, Haldane made little contribution to the therapy of decompression sickness although he recognized that recompression was the treatment of choice. Haldane had doubts about the safety and efficacy of 'uniform decompression' practice. Haldane's experiments were conducted at the Lister Institute of Medicine in a recompression chamber and he assumed the following: a) for bubbles to form, the pressure of gas in the tissues must exceed the external pressure; b) that body tissues will hold gas in a supersaturated state unless a certain limit is reached; c) that any decompression is free from risk only if the degree of supersaturation "can be borne with safety;" and, d) that tissue perfusion was the limiting factor in inert gas uptake (Boycott *et al.*, 1908).

His decompression experiments examined the depth and pressure exposure, duration, and the pattern of decompression. Initially, a few experiments were conducted on rabbits, guinea pigs, rats and mice but it was difficult to detect symptoms in these smaller animals. The goat (Figure 4 a, b) was chosen as the experimental model "because they were the largest animals which could be conveniently dealt with" and "those who are familiar with them can detect slight abnormalities with a fair degree of certainty." The dog was rejected because of the findings of Heller *et al.* (1900) who had previously used them to produce 'safe' decompression profiles that failed for humans.

Goats were excluded from the experiments if they were ill. Only five to eight goats were used per experiment. The chamber was not ventilated because they believed CO_2 to have a minimal effect on the susceptibility to decompression sickness. The chamber temperature was not controlled and no allowance was made for any variation in atmospheric pressure. Large pressure variations were used to produce minor to severe symptoms. The compression time of six minutes was neglected in short exposures but included in longer, deeper exposures.

At the time of the experiments, Haldane knew from Naval diving data that decompression from 2.0 bar produced no symptoms irrespective of the duration of exposure. However, decompression from 2.25 bar produced the "occasional slight case;" hence, Haldane's assumption that halving the pressure would not produce symptoms. He used a 'perfusion' mathematical model of gas uptake, the half lives of which were calculated from data available at that time (Acott, 1999).

A common bends symptom in goats was limb pain where the affected limb, often the foreleg, was raised (Figure 4a). Pain was detected by "urgent bleating and continual restlessness" with the goat often gnawing at the affected area "such as the testicles;" temporary paralysis noted about 15 min after decompression with improvement within 30 min and the animal being "quite well" the next day. Permanent post-decompression paralysis also occurred where the hind legs were noted to be paralyzed immediately with any spontaneous improvement followed by a permanent relapse (urinary retention and an acute gut distension were also noted). "Obviously ill" goats were noted to be apathetic, refusing "to move or to be tempted with corn (of which goats are inordinately fond)." Dyspnea, a sinister symptom usually occurring just before the animal died was also observed. Importantly, Haldane's data showed that goats had an individual variability and susceptibility to decompression sickness.

Figure 4a. Bends of foreleg in a goat.
Both figures from Boycott *et al.* (1908).

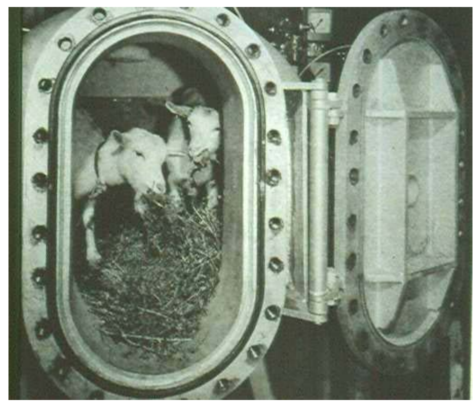

Figure 4b. Goat chamber dives.

Diving tables were published in 1907**,** the Royal Navy adopted them for military divers in 1908, and the U.S. Navy adopted them in 1912. They became the Blue Book for civilian divers who felt no discomfort after ascending from 210 ft (64 m). Referring to applied physiology, Richard Haldane, John Scott's brother, stated "Dr. Haldane has shown yet one more instance of the application of science to practical work." Haldane continued to think about the decompression problem for the rest of his life, considering how to extend and extrapolate the tables.

The S.S. *Laurentic* (White Star Lines), built by Harland & Wolff at their Belfast yard, went down the slipway on 29 April 1909 at the time that construction on the *Titanic* started. Captain Reginald Norton was chosen to carry 43 tons of gold bullion from Great Britain to Canada. On 25 January 1917, she struck a mine and sank within an hour in 130 ft (40 m) of water in Lough Swilly, Donegal, Ireland, with a huge loss of life and all the gold bullion. In 1906, Commander Guybon C.C. Damant had set a world diving record of 210 ft (37 m) during Naval endurance diving tests. His experiences as a salvage diver were well known to the Admiralty. In 1917, the 36-year-old Damant's dive team included Augustus Dent. He was aboard S.S. *Laurentic* when she sank and knew where the bullion room was. Between 1917 and 1924 this incredible salvage operation recovered 3,186 of the 3,211 missing gold bars. In 1932, an additional five bars were recovered by another salvage operation. Twenty gold bars, currently worth some £10 million, are still unaccounted for at the bottom of Lough

Swilly. Over 5,000 salvage dives were conducted using Haldane's tables in a 200 yd^2 working area at 120 ft with no loss of life or serious problems.

Death - The End
Naomi Mitchison reported that her father "had a look of intense interest in his face, as though he was taking part in some crucial experiment in physiology which had to be monitored carefully… It made me feel that was an experience deeply worth having." Born into a Scottish aristocratic family whose motto was "suffer," Haldane certainly suffered for his science (Anon. 1936). His life was "the greatest sustained physiological experiment in the history of the human lung" (Goodman, 2007).

100 Years after Haldane and the Future of Diving

In celebration of Haldane's work, the Baromedical and Environmental Physiology Group of the Norwegian University of Science and Technology, Trondheim, convened the international symposium *The Future of Diving: 100 Years of Haldane and Beyond*, December 18 and 19, 2008 (Lang and Brubakk, 2009). Presented below are some examples of the Haldane Symposium historical and future-direction research highlights to illustrate our trajectory since 1908 and new directions currently being investigated in an effort to increase our understanding of the systemic disease called decompression illness.

The first half of the 20th century was spent adjusting the ratios, the second half with ascent rules, Workman's M-values, the Thalmann algorithm, probabilistic models, bubble models, and deep stops, but HALDANE STILL RULES! (Doolette, 2009).

Wisloff *et al.* (2004) investigated the effects of exercise at different intervals before diving rats to 196 ft (60 m) for 45 min on air. Exercise performed 20 h before diving resulted in lower bubble scan grades and increased survival times. Møllerløkken *et al.* (2006) reported from their diving study using pigs (3 h, 130 ft [40 m] dive - 0.35 ATA PO_2) on the role of nitric oxide (nitroglycerine administered at 0.4 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for 30 min pre-decompression) in preventing vascular bubble formation after decompression. Richardson (2009) discussed exercise performed 24 h prior to decompression (and during decompression stops) as not harmful, but instead appearing to protect from DCS, reinforcing that a reduction in the number of venous gas bubbles may be related to the reduced risk of DCS. The mechanism appears to be NO-related and thus the administration of an NO donor might be a reasonable pharmacologic alternative to exercise. Dujic *et al.* (2004; 2005a; 2005b; 2006; 2008) concluded from a series of experiments that reducing the number of bubbles could be accomplished by exercise before, during decompression and after diving, and an NO donor. Asymptomatic cardiovascular and endothelial dysfunction after diving lasted for several days after a single field dive with unknown long-term effects. Acute and long-term use of antioxidants may prevent some of these effects, but not all.

Kayar *et al.* (2001) continued investigations of biochemical decompression by asking whether a capsule of *Methanobrevibacter smithii* could stop pathology pathways activated by bubbles (*e.g.*, inflammatory cascade activation**,** platelet activation**,** vascular endothelial biochemistry alterations) by converting inert gas to non-gas molecules. The proof of concept was established in small and large animal models where inert gas was eliminated from tissues by converting hydrogen and carbon dioxide to methane and water. The greater methane release correlated with lower DCS risk.

Perdrizet (1997) continued investigations of heat-shock proteins, cellular response to stress and hyperbaric oxygen therapy stress pre-conditioning. Blatteau *et al.* (2007), on the topic of dehydration prior to diving, observed that the uptake of inert gas by a particular tissue depended on the rate of blood flow to the tissue and dehydration-induced hypovolemia reduced stroke volume. A single predive sauna session significantly decreased circulating bubbles after a chamber dive, which may reduce the risk of DCS. Heat-exposure induced dehydration and NO pathways could be involved in this protective effect. Because heart rate was unchanged after the sauna session, it was hypothesized that blood flow could be reduced at the start and during the dive, thus limiting inert gas load and bubble formation afterwards. A rise in flow-mediated dilation was observed, suggesting an NO-mediated effect on endothelial function after a single sauna session.

Fahlman *et al*. (2006) are convinced of the untapped diving physiological knowledge to be gained from studying natural divers, marine mammals, which probably live with extremely high blood- and tissue-N_2 levels. Diving adaptations such as lung collapse, tracheal compression and behavioral responses may be important in reducing bubble formation. Future marine mammal studies should determine if biochemical adaptations reduce DCS risk.

Acknowledgments

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Community Science for In-Shore Marine Resource Management Building a Toolkit Drawing on the Magothy River Association Experience

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Abstract

We report on the growing trend to engage citizens and communities directly in the stewardship of in-shore marine resources as a complement to scientific and public policy initiatives. We begin by providing some background on the circumstances and premises which have fostered this community-based approach. We identify how efforts to strengthen community-based initiatives are being enhanced by an examination of the 'lessons learned' from some of the longer-standing initiatives, and how this learning is informing practices in West Africa. We consider the interesting 'lessons learned' from one of case studies, that of the Magothy River Association (MRA) which operates in Maryland (USA). Finally, we also consider how the experiences of the MRA and case studies of other community based volunteer initiatives are informing the preparation of a 'Community Science Toolkit for In-shore Marine Resource Management.'

Keywords: sustainability, fisheries, public policy, West Africa, World Bank

Introduction

In-shore marine resources, being essentially a public good, generally require government management and stewardship. In the absence of such stewardship, these resources tend to be quickly, and often irretrievably, degraded. In most countries, this means that government, drawing on inputs from scientific and research communities, implements public policies intended to manage and sustain these resources. While there certainly have been notable successes resulting from government programs, there have also been many instances in which progress and outcomes have fallen well short of goals set. As in-shore marine resources suffer increasing degradation from the mounting pressures on them, both from pollution and over-exploitation, the need for improved management and monitoring is becoming ever more urgent. This urgency demands more of public policy, yet, in many countries, government's ability to effect the needed changes is constrained. The scale of actions needed at the local level to ensure there is citizen and private sector compliance with regulations; to ensure effective monitoring of resources is undertaken; and to ensure sufficient resources are allocated appropriately is enormous.

These issues are of key concern to the World Bank which has programs in place to assist countries in achieving sustainable industries including in-shore marine resource management. In particular, we focus here on challenges related to the West Africa region and how we may learn from best practices elsewhere in the world. We report on the growing trend to engage citizens and communities, often on a volunteer basis, directly in the stewardship of in-shore marine resources as a complement to scientific and public policy initiatives.

We begin by providing some background on the circumstances and premises which have fostered this community-based approach. We go on to describe how, and why, the approach, which is now common across much of North America, is increasingly being adopted by developing countries, and is of great interest now in the West Africa sub-region. We identify how efforts to strengthen community-based initiatives are being enhanced by an examination of the 'lessons learned' from some of the longer-standing initiatives, and how this learning is informing practices in West Africa. We consider the interesting 'lessons learned' from one of case studies, that of the Magothy River Association (MRA) which operates in Maryland. Finally, we also consider how the experiences of the MRA and case studies of other community based volunteer initiatives are informing the preparation of a 'Community Science Toolkit for In-shore Marine Resource Management.'

Introducing the Community-Based Science Approach in West Africa

A nascent, but growing, body of experience is showing that community volunteer groups can potentially play a very supportive and cost-effective role in natural resources stewardship whilst working within the umbrella of national and state policies and regulations. The premise underlying this community-based approach is that local communities are the obvious custodians of resources in their locality. These communities have the most immediate interest in ensuring their maintenance and being very well-placed to monitor the conditions and health of the resources. By taking advantage of local knowledge and expertise, community volunteers can often complete projects in less time and with lower cost than those undertaken by government entities alone.

Due to exceptional natural conditions the countries of West Africa, from Senegal to Ghana (Figure 1), were endowed with some of the richest fishing grounds in the world. The in-shore marine fisheries, which include demersals, smaller pelagics, cephalopods, and a wide variety of shrimp and shellfish, constitute a significant natural capital for these countries. Approximately 1.5 million tons of fish and marine creatures are legally captured in these countries' waters annually, the bulk of it by small-scale artisanal fishers operating in small boats holding between two and 20 crew and using small outboard motors, the largest being 40 hp. The in-shore marine resources are a major source of employment, provide a vital source of animal protein for the population, are an important contributor to countries' GDP, and an impressive earner of foreign exchange.

Figure 1. Political map showing selected West African Countries. (source: University of Texas at Austin Perry-Castaneda Library Map Collection).

In Senegal, for instance, the in-shore marine fisheries sector plays an important role in the culture, lives and economy of the population at large. Fishing and associated activities such as processing, marketing, services and other part-time activities together provide more than 600,000 jobs which accounts for 17% of the labor force. The population relies on fish products to supply as much as 70% of its animal protein needs, and have a higher annual per capita consumption of fish (26 kg) than most nations. Fisheries account for around 2.3% of the country's GDP and roughly 37% of the country's total export value (World Bank, 2008). Similarly, in Ghana, the fisheries sector contributes up to 4.5% of GDP (totaling around US$1.35 billion in 2008), provides employment for as many as 1.5 million people, supplies two thirds of Ghanaians' animal protein needs, and is the country's third most important export (World Bank, 2009a). And, in Sierra Leone, fisheries directly employ some 100,000 people and indirectly some 500,000 people, which together comprise almost 10% of the population. Artisanal fishers in Sierra Leone landed about 120,000 tons of fish in 2006 (World Bank, 2009b).

Despite the clear economic and social importance of the in-shore marine fisheries to these countries, the sector has been facing major difficulties in recent years. These are most evident in Senegal and Ghana, but are also becoming increasingly pronounced in countries such as Sierra Leone and Liberia. Catch levels are declining significantly, higher value fish are increasingly rare, and significantly higher levels of fishing effort are required to land the same, or a lower, catch. These problems are largely a consequence of overfishing.

Over the past two decades, there has been an uncontrolled expansion in the number of fishers (mainly artisanal), boats and gear; the unbridled use of highly destructive fishing gear, including small mesh monofilament nets and beach seining; and a rapid expansion of often inefficient and wasteful land-based fish processing systems. A small, but poorly regulated, fisheries industry which frequently employs highly damaging methods (including pair trawling) and which transships most of its catch to foreign countries is adding to the problems. Countries' economies and the livelihoods of a significant segment of their populations are already being impacted by these problems. And, the small scale artisanal fishers, once relatively wealthy from their industry, are now caught in a cycle of poverty in which they must invest increasing effort to get ever-diminishing returns. There is, of course, a ripple-up effect for the countries at large: in Ghana, for instance, poor fisheries management is estimated to be costing the country around US$100 million in lost wealth annually, at the same time that it is contributing to the imminent collapse of fish stocks (World Bank, 2009a).

To redress these difficulties, improved sector governance is required in the countries. This would require introducing and, very importantly, implementing effective regulations; limiting or capping further expansions in the number of fishers; ensuring careful assessments and monitoring of fish stocks and the in-shore marine environment; and educating fishers and the broader public on the need for sound management of the resources, amongst other actions. Governments in many of these countries, however, face significant challenges in this regard. They face some of the same problems as governments of more developed countries. The resource requirements are very high and government's reach is limited. Additionally, though, these countries often lack the institutional capacity to craft and, very importantly, implement effective legislation and regulations. Thus, many fishers have only a limited understanding of regulations in place and flout them in the absence of oversight and sanctions. Moreover, assessments of existing fishery stocks and the capacity to monitor their status are very limited, which makes effective stewardship very difficult. The possible political implications of remedial actions also make some governments hesitant to introduce and enforce some measures.

Local fishing communities in these countries, however, face an increasingly harsh existence as they struggle to make a very minimal livelihood. Artisanal fishers are now believed to be one of the poorest population groups in these countries. With very limited education, and very few, if any, alternative employment opportunities, they are caught in a poverty trap. Many communities, keenly aware of their dire circumstances, want better management of their local fisheries resources. They are reconsidering traditional and once-common practices of allowing biological rest periods for species, and setting aside no-fish areas where species are known to reproduce, and are interested in newer practices such as the introduction of artificial reefs. Traditional community structures can support the re-introduction of these useful practices, but they are requiring support and guidance, both of a logistical and scientific nature, on how to better manages the in-shore marine resources in their locality.

Experience elsewhere suggests that the best chance for improved sector governance lies in an approach where government establishes an umbrella of policies and practices in concert with communities being given the right and responsibility for managing, monitoring and sustaining in-shore marine resources in their locality. Central governments have recognized this and are moving to increase communities' capacity to take on stewardship by learning from successful, community-level, volunteer initiatives in other countries. Accordingly, the World Bank, through its technical assistance and lending program, is supporting the introduction of community co-management in these countries to improve stewardship of these in-shore marine resources, whilst also supporting needed capacity building at the central government level. In concert with those efforts, the World Bank is working to develop a 'Community Science Toolkit for In-shore Marine Resource Management' which will provide communities, and also interested non-governmental organizations and other civic groups, with the information and tools needed for local stewardship of the in-shore marine resources.

The Community Science Toolkit: A Case Study of the Magothy River Association

The 'Community Science Toolkit for In-Shore Marine Resource Management' (hereafter referred to as the Toolkit), draws on a number of case studies of community-level, volunteer organizations whose primary objectives include stewardship and conservation of the in-shore marine environment. The Magothy River Association's (MRA) Scientific dive team unit is one of the case studies and is yielding sound 'lessons of experience.' We provide some context and background on the MRA, and discuss its objectives, structure and operation, and achievements. The section concludes by highlighting some of the key 'lessons learned' that can inform the launch and effective operation of other such organizations.

The Magothy River is located within the upper western shore watershed of the Chesapeake Bay, between Baltimore and Annapolis in Maryland, USA (Figure 2). The Magothy River (Figure 3) is six miles long and covers nine square miles of the total approximately 40 square miles of the watershed. The area surrounding the Magothy River is residentially developed except for a small portion on the north shore which is preserved by a land trust. As the Chesapeake Bay opens to the Atlantic Ocean, the Magothy River waters are brackish.

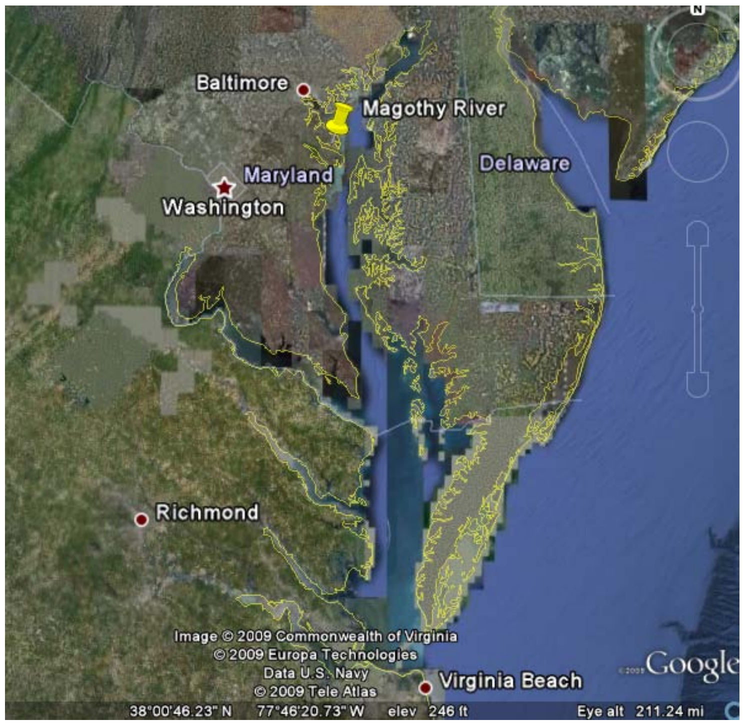

Figure 2. Map showing location of Magothy Watershed within the Chesapeake Bay (source: Google Earth).

Figure 3. Detail of Magothy River watershed (source: Google Earth).

The Chesapeake Bay, including the Magothy River area, once had an abundance of oysters (*Crassostrea virginica*) at the turn of the century. Oyster beds were so profuse that they would break the surface at low tide. However, over time, the entire watershed has suffered from over-harvesting of resources, habitat destruction, pollution and disease. As a result, the Bay's oyster population is now a mere one% of what it was at historic levels (NOAA, 2007). The Magothy watershed also has suffered severe environmental degradation. Oysters were exploited to the point of collapse (all commercial and recreational harvesting was closed in 2001). Throughout the Chesapeake Bay and its tributaries, water input into the watershed has been reduced by damming. Sediment loads in the water are very high from storm water run-off. Nutrient enrichment of the water (*i.e.*, eutrophication) from point sources and non-point sources (runoff from agriculture and lawn fertilizers, septic systems and atmospheric pollution) is pervasive. Eutrophication leads to algal blooms and subsequent algal die-offs which fuel oxygen consuming bacterial decomposition processes that further reduce the dissolved oxygen levels (Magothy River Association, 2001).

Efforts to restore the Chesapeake Bay, including the Magothy River area, started in the early 1980s with legislative efforts such as "The Chesapeake Bay Agreement of 1983" involving Pennsylvania, Maryland, Virginia and the District of Columbia. These efforts expanded to a wide spectrum of groups, including government entities from six States and the District of Columbia, non-government organizations, community and volunteer groups, fishermen's groups, and some private sector organizations with the "Chesapeake Bay 2000 Agreement." The 2000 Agreement set a strategy for recovery supported by a wide array of stakeholders, laid out some core goals for rehabilitation. The restoration of the oyster population has been a priority because, as filter feeders, they contribute significantly in cleaning the water and removing pollutants. The Agreement established a specific goal of achieving a ten-fold increase in the oyster population by 2010 from their 1994 levels (NOAA, 2007). The State of Maryland and a number of non-profits, including the Oyster Recovery Partnership, the Chesapeake Bay Foundation, and the Chesapeake Bay Trust, have established goals consistent with those of the 2000 Agreement.

The Magothy River Association, a non-profit 501(c)(3) association serves its watershed community and has, over the past two decades, become an important player in the oyster restoration and water quality improvement efforts in the Magothy River. Founded in 1946 by residents organizing to prevent the area from becoming a US Navy seaplane base, it later took on issues of zoning, land use, and land preservation. It then increasingly took on environmental concerns and as early as 1983 began efforts to monitor water quality. It is now very actively engaged in monitoring the environmental health of its watershed area. The MRA now represents 46 communities, has approximately 350 members, and rallies many volunteers to work on a range of environmental stewardship initiatives. With programs now focusing on submerged aquatic vegetation, oyster reef restoration and monitoring, water quality monitoring, and fish habitat restoration, the MRA is well-recognized for its work in the Magothy watershed.

One of the most active stewardship initiatives operating under the MRA umbrella is the Volunteer Scientific Dive Team, which got underway in 1998. The Dive Team was initially launched by the then MRA President who believed that more effective monitoring of the watershed, including its recently re-planted oyster beds, could be undertaken by underwater reconnaissance. The initial team of just two divers has now grown to include a roster of 50 divers, with around 15 divers being active at any time. The dive team directly supports four of the six environmental activities which are under the MRA umbrella (Figure 4). The team typically undertakes restoration and monitoring dives in the Magothy watershed in the summer months. Low water temperatures require winter dive activities to be more limited.

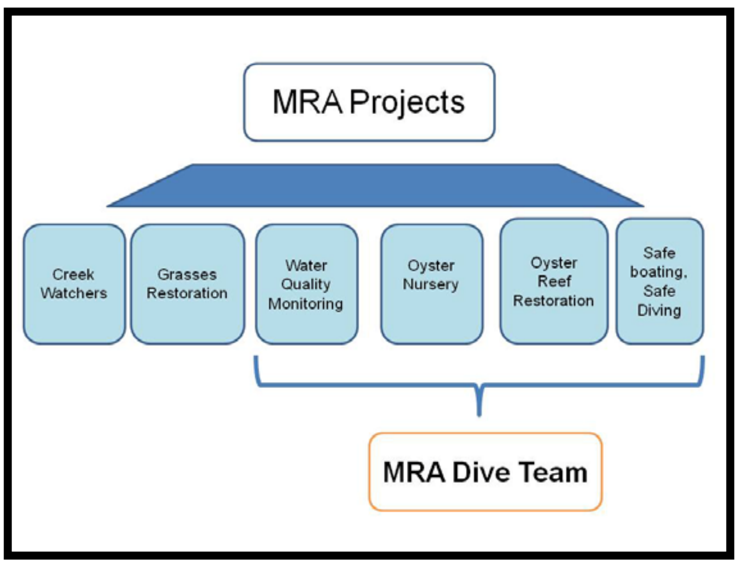

Figure 4. MRA scientific dive team support for MRA environmental projects.

There was a need for clearer leadership of the dive team as its activities expanded. A dive coordinator position was established and was filled by an existing volunteer. The coordinator brought a high level of technical dive training, experience in the dive industry, good connections in the scientific diving community, personal relationships with many residents and administrators in the Magothy area, great drive and commitment, and free time accorded by retirement. The coordinator was well-positioned to further develop the Team's purpose and objectives and establish plans for longer-term initiatives. Dive team leadership has continued to be provided by the original dive coordinator who remains its champion, serving as the person who sets dive schedules, recruits and works to retain qualified volunteer divers, provides the boat for dive trips, liaises with the MRA, manages data collection and archiving efforts, liaises with scientific and research entities, prepares proposals and requests for grants and in-kind contributions (of oyster spat-on-shell, for instance). The dive coordinator leads the dive organization in a number of outreach events (such as those for Earth Day, school outreach, etc.). While the dive coordinator receives support from dive team volunteers and other non-diving volunteer for these activities, at times it tends to be intermittent and spotty, and the continuance and success of the dive team activities often depends very much on his continuing commitment.

Dive team volunteers tend to be engaged primarily in the actual diving events, the planting and sampling of oysters, the setting of transect lines and buoys, the videographing of oyster reefs. As most of the volunteers hold down regular employment, they provide a few hours of dive time on weekends when it is convenient to them. The volunteers tend to go through cycles in which they are either frequently or infrequently able to assist, depending on their life circumstances at the time. New volunteers are attracted by word-of-mouth, through referral from area dive shops, or recruited by structured scientific diver workshop events. The workshops are held with the collaboration of the local community colleges, and institutions such as the US Naval Academy Oceanography Club and local recreation centers.

Diver training is conducted by volunteer instructors. These instructors are all teaching status qualified and actively teach as an independent or dive center affiliated instructor. During workshops and team training, member divers are integrated into program to help improve between diver cooperation. NOAA divers are often integrated into the program so they can meet their dive requirements and maintain their skills. When large groups of divers are employed in a project the traffic in the river often requires traffic control for the safety of the dive site. This is obtained by preparation of the USCG Marine Event Permit Request for USCG or USCG Auxiliary patrol. Monitoring of shellfish and other organisms requires a scientific permit for the activity. To insure proper technique and methods are used, Maryland Department of Natural Resources scientists are often invited to participate and coach the divers.

Qualification standards for dive team volunteers have also been upgraded over time and as activities and procedures have been developed and institutionalized. This is a particularly interesting example of a volunteer organization given the high level of technical training and expensive equipment required to undertake the activities. Divers have always been required to have appropriate diving certifications from nationally recognized agencies. But, in 2006, the MRA dive team became an organizational member of the American Association for Underwater Sciences (AAUS) which helped significantly in formalized practices around dive planning, maintenance of diving records, pro forma for medical procedures, etc. To ensure consistency with AAUS standards, a "New Diver Package" was issued which requires that all dive team members annually lodge copies of their diving certifications, medical and diving history, liability release forms, emergency notifications, and photographic release forms with the dive coordinator.

Financing for dive team activities is derived from a number of sources. The team has adopted a particularly efficient approach to its management. Many volunteer organizations struggle to meet the financial requirements that come with monetary contributions, which include frequently bookkeeping, auditing, etc. The dive team has avoided much of the burden of dealing with finances by receiving much of its inputs in the form of in-kind contributions. Some monies (around US$5,000 in 2008) are gathered. This has been clever approach, which has all but eliminated the need to resource and manage the standard accounting and audit costs involved in running a volunteer group.

The dive team largely is self supporting with dues and grants income (Figure 5). Members pay annual dues to the Magothy River Association and these monies are earmarked for dive team operations. Other funding is from reimbursement of expenses incurred on behalf of the MRA or grants obtained for projects. Occasionally the dive team renders assistance to local boaters or residents. Any gratuities are donated directly to the dive team MRA account. These funds are normally used for fuel, air fills and AAUS membership dues. The diagram below provides a schematic of the principal sources and proportional contribution of the dive team's resources. The MRA manages these revenues on behalf of the dive team. The dive team has written a few grant proposals for financing projects. These have provided only limited financing and are modest in scope. In-kind resourcing supports the bulk of the dive team's needs, and is received in response to specific requests and proposals. Thus, for example, in 2007, the dive team received substrate to install a new reef with a value of around US$125,000 from the Maryland Department of Natural Resources. In 2008, they received 15 million oysters for planting from the Oyster Recover Project with an estimated value of US$300,000.

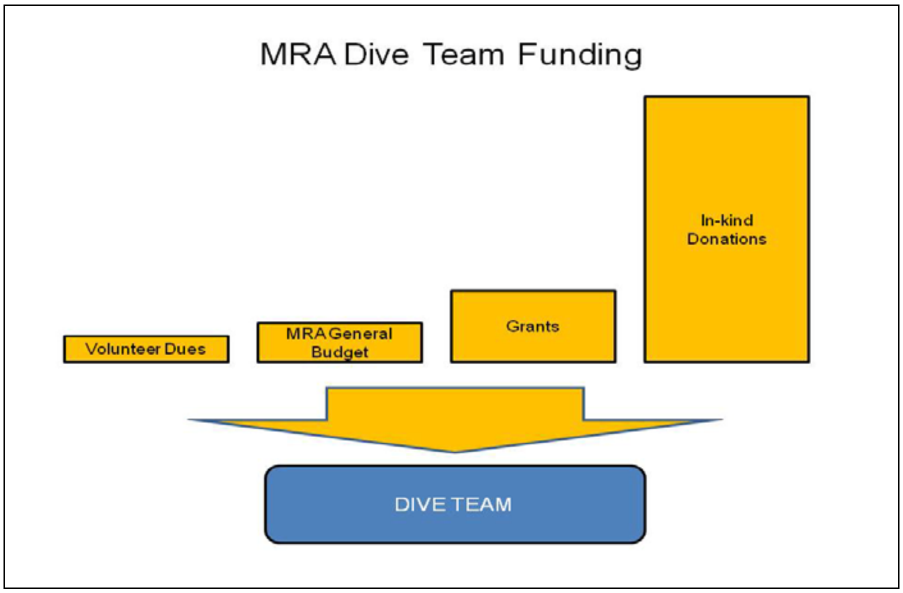

Figure 5. Magothy River Association scientific dive team funding.

Dive team activities were boosted considerably in 2001 with the publication of the MRA's five-year plan for oyster restoration in the Magothy River (Magothy River Association, 2001) and revised in 2006 "Clear and Clean Water, A Five Year Plan for the Magothy River 2005-2010" (Magothy River Association, 2008). This plan was presented at the February 2006 State of the Magothy meeting. It has been updated periodically to reflect current knowledge and conditions with the latest revision July 30, 2008. This plan reviewed conditions in the Magothy watershed, provided important background on the status of oyster populations in the watershed, developed a clear rationale for focusing on oyster restoration in the locality, and presented a strategy and plan for oyster restoration efforts. The restoration plan was based on four elements: i) system characterization (essentially the identification of sites most suitable for restoration activities); ii) a brood stock study (under which the most appropriate sources for new oyster spat were identified); iii) restoration projects (which identified sites and modes for oyster restoration); and iv) adaptive management (which laid out schedules for reviewing and refining strategies). This five-year plan was significant in helping achieve closure of all commercial and recreational oyster harvesting in the Magothy River. Closure was critical if restoration was to be undertaken effectively.

The dive team's objectives and activities were thus sharpened in 2001 and have since been directly supportive of the five-year plan. It is informative to consider a few of the dive team's activities as they illustrate the technical nature and scientific value of the work. The team has, for instance undertaken a number of recruitment studies where oyster shells were placed in suitable areas to serve as oyster spat collectors. Laid carefully along pre-set transect lines, the shells were later recovered and sampled for spat set. In the 2002 Recruitment Study, 3.0 to 4.5 spat per 1,000 shells were recorded for three different sites (Carey and Ducey, 2005).

In another effort in 2003, the dive team supported the MRA in conducting an oyster brood stock study. In this case, the Team recovered oysters and remnants from an old oyster lease where some of the oysters were estimated to up to 10 years old. Working with the Maryland Department of Natural Resources and the University of Maryland Center for Environmental Science (UMCES), brood oysters from this stock, and a separate hatchery stock were produced for a blind oyster growth study undertaken by oyster gardeners who grew oysters in cages at private piers around the watershed. This study was interrupted by an explosion of the dark false mussels (*Mytilopsis leucophaeata*) which resulted after Hurricane Isabel. We will discuss the potential impact of hurricanes like Isabelin a moment. From the brood study, it was noted that initially the hatchery stock grew faster than the brood stock but after several years the brood stock was slightly larger than the hatchery stock. This variation between the two samples could have been a result of the size at planting and environmental conditions (hurricane Isabel and 10 inches rain from tropical storm Ivan).

The explosion of dark false mussels in 2003-2004 attached to pilings in the creeks of the river created a lot of excitement. Creek water became clean and clear. One NOAA scientist hypothesized that the dark false mussels rode in on the coattails of Hurricane Isabel in late 2003, their larvae catching a plume of water that moved up from the saltier mid-Bay, where these creatures tend to live among oyster reefs (Goldman, 2007). Government researchers were unable to respond to assess the dark false mussels primarily because funding was not available and insufficient time was available to redirect resources. The dive team was asked to step up and fill the gap. With essentially no funding the team produced a protocol, obtained peer review and approval, sampled, processed data, prepared a video report and paper (Magothy River Association, 2008). The results and findings of this project formed the bases and guide lines for the revised five year plan and subsequent revisions (Magothy River Association, 2001). A NOAA scientist revisited these data on numerous occasions which has lead to presentations at the 2005 and 2009 meetings of the Coastal and Estuarine Research Federation.

In 2006, the team worked with the Oyster Recovery Partnership (ORP) and obtained a planting of 5.5 million spat on shell on three reefs. By 2008, an additional 15 million oyster spat on shell, again provided by ORP was planted in the Magothy. In 2009, plans are to plant an additional 6.4 million oyster spat on shell to renew oyster levels on a reef planted in 1998. To support the planting initiatives, the Team has, since 2003, conducted frequent monitoring of the five main oyster reef sites in the Magothy, Chest Neck Point, Rock Point, Ulmstead Point, Dobbin Hill and Persimmon Point. The protocol and procedures for monitoring have been developed with input from the UMCES to ensure that it conforms to scientific standards and procedures. Randomized sampling is also undertaken periodically to measure oyster health and growth. Samples are collected periodically and sent to laboratories at UMCES/VIMS (Virginia Institute for Marine Science) for disease testing. Videos records are made of the different oyster reefs so recording substrate condition, oyster size and reef structure. This recorded information is archived for future reference.

Another important activity undertaken by the dive team in the course of their oyster monitoring work is the collection of information on water quality, including dissolved oxygen content, clarity, and salinity, amongst other measures such as oyster growth (Figure 6). Appropriate scientific equipment has been obtained for this purpose and time-series data provide important input on the suitability of environmental conditions for oyster recovery. The data are shared with various research and academic institutions and are made available to the broader public, including at the MRA's annual "State of the Magothy" event which is held for all residents of the watershed and general public.

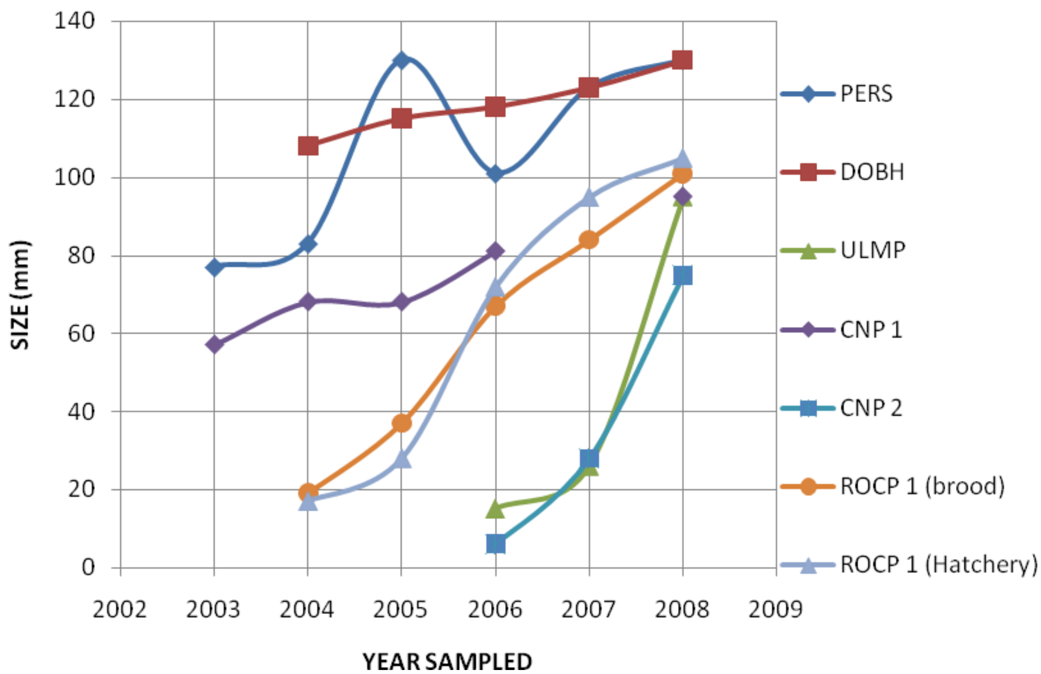

Figure 6. Chart of dive team Data showing Oyster Growth by Location over Time
Notes: PERS is Persimmon Point; DOBH is Dobbins Point; ULMP is Olmsted Point
(source: Richard Carey, dive team Coordinator, MRA Dive Team).

The dive team also undertakes activities beyond those involved with oyster rehabilitation. In 2004 the MRA and the MRA dive team with partners from Maryland Environmental Services (MES), funded by Fish America and Chesapeake Bay Foundation undertook a project to increase habitat in the Magothy River by installing reef balls. The project involved two sites one adjacent to an oyster reef and one in an open area. Each site received 55 reef balls. As part of the program two reef ball pours, one at Anne Arundel Community College and one at Ferry Point Marina were made. These reef balls were moved by divers and positioned on a third oyster reef. Working with Department of Natural Resources Fisheries Department the Pasadena Fishing Club fished these sites reporting their catch. Although not part of this program Maryland Saltwater Sportfisherman Association (MSSA) working with the watershed's only green school. Gibson Island Country School produced several reef balls. MRA divers provided in water support for placement of these reef balls adjacent to their pier.

Data collection is, of course, a critical component of the dive team's work. Data are immediately important to the Team because it provides feedback to the volunteers on progress in the watershed that might, at least in part, be attributed to their efforts. However, it is also used to inform Magothy community outreach and education efforts, including on pollution incidents, effective implementation of critical area laws which restrict development within 1,000 feet of the shoreline and zoning requirements. These data also are given to a number of scientific, research and public policy entities, complementing their more periodic assessments of the Chesapeake Bay watershed with frequently-gathered data on a specific area. The dive team has liaised with various institutions (Department of

Natural Resources, UMCES, and NOAA) to establish scientifically acceptable data collection protocols and has ensured that any equipment used in data gathering is trade standard and approved by the scientific institutions. The dive coordinator archives all data collected by volunteers.

The team undertakes only very limited analysis of the data, instead forwarding the information to interested scientific and policy entities such as the Department of Natural Resources and UMCES. It is not clear to what extent these institutions actually use the data. UMCES, for instance, reports that it does not actively utilize the data but does keep an eye on it to identify any unexpected trends or findings which it then follows up on. The data are used in the preparation of the annual "State of the Magothy" report, which includes the 'Magothy Index Card' produced by the NOAA Chesapeake Bay office (Figure 7).

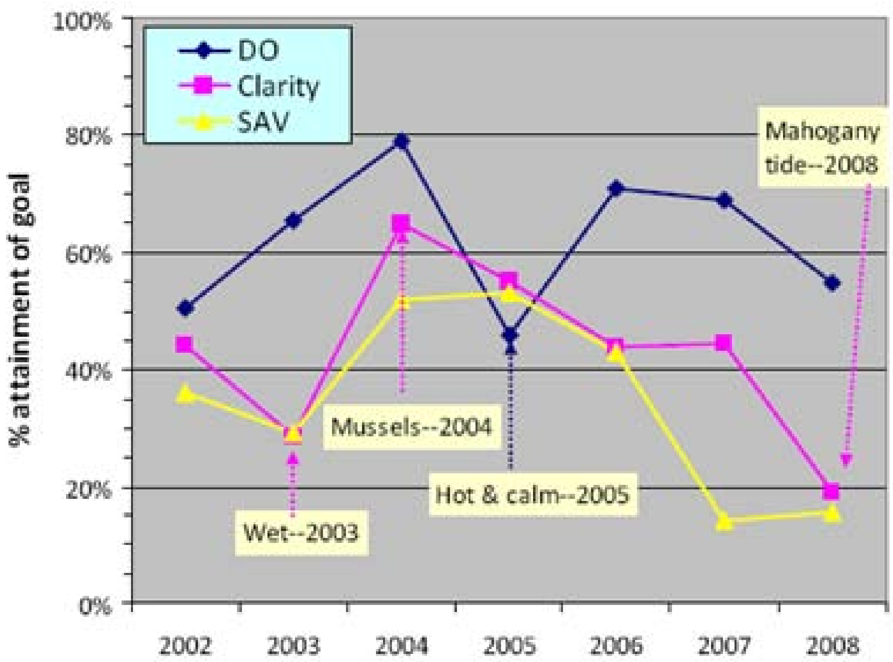

Figure 7. Magothy Index Card (2008) which draws on MRA Scientific dive team Data (source: NOAA Chesapeake Bay Office, 2008).

Community education and outreach to raise awareness about the health of the Magothy watershed is also an important activity for the dive team. The dive coordinator, usually with support from some volunteers, makes use of many venues to educate the local community on the health of the oysters and water quality. The dive coordinator makes presentations on the dive team's work and findings at annual community events organized by the MRA such as the State of the Magothy meeting, the annual MRA picnic, etc. Each year on Earth Day the dive team hosts the practical training and open water exercises for its scientific dive training with participation from the U.S. Naval Academy Midshipmen. Other outreach occurs through the MRA web site where information, including videos on the scientific dive workshop, oyster monitoring, and the dark false mussel study is hosted (see: www.magothyriver.org/projects/volunteer-diver-program). The dive team also provides assistance, including with data collection, to college students who choose to study aspects of the Magothy for theses and coursework. At the community level the dive coordinator oversees 4 oyster nurseries, one each located in Cape St. Claire and Ulmstead communities and two located at the county Downs Park. Periodically divers are needed at Downs Park to repair or clean marine growth from the water intake which extend several hundred feet into the Bay

Informing the Community Science Toolkit: Lessons from the MRA Scientific Dive Team

The MRA Scientific dive team is an interesting example of a community-level, volunteer organization. It has achieved some considerable success in advancing its agenda of improving management of in-shore marine resources so conditions in the Magothy watershed can be improved. The dive team's success can be measured by the fact that it has: sustained itself for almost a decade; identified and focused on activities where it, very specifically, can add value (underwater oyster and resource management); attracted and maintained a sizeable roster of technically competent volunteers; garnered adequate resourcing to advance its objectives and operations; and has engaged and partnered with different entities that both provide it with technical and scientific support and draw on its work and output. These are all hallmarks of an effective volunteer organization.

Discussion

In general, community-level, volunteer groups confront considerable challenges in achieving effectiveness, including those of leadership, financing and resourcing, and continuity of membership. And, when those factors are in place, possibly the biggest challenge of all arises, which is making sure that the group's work is sustainable, resourced, relevant, recognized, drawn on, and of utility to some wider community. The MRA scientific dive team has met these challenges quite effectively and, for this reason, provides some useful 'lessons of experience' for others wanting to establish or strengthen a community-level, volunteer organization working in the realm of community science. Many of these lessons are generic and have relevance across different communities, cultures, economic conditions, and even countries. It is these 'lessons of experience' that are informing development of the "Community Science Toolkit for In-shore Marine Resource Management," and which are likely to have direct applicability to community management initiatives in West African countries. These lessons highlight the importance community-level, voluntary organizations should give to:

- ***Developing clear objectives:*** The dive team's effectiveness rests, to some considerable extent, on the fact that its purpose and objectives are well-defined and clear. It benefitted greatly from the MRA's publication of its five-year plan for oyster restoration in the Magothy River from which its objectives were immediately derived. Clarity of objectives and purpose has ensured that the Team's limited energies and resources have been utilized efficiently in the pursuit of a specific purpose. It has also played an important role in retaining and energizing volunteers since they have been better able to appreciate how their time and inputs contribute to these objectives.

- ***Ensuring they provide a 'niche' service:*** The dive team, because of the specialized nature of its activities, has developed a niche which could not easily be filled by other volunteers or by private contractors at a reasonable cost. It generates fairly unique data because of the way the data are collected (underwater), which helps to ensure that there is a 'market' for it.

- ***Fostering a 'champion':*** Volunteer organizations, including the dive team, seem to flourish best when they have strong, steady, and recognized leadership. Given that these entities are comprised entirely of volunteers, this means providing the space for a champion to emerge who has the energy, knowledge, organizational capacity, people skills and, very importantly, time, to provide the necessary leadership. As was the case with the dive team, this person might not necessarily be the individual who launched the initiative. The champion is likely to emerge only once a volunteer base has been established and activities have gotten underway; they engage, become increasingly integrated into the entity's activities, and grow to become central to its growth and continuance. It is also very helpful to establish a formal title/position for the champion – as was done by the dive team when the dive coordinator position was established – as this consolidates his/her leadership of the group and creates an organizational structure for the entity. While it is very important to foster a champion, it is also important that the entity keep the following points in mind. First, while a champion brings a skills mix and experience with them from a previous job or position, their skills and experience are unlikely to mesh entirely with the entity's needs since the person is a volunteer rather than a screened and selected job applicant. Any mismatch with skills needed by the entity can cause problems, and mean that the champion's role as leader may be difficult, and sometimes contentious; this needs to be acknowledged. Second, it is also important to recognize that many volunteer entities come to rely very heavily on the champion's support because other volunteers have more limited time or inclination. When this happens, the retirement of the champion from the entity often leads to its collapse. To ensure continuity attention must be paid to a successful succession plan.

- ***Being savvy about resourcing:*** Many volunteer groups flounder under the demands of raising funds and managing them. Proposal writing is time consuming and often requires technical input. And, once funding is secured, it comes with the burden of management, auditing and reporting, a resource and time-intensive function that must then performed either by a volunteer with the necessary qualifications or by contracting and paying for the service. The dive team has benefited greatly by being very savvy about generating resources. It has generated a small amount of funding from membership dues to cover basic operating expenses, but has obtained most of its resources in-kind (as oysters, reefballs, etc.) which, therefore avoiding the burden of financial management. This has allowed it to pursue its activities while minimizing the requirements for financial management and reporting.

- ***Working to establish and maintain symbiotic partnerships:*** The dive team has, over the years, developed strategic relationships that are of mutual benefit to both parties. A case in point is the relationship with UMCES; the dive team shares its data with UMCES for its use, and the UMCES provides technical advice to the dive team on establishing scientific protocols for data collection. Similarly, the MRA uses the dive team's data for its purposes (environmental monitoring, zoning, etc.) while providing assistance in gathering and managing Team membership dues. The dive team has also, on occasion, undertaken specific data collection activities at the request of a partner and this has consolidated the partnership. Symbiotic partnerships can be enormously beneficial to a volunteer organization; they can be a source of technical assistance, a source for ensuring that volunteer outputs are used and disseminated; and serve as a 'reality check' against which the volunteer organization can assess the adequacy and utility of their outputs to a broader community. There is obviously benefit to ensuring that such partnerships are built with a range of different entities – government, research, scientific, community, etc.

- ***Recruiting a sizeable roster of volunteers:*** In all volunteer entities, the time commitment of volunteers fluctuates constantly; volunteers' levels of engagement change as the demands of regular employment, family, travel, etc. on them change. To ensure continuity and follow-through on the entity's commitments and activities, it is therefore important that volunteer entities establish a sizeable roster of qualified volunteers. The dive team illustrates this principle well – it maintains a roster of around 50 qualified divers knowing that only around 15 will be active at any time. And, it works to augment its roster each year by running an annual workshop draws potential recruits by offering training in scientific diving.

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Assessing Seasonal Variation of Epibenthic Community Structure on Restored Oyster Reefs: Macroinvertebrate Biodiversity and Polychaete (*Nereis succinea*) Biomass

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Abstract

A novel sampling apparatus using quadrat procedures was used to perform benthic sampling on three restored oyster reefs in the Magothy River of the Chesapeake Bay. Changes in macroinvertebrate biodiversity and biomass of the common clam worm *Nereis succinea* associated with oyster reefs were determined for the summer-fall transition and fall-winter transition. Eleven species were reported, with amphipods, hooked mussels (*Ischadium recurvrum*) and *N. succinea* accounting for 90% of the total individuals found across the three reefs with a total of 5,836 individuals collected. Significant increases in biodiversity from the summer to fall were seen on Persimmon Reef and Ulmstead Reef but a decrease was seen on Dobbins Hill Reef. Significant increases in biodiversity from the fall to winter were seen on Ulmstead and Dobbins Hill Reef. *N. succinea* biomass significantly increased from the summer to fall only at the Dobbins Hill Reef. Continued research on benthic macroinvertebrate biodiversity is important in order to protect essential finfish species that rely on these organisms for prey.

Keywords: *Crassostrea virginica*, health, species abundance, sustainability

Introduction

Oyster reefs constructed by the Eastern Oyster (*Crassostrea virginica)* used to be a dominant feature and critical component of the Chesapeake Bay ecosystem. However, present Chesapeake Bay oyster populations have declined so drastically that they were estimated to be below 1% of historical populations by the late 1980s (Newell, 1988). By the mid 1990s, oyster bar acreage dropped to 50% of what it used to be the previous decade (Rothschild *et al.*, 1994). These massive declines have been influenced by multiple factors including reduced water quality (Haven and Morales 1966), diseases such as Dermo and MSX (Kennedy and Breisch, 1981, 1983) and overharvesting (Heral *et al.*, 1990).

The demise of the oyster population in the Chesapeake Bay is particularly problematic, as oysters are considered keystone species because they affect the livelihood of numerous organisms by filtering the water column, increasing vital habitats, and creating a nutrient rich environment for invertebrate prey essential for apex predators (Sanjeeva, 2008). Oysters create three-dimensional reefs that are formed over years of successful larval settlement and colonization (Dame, 1996). The gaps between the shells cause interstitial spaces that provide complex habitats and increased niche availability which give protection for small invertebrates. This effect of increasing habitat heterogeneity has earned oysters the name "ecosystem engineers" from Jones *et al.* (1994). As filter feeders, oysters reduce total suspended solids (TSS) as well as chlorophyll *a* concentrations in the water column (Nelson *et al.*, 2004). Filtering TSS in the water column can help increase water clarity, positively affecting species such as underwater Chesapeake Bay grasses known as submerged aquatic vegetation (SAV), by allowing for sunlight to penetrate the water column to support photosynthesis. SAV also helps provide additional vital habitats for juvenile fish and invertebrate species.

As oysters filter TSS from the water column, they concentrate and expel the filtered product in feces and pseudofeces, otherwise known as biodeposits. Biodeposition causes sedimentation of TSS to occur at a faster rate than passive sedimentation rates (Dame, 1993). This causes the sediment surrounding oysters to contain significantly higher levels of nutrients such as phosphorus and organic carbon than unfiltered sediments (Haven and Morales-Alamo, 1966). The nutrient laden sediment provides a food source for benthic deposit feeders (Lopez and Levinton, 1987) as well as stimulates microbial growth (Stoeck and Albers, 2000) which further attracts benthic macroinvertebrates (Marsh and Tenore, 1990).

Macroinvertebrates associated with oyster reefs include mussels, clams, polychaetes, snails, crabs and amphipods. These macroinvertebrates have been recognized for their importance in nutrient cycling and benthic pelagic coupling because they consume high energy substances like detritus and phytoplankton which then get passed to higher trophic levels when the invertebrates are preyed upon by larger species (Marsh and Tenore, 1990; Marcus and Boero, 1998). In the Chesapeake Bay, such higher level consumers are striped bass (*Morone saxitilis*), white perch (*Morone americana*), spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogonias undulates*) (Rodney and Paynter, 2006). All of these fish species are commercially and recreationally important, thus making the welfare of their prey species equally as important. Restored oyster reefs (supplementing historic oyster reefs with new oyster shell and seeding with juvenile oysters) have been shown to support higher densities of these macroinvertebrates than non-restored reefs, making them an important habitat in estuarine systems (Rodney and Paynter, 2006; Meyer and Townsend, 2000).

With oyster reefs being exposed to the hardships previously mentioned, it is important to observe the health of the reefs over time in order to determine whether or not they are sustainable. Biodiversity, or the number and abundance of species, is one of three components in determining a healthy ecosystem, alongside vigor (productivity) and resilience (ability to endure over time in the face of stress) (Costanza and Mageau, 1999). As proposed by Costanza and Mageau (1999), a 'healthy' ecosystem requires a productive diversity of components (biodiversity) with the ability to maintain resiliency during periods of stress instead of collapsing. If the habitat is sustainable, biodiversity, as well as the other components, should be maintained over time. This means that on a healthy reef, occasional stressors like disease, dredging and eutrophication will not detrimentally affect the habitat. However, with the current level of damage being done to oyster reefs in the Chesapeake Bay as previously mentioned, the ecosystems, in this case an oyster reef, cannot rebound. One way to quantify biodiversity on oyster reefs and assess sustainability or ecosystem health is to determine the number and abundance of benthic macroinvertebrates associated with the oyster reefs.

Macroinvertebrate biodiversity is subject to change due to environmental influences such as salinity, dissolved oxygen and temperature variation (Larsen, 1985; Holland *et al.*, 1977; Dauer *et al.*, 1992; Tyson and Pearson, 1991). Salinity influences the number of species present in a habitat as increasing salinity allows marine organisms to enter an area, whereas lower salinity areas only harbor hardier and more opportunistic species (Zettler *et al.*, 2007). Montague and Ley (1993) demonstrated that in Northeastern Florida Bay, for every 3% increase in standard deviation of salinity, benthic plant biomass and benthic animal biomass should decline by an order of magnitude.

Habitats with consistently low dissolved oxygen will have lower biodiversity than habitats with higher dissolved oxygen. For example, sections of the Rappahannock River exposed to low dissolved oxygen have significantly lower species diversity, lower biomass and lower proportion of deep-dwelling biomass compared to areas with higher dissolved oxygen (Dauer *et al.*, 1992).

Anthropogenic eutrophication (*i.e.*, runoff) also increases chances of severe declines in dissolved oxygen by causing abnormal algal blooms (Paerl and Whitall, 1999). Seasonal algal blooms can influence dissolved oxygen levels as the organisms die off as summer approaches, starting a decomposition process that can consume oxygen to such an extent that anoxic zones are created (Paerl and Whitall, 1999; Hallegraeff, 1993).

Seasonal temperature changes can also be important for biodiversity of epibenthic communities via reproductive cues. Many macroinvertebrate species, such as in the common clam worm, *Nereis succinea*, have their life cycles tied to the influence of seasonal transitions on water parameters such as temperature and salinity (Fong, 1991; Hardege *et al.*, 1990). Hardege *et al.* (1990) found in laboratory studies that elevating water temperatures during the new moon induced swarming in *N. succinea*, thus supporting the importance of temperature changes cuing reproduction. Female *N. succinea*, and potentially the males, die after reproduction (Detwiler *et al.*, 2002). *N. succinea* has a tight correlation between biomass and spawning cycle with a marked increase occurring prior to spring time spawning followed by a significant decrease directly after (Neuhoff, 1979). *N. succinea*, which is found on oyster reefs as well as other mesohaline habitats, is a euryhaline, opportunistic feeder that can either be a deposit feeder or prey on small invertebrates such as amphipods (Craig *et al.*, 2003). Due to their larger size compared to other invertebrates as well as being a dominant species in most areas of the Chesapeake Bay, these polychaetes are a vital prey species for the predatory fish (Kuhl and Oglesby, 1979; Larsen, 1985; Rodney and Paynter, 2006).

Studies on macroinvertebrates for measures such as biodiversity and biomass have been extensive in soft-sediments (Hines and Comtois, 1985; Holland *et al.*, 1977; Dauer, 1993; Snelgrove, 1998) but are limited on oyster reefs. This is because it is physically difficult to measure such parameters on oyster reefs due to the oyster shells hindering the ability to collect quantifiable samples. The present study aimed to create a protocol that can be used for studying the macroinvertebrate community associated with oyster reefs as well as quantifiably sampling oysters at the same time. This can lead to improved methods for hard substrate habitats to be studied as extensively as soft sediment habitats. The goal for the present study was to observe three restored oyster reefs in the Magothy River for changes in the biodiversity of the epibenthic community structure as well as total biomass of the polychaete *N. succinea* between the summer and fall seasons and the fall and winter seasons

Considering the combined effects of salinity, dissolved oxygen and temperature during seasonal changes on benthic macroinvertebrates, the biodiversity of macroinvertebrates associated with oyster reefs should vary with the seasons such that: 1) There will be an increase in biodiversity from the summer to fall transition as water temperatures decrease and dissolved oxygen and salinity increase, and 2) There will be a further increase in biodiversity from the fall to winter transition as dissolved oxygen and salinity levels remain relatively high. Additionally, *N. succinea* biomass should vary seasonally by increasing from the summer to the fall and then again from the fall to the winter due to its life cycle. This study focused on the changes between adjacent seasons, so only comparisons will be made for the summer to fall transition and the fall to winter transition.

Methods

Study Site

The Magothy River runs through Anne Arundel County in Maryland and is a mesohaline tributary of the Chesapeake Bay, located between the Patapsco River and Severn River (Figure 1).

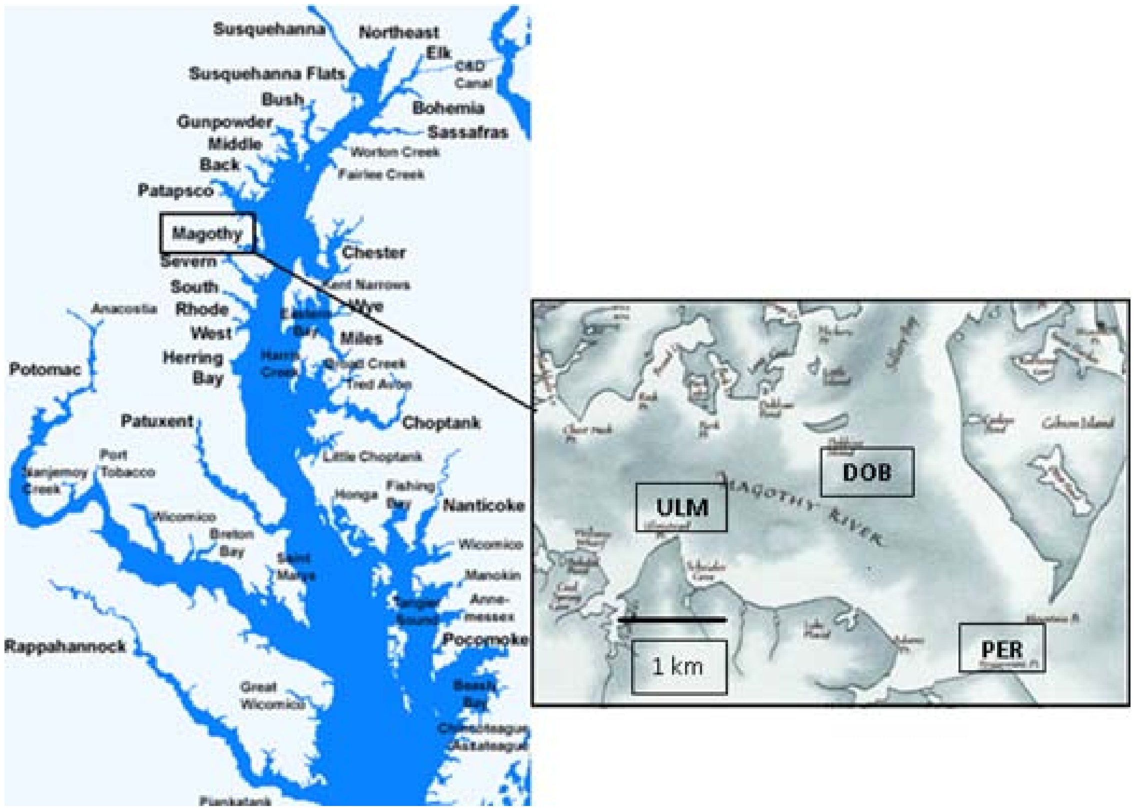

Figure 1. Map of the Chesapeake Bay (Inset: Magothy River and three oyster reefs in study).

The Magothy River is currently designated as an oyster reserve where oysters are protected against harvesting or other acts of removal (Natural Resources Article §4-1103 Harvest Reserve Regulation 08.02.04.13). The three oyster reefs focused on in the present study are Persimmon Reef (PERS), Ulmstead Reef (ULMP) and Dobbins Hill Reef (DOBH) which are listed in order of increasing silt substrate underneath the oyster shells (Figure 1). These reefs were chosen because of similarities in substrate, reef age and water depth. All three reefs are composed of disarticulated shell substrate (dredged shell), and were seeded between 1998 and 1999. The substrate is primarily sand below the shell layer on Persimmon Reef, sand and silt on Ulmstead Reef, and primarily silt on Dobbins Hill Reef. The water depth ranged on average from 3.7 m for Ulmstead and Dobbins Hill reefs to 4.3 m at Persimmon Reef. All three reefs are seeded sporadically with new oyster spat when resources are available. As oysters are not harvested, the age of the oysters present on these three reefs varies from a couple of years to a decade.

To determine where on the reefs to sample, locations were arbitrarily selected and assigned GPS coordinates. In order to protect the scuba divers involved in the study, samples on each reef were kept within 15 m of adjacent samples.

Water Quality Parameters

To determine whether or not water quality during the course of the study was similar to previous years, data for salinity, dissolved oxygen and temperature were obtained from the Magothy River Association. Measurements were taken using a handheld YSI Model 85 Instrument (Yellow Springs, OH) on all three reefs within a week of sampling.

Sampling Apparatus and Invertebrate Collection Method
To be able to sample the benthic macroinvertebrates on the oyster reef substrate, the Magothy River Association oyster sampling apparatus (Carey and Ducey, 2005) was adapted by adding a double layer mesh lining consisting of a sewn open top cube (29 cm x 29 cm x 35 cm) made from charcoal fiber window screening that rested inside a standard mesh laundry bag (4 mm) with a drawstring close (Figure 2). This allows retention of macroinvertebrates down to approximately 5 mm in size.

Figure 2. Oyster sampling apparatus used in the Magothy River Association along with mesh liner used to collect benthic macroinvertebrates. The oyster sampling apparatus was adapted from the Magothy River Association protocol which samples viability of the oyster reefs in the Magothy River. A mesh lining was inserted to collect macroinvertebrates while excavating dredged shell substrate along with live oysters. The quadrat used was 29 cm x 29 cm x 35 cm.

Samples were collected over three seasons, summer (July and August 2008), fall (November 2008) and winter (February 2009). Four samples were collected on each of the three reefs for each season. To obtain the benthic macroinvertebrate biodiversity and biomass samples for each reef, each sample entailed excavating the top 10 cm of substrate within the quadrat. All excavated material was placed into the lined crate. If no oysters were observed in the immediate area, the divers arbitrarily picked a new location with oysters present. After the sample was collected, the divers closed the drawstring on the laundry bag and left the crate for pick-up after all samples were completed.

To collect and sort the fauna, the contents of the mesh cube were moved into a clean five gallon plastic bucket and both the cube and the laundry bag were washed into the bucket with fresh river water. Because the oyster reefs are protected by law and no oysters can be taken off site, all live oysters were counted on the boat and returned to the reefs. To collect invertebrates living directly on the oysters a soft bristle brush was used to remove all sediment off the shells back into the specimen bucket. Any mussels attached to oysters were also counted before throwing the oysters overboard. Only live oysters and attached organisms were counted on the boat to reduce time spent in the field. The rest of the samples were packaged into labeled buckets and brought back to the laboratory for identification and enumeration. Macroinvertebrates were identified to major taxa and species. *N. succinea* polychaetes larger than 5 mm were counted and preserved in 70% isopropyl alcohol for future determination of biomass.

***Nereis succinea* Biomass**

The biomass of *N. succinea* samples was determined by blotting the entire sample on filter paper for one minute and weighing in grams. Because samples were preserved in alcohol and not immediately weighed, the wet weight was corrected by adding 13% to the measured value for each sample. According to Wetzel *et al.* (2005), weight loss in alcohol preserved specimens is largely restricted to the first 21 days, with *Nereis diversicolor*, a relative of *N. succinea,* losing 13% of its original mass during this time. Assuming these species are physiologically similar enough due to their phylogeny, both the summer and fall samples were held for at least 21 days before taking biomass measurements. Due to time constraints, the winter sample was measured immediately before being preserved and the correction factor for weight loss was not applied.

Statistical Analyses

To determine whether macroinvertebrate biodiversity changed from season to season for each reef, a t-test designed to compare Shannon Diversity Index values was used (Zar, 1999). Comparisons were made between summer and fall samples and fall and winter samples. A one-way ANOVA was used to test for differences in total *N. succinea* biomass between the seasons on each individual reef. A Tukey's post hoc test was used if data were significant. All statistics were conducted using SPSS version 16.

Results

Water Quality Parameters

Salinity ranged from 8 ppt in the summer to 15 ppt in the fall with the salinity reducing during the winter to 10 ppt. Salinity and temperature were the same on all three reefs and therefore reported as mean values, but dissolved oxygen is reported individually for each reef as there were greater differences among sites. All values can be found in Table 1. The mean depth was 3.7 m each for Ulmstead and Dobbins Hill and 4.3 m for Persimmon. The dissolved oxygen measurement for Persimmon in the winter season could not be collected due to inclement weather.

Table 1. Mean salinity and temperature parameters of Persimmon, Ulmstead and Dobbins Hill oyster reefs.

Season	Salinity (ppt)	Temperature (°C)	Dissolved Oxygen ($mg \cdot L^{-1}$)
Summer (Jul-Aug 2008)	8	25	6.72
Fall (Nov-Dec 2008)	15	10	10.15
Winter (Feb-Mar 2009)	10	3	12.29

Overall Macroinvertebrate Biodiversity

A novel sampling apparatus was used to measure macroinvertebrate biodiversity and *N. succinea* biomass on three oyster reefs in the Magothy River for the summer, fall and winter seasons. A total of 7,897 macroinvertebrate individuals were counted and sorted into 11 species representing six taxa. Three organisms were not identified to species - two unidentified species of gammerids (Order: *Amphipoda*) were labeled as *Gammarus* "A" and *Gammarus* "B" and one unidentified invertebrate species labeled as Species A. A significant increase in macroinvertebrate biodiversity was found in the fall when compared to summer on both Persimmon Reef ($t_{0.05\,(2),}$ 1818 = 5593.93, $p<0.05$) and Ulmstead Reef ($t_{0.05\,(2),}$ 1010 = 952.39, $p<0.05$). There was a significant decrease in macroinvertebrate biodiversity on Dobbins Hill Reef in the fall, as compared to summer ($t_{0.05(2),\,1831}$=2584; $p<0.05$) (Figure 3A).

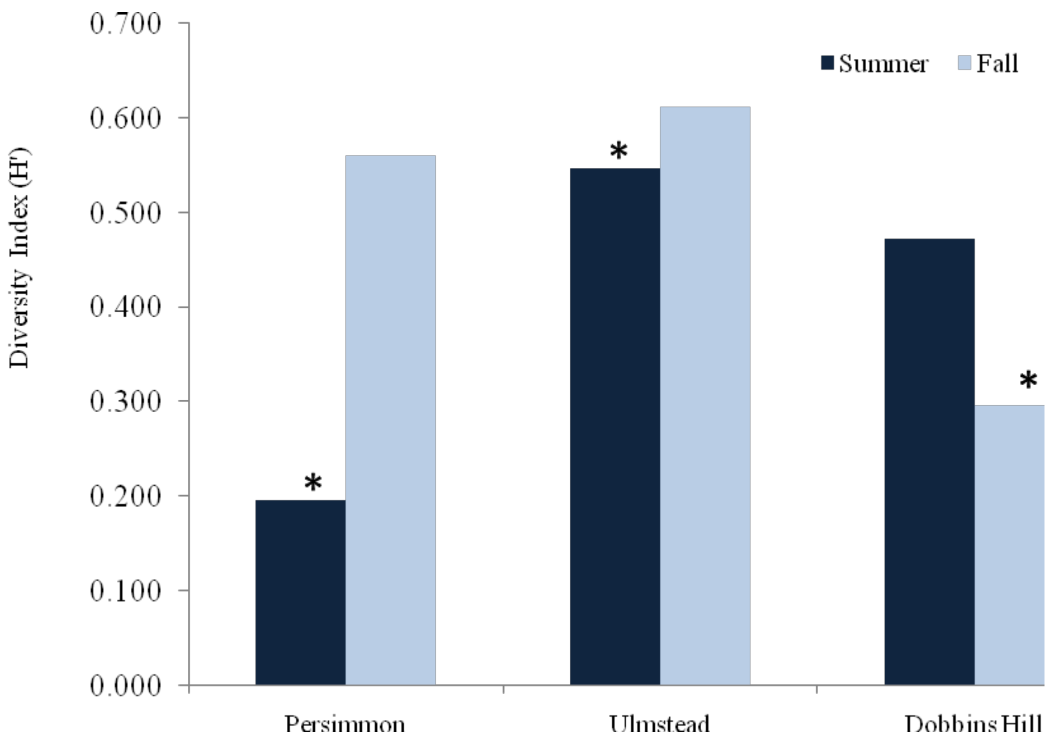

Figure 3A. Summer-Fall comparison.

Biodiversity was also significantly higher in the winter as compared to fall on both Ulmstead and Dobbins Hill Reefs ($t_{0.05(2),}$ 728 = 311.57, $p<0.05$; $t_{0.05(2),}$ 179 = 193.11, $p<0.05$) (Figure 3B). The three dominant species in the samples were *Gammarus* A, *Nereis succinea*, and *Ischadium recurvrum*, accounting for 95% of all individuals found. The comparison of the summer-fall seasons shows a significant increase in biodiversity on Persimmon ($t_{0.05(2),\,1818}$= 5593.92, $p<0.05$) and Ulmstead ($t_{0.05(2),\,1010}$ =952.39, $p<0.05$), but a significant decrease in biodiversity on Dobbins Hill ($t_{0.05(2),\,1831}$=2584, $p<0.05$). The fall-winter comparison shows that there was a significant increase in biodiversity on the Ulmstead ($t_{0.05(2),\,728}$ =311.57, $p<0.05$) and Dobbins Hill Reef ($t_{0.05\,(2),\,179}$ =193.11, $p<0.05$) as denoted by the asterisks (n=4).

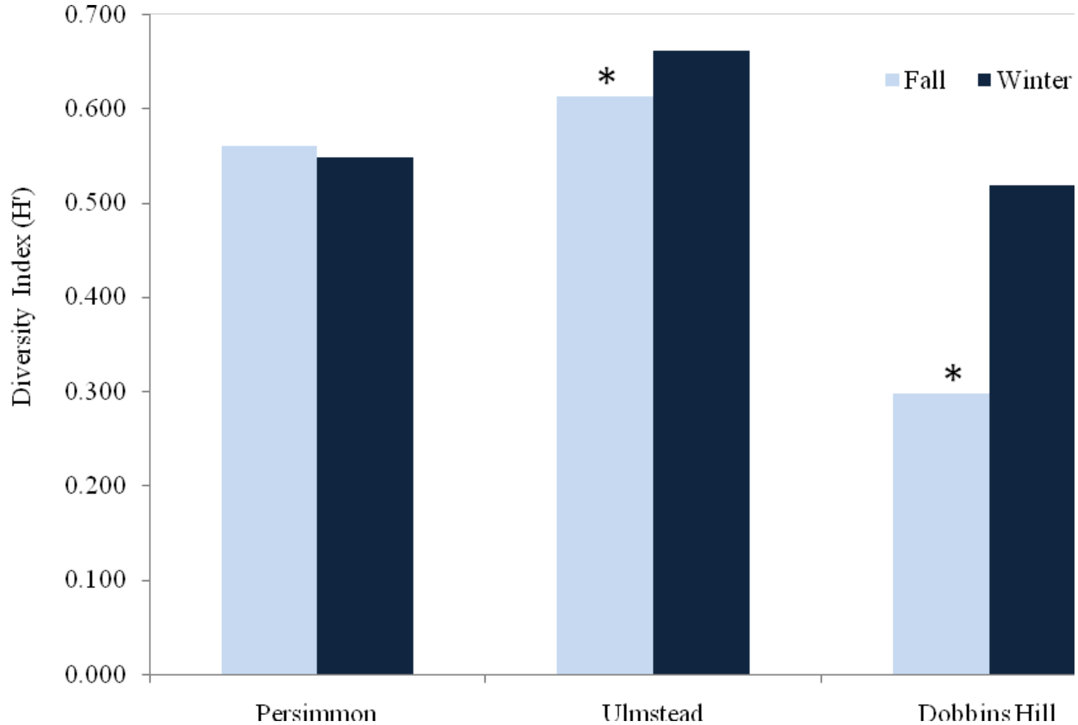

Figure 3B. Summer- Fall comparison.

The distribution of all the species across the seasons on each reef with the exception of the three dominant species are shown in Figure 4A with the dominant species being shown separately (Figure 4B) as their large numbers overshadow the representation of the less common species.

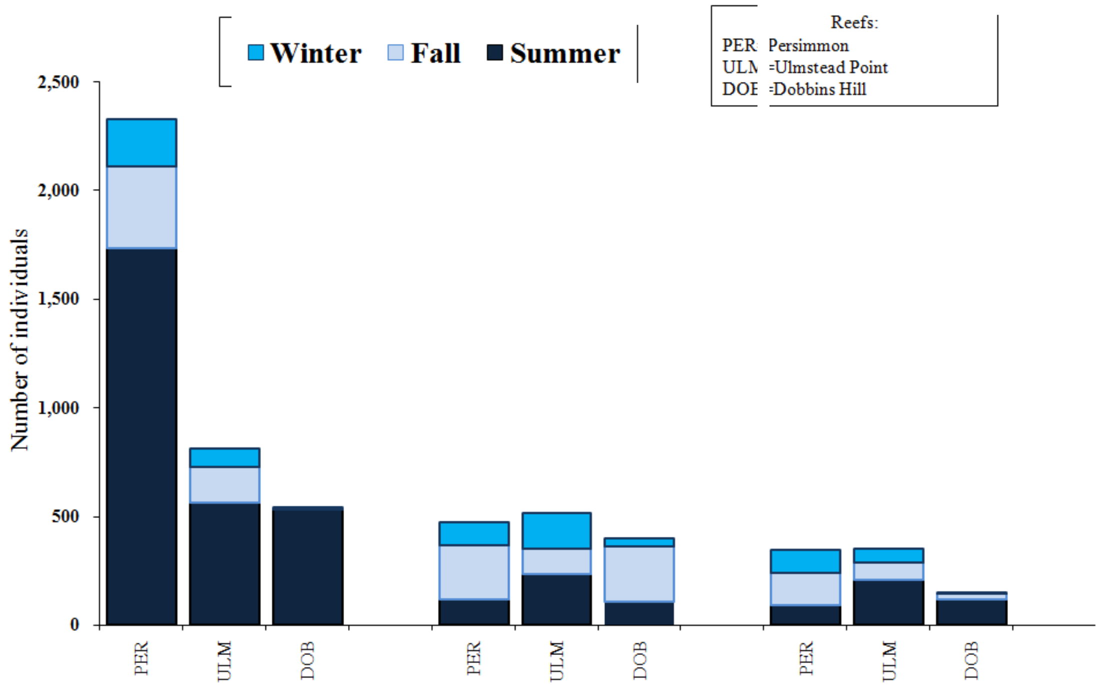

Figure 4A. Seasonal abundance of less common species.

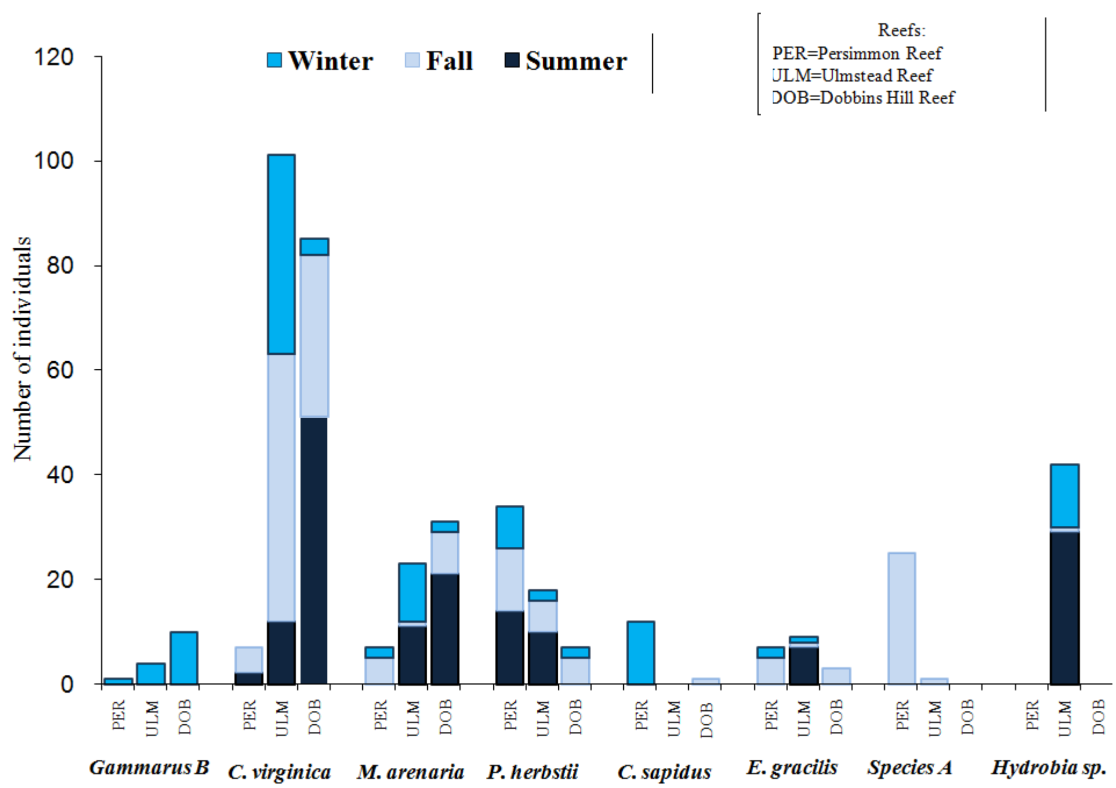

Figure 4B. Seasonal abundance of the top three dominant species, *Gammarus* A, *Nereis succinea* and *Ischadium recurvrum*.

Total Polychaete Biomass on Oyster Reefs

The total polychaete biomass on Dobbins Hill Reef was significantly greater in the fall as compared to the summer (ANOVA; p=0.001; Tukey's HSD; p=0.007, (±SEM; n=4)) (Figure 5). When comparing summer to fall on Persimmon Reef and on Ulmstead Reef, there were no significant differences in biomass. When comparing changes in biomass from the fall to winter, no significant differences were seen on any of the three reefs (data not shown).

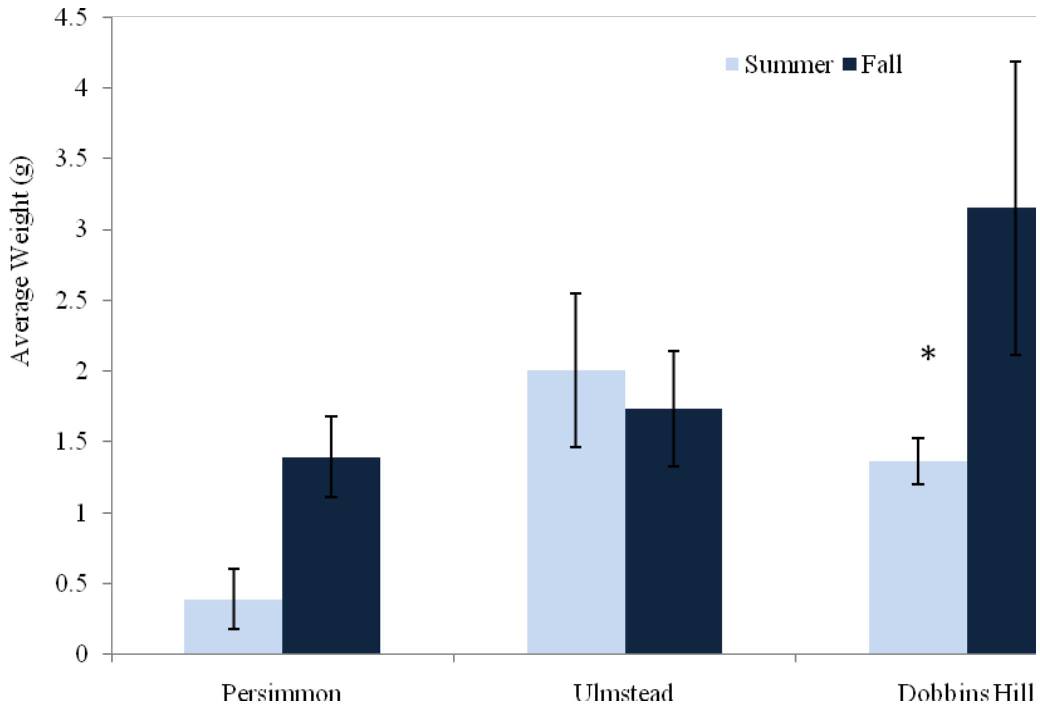

Figure 5. Average wet weight of total *Nereis succinea* biomass for the summer and fall seasons.

Sampling Apparatus Efficacy

Using the novel protocol adapted from the MRA oyster sampling apparatus, the average time it took to determine biodiversity and biomass for four samples on one reef was approximately six hours excluding transportation with two divers, a boat captain and a surface support coordinator. The collection process took approximately two hours and sorting took approximately 60 minutes per sample for a total of four hours of analysis. Given that only two researchers were analyzing the samples, only two reefs could be completed on any given day.

Discussion

Macroinvertebrate Biodiversity

The macroinvertebrates associated with oyster reefs in the Magothy River showed seasonal variation in biodiversity over the course of the study. An increase in biodiversity was observed from the summer to the fall on Persimmon Reef and Ulmstead Reef as well as an increase from the fall to the winter on Ulmstead Reef and Dobbins Hill Reef (Figure 3). The majority of the species found in the study occurred in numbers rarely exceeding 10 individuals including *Mya arenaria*, *Callinectus sapidus*, *Euplana gracilis*, *Panopeus herbstii*, *Hydrobia sp*. and the unknown invertebrate Species A with the exception of *Crassostrea virginica* (Figure 4A).

N.succinea, *I. recurvrum* and *Gammarus A* were the most abundant species for the three seasons sampled in the study, comprising 95% of all individuals collected (Figure 4B). These findings are supported by Patuxent River studies where the dominant species found in soft bottom sediments were also polychaetes (*N. succinea* and *Streblospio benedicti*), bivalves (*Macoma balthica*), and amphipods (*Leptocheirus plumulosus*); accounting for over 90% of the macroinvertebrate community observed (Marsh and Tenore, 1990). *N. succinea* was also found to be 91% of polychaetes found in sanctuary reefs located in the Severn, Patuxent, Chester and Choptank Rivers (Rodney and Paynter, 2006).

Effects of Salinity
The salinity in the Magothy River was higher in the fall than in the summer, and the increases in biodiversity observed on both Persimmon Reef and Ulmstead Reef for the summer-fall transition supports the hypothesis that macroinvertebrate biodiversity increases with increased salinity. Over the course of the study, salinity was the lowest in the summer and highest during the fall (Table 1). The Department of Natural Resources has recorded salinity levels for the Magothy River since 1965 and found the mean salinity to range from 6 ppt during the summer to 11 ppt during the fall, and begin to decrease once again in the winter (DNR, 2009). Compared to the Magothy River, salinity in the mid-channel of the Chesapeake Bay does not fall much below 9 ppt during any time of the year (DNR, 2009). This may account for the lower species number of 11 in the study as compared to the 108 species, the majority of which were invertebrates, found by Larsen (1984) on an oyster reef in the James River with a salinity range of approximately 13-18 ppt.

The salinity gradient present in the Chesapeake Bay tributaries also creates a species gradient. Areas with increased freshwater input will have a lower number of species than areas more in the mainstem of the Chesapeake Bay (Wells, 1961). Wells (1961) observed a decrease from 67 to 16 in the number of species as salinity decreased from 32 ppt to 19 ppt. Heavy fluctuations in salinity can also reduce biodiversity, resulting in a higher abundance of opportunistic species that are capable of surviving periods of low salinity (Wells, 1961). Seasonal changes in salinity also influence biodiversity in estuaries. In a biodiversity study in the Caloosahatchee and Estero estuaries of Southwest Florida, decopod biodiversity was higher during drier seasons when the salinity was highest (Tolley *et al.*, 2005). This could explain why in the study the number of species representing each taxa was so low (Fig. 4). For example, *N. succinea* was the only polychaete species found in the study.

Effects of Dissolved Oxygen and Temperature
Over the 2008-2009 study period, the dissolved oxygen level at all three reefs in the Magothy River was lowest in the summer and highest in the winter, while the temperature was highest in the summer and lowest in the winter (Table 1). Dissolved oxygen and temperature during the study corresponded with average measurements for the Magothy River recorded by the Department of Natural Resources for the past twenty years (DNR, 2009). The macroinverterbate biodiversities for both Persimmon Reef and Ulmstead Reef were significantly higher in the fall when the temperature was lower than the summer (Figure 3A).

Biodiversity may have decreased due to dissolved oxygen levels and increased temperatures during the summer, but was most likely not affected by dissolved oxygen during the fall and winter season, as these two seasons had very similar dissolved oxygen levels. This could potentially explain why not all three reefs had a significant increase in biodiversity from the fall to winter (Figure 3B). Other tributaries of the Chesapeake Bay that experience hypoxia, such as the York and Rappahannock Rivers, have been shown to exhibit a decreased macrobenthic biomass and macrobenthic community which becomes dominated by opportunistic species such as polychaetes (Llanso, 1992; Long and Setiz, 2009).

Nereis succinea Biomass

The increase in total polychaete biomass documented on the Dobbins Hill Reef from the summer to fall (Figure 5) is supported by Neuhoff (1979) who noted an increase in biomass from the summer to fall in *N. succinea* populations of the Keil Fjord (Baltic Sea). No significant increase in *N. succinea* biomass was seen on any of the reefs in the Magothy in the winter as compared to the fall, which is also supported by Neuhoff (1979) who found that unlike other polychaete species, *N. succinea* has a rapid increase in biomass immediately preceding spring spawning instead of a gradual increase from the fall to winter. Similar species like *N. diversicolor* have also been found to have delayed spawning due to water temperatures not warming up past 10°C as a certain threshold must be reached for spawning to occur (Olive, 1981). In addition, *N. succinea* is relatively larger than other macroinvertebrates like amphipods, making them more accessible to predatory fishes which may cause them to feel a higher predatory pressure (Neuhoff, 1979). This may further explain the observations in the current study where biomass did not increase from the fall to winter.

Evaluation of Sampling Protocol

The novel sampling protocol developed for this study was modified from the protocol used in the oyster reef monitoring program established by the Magothy River Association. The sampling apparatus was a quadrat attached to a mesh-lined crate used to excavate substrate to a depth of 10 cm. Two scuba divers worked from a boat to collect samples, and the protocol required a full day to completely sample two reefs (eight samples total). Two researchers worked individually to examine the samples on board as well as in the laboratory. Each oyster shell collected was examined to determine if they were live or disarticulated, and to record numbers of epifauna. This included fragmenting the disarticulated shells in order to retrieve specimens that had burrowed into recesses within the shell. Only the top 10 cm were sampled, which could potentially exclude the collection of individuals burrowed deeper into the sediment. Substrate differences between the three reefs selected for the study may also have affected the sampling efficacy of the current protocol.

After collection each sample was washed to remove sediment from the organisms by pouring water through the sample while it was contained in a mesh bag. Dobbins Hill Reef contained higher silt content than the other two reefs, with Persimmon Reef being almost completely sand underneath the disarticulated shells and Ulmstead having a mixed substrate of both silt and sand. As a result, the silt in the Dobbins Hill samples may have made it more difficult to find cryptic species compared to Persimmon Reef as the silt was much more difficult to remove and wash away than the sand. These differences in sediment substrate may have influenced the composition of macroinvertebrates found within each sample which has been seen in Larsen (1985) where oyster reefs with increased sandy substrate have lower macroinvertebrate densities than areas with hard clean shell bottoms. Other methods to measure biodiversity on oyster reefs include a surface suction sampler used by Larsen (1985) and periodically checking on containers filled with oyster and substrate (Wells, 1961; Rodney and Paynter, 2006).

Overall sampling differences between the oyster reefs may be a result of random exclusion. Larsen (1985) describes how sampling differences may occur whenever densities of particular species are very low as they may go unnoticed with small sample sizes such as in the present study which only had four samples per season. This may be the case for the species observed in low numbers (Figure 4A). Increasing the number of samples per reef as well as the number of times each season is sampled may overcome this potential problem. While time consuming, this protocol was effective in sampling benthic macroinvertebrates on hard substrates. Larger research teams contemplating research on macrofaunal communities associated with the hard substrate that comprises oyster reefs may be better suited to using this protocol. With recent research on macroinvertebrate composition on oyster reefs being limited, it is imperative to determine if the present protocol can be used for large scale research, as it allows for the quantifiable study of macroinvertebrates on oyster reefs.

Conclusions

While no samples were taken off the oyster reefs to compare the effects of oysters on the macrobenthic communities, there has been documentation of increased levels of both biodiversity and abundance of macroinvertebrates on oyster reefs compared to areas without oysters. Kellog *et al.* (2006) found that restored reefs in Blege Bay and Duvall Creek in the South River contained more blue crabs than non-restored sites. This relationship between blue crabs and oyster reefs is important to note as blue crabs comprise the largest fishery in the Chesapeake Bay (Hines *et al.*, 1990). Oyster reefs also attract predatory fish species such as striped bass, whose habitat use have been positively correlated with the presence of oyster reef habitat in the Piankatank River in Virginia (Harding and Mann, 2003). Lenihan *et al.* (2001) found 18 fish species that have commercial or recreational value on oyster reefs in the James River, 12 of which were found as juveniles, providing support that oyster reefs are multidimensional in their ecological importance. Restored reefs, such as the ones in the Magothy River, hold promise for harboring species that can directly affect Maryland's commercial fishing industry.

As previously mentioned, the health of oyster reefs and other ecosystems is based on the ability to maintain the integrity and structure of all components over the lifespan of that habitat (Costanza and Mageau, 1999), in this case the physical structure of the reef. Unfortunately, the hardships oysters face through exposure to over-harvesting, disease and eutrophication of the Chesapeake Bay have caused many reef habitats to fall short of reaching sustainable levels, even on restored reefs. Additionally, restoring oyster reefs by artificially spreading disarticulated shell may not improve conditions the same way as restoring a natural oyster reef. Boudreax *et al.* (2006) found more fauna associated with live oyster clusters with the natural three-dimensional habitat, compared to disarticulated shells that create two-dimensional habitats, which are more likely to move around and be covered by sediment. The interstitial spaces between disarticulated shells have been shown to become compacted with sediment after five years by Smith *et al.* (2005), leading to their conclusion that the oyster bottom in Maryland is severely degraded and cannot be revived to a self-sustaining level with the current level of management practices.

If research is not increased on oyster reefs and the benthic macroinvertebrates associated with them, the ecological functioning of the Chesapeake Bay may be put at risk. Oysters are a keystone species that affect the livelihood of numerous benthic macroinvertebrates, which in turn influence populations of predatory finfish species. Decreased abundances of macroinvertebrates may detrimentally affect the finfish populations that are relied on for both recreational use as well as commercial use in the Chesapeake Bay. Long term research of biodiversity on oyster reefs needs to occur in order to determine whether or not macroinvertebrate populations are declining as a result of unhealthy oyster reefs.

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Exploring the 'Marine Twilight Zone' in the Gulf of Eilat, Red Sea, Israel

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In 2003, the Marine Twilight Zone Research and Exploration (MTRX) program, a deep reef research and exploration program, was initiated at the Interuniversity Institute for Marine Sciences of Eilat (IUI). The IUI is the major marine sciences research facility in Israel and the IUI's diving center stands among the busiest research diving facilities in the world, with an average of about 3,500 dives annually. The idea of exploring the 'marine twilight zone' was born out of the fact that virtually no work had been done on the deep coral reef of the northern Red Sea. This was a particularly remarkable oversight given the unusual water clarity, and related deep light penetration in this area. We erected an infrastructure to support technical diving, as well as a training program, starting with open-circuit technical nitrox through OC trimix and finally mixed gas closed-circuit rebreathers. Hundreds of research dives have been conducted to depths of between 40 to 92 m, working on subjects as broad as deep seagrasses, coral and fish distribution and community structure, coral physiology, geological aspects of ancient reefs and bottom morphology. The MTRX program has become an important resource for researchers at the IUI.

Keywords: marine twilight zone, Red Sea, technical diving

Introduction

Diving technology and marine sciences have long shared a pleasant symbiotic relationship. As advances in the accessibility and convenience of underwater breathing systems improved, so did marine researchers access to the submerged realm, and alternatively—as the desire of researchers to record, describe, study and understand the sea so too was diving technology further propelled. The Interuniversity Institute for Marine Sciences in Eilat (IUI) embraced the opportunities afforded via these advances by investing in and supporting a scientific technical diving operations center referred to as 'MTRX.' This center provides the training and equipment necessary to extend diving times and depths for a wide range of research activities, thereby improving access and the feasibility for cutting-edge research in the Red Sea.

IUI is a multi-disciplinary marine research center located on the Gulf of Eilat in the northern Red Sea (Figure 1). It supports research activities from seven research universities in Israel and is financially supported by the Israel Council for Higher Education (ICHU). In addition to the research activities of the resident scientists, the facility also hosts accredited science courses, visiting research expeditions, conferences, and graduate students. The dive center of the IUI is very active, logging a minimum of 3,000 scientific dives a year. The IUI recently became an organizational member of the AAUS as well as a member of the European Marine Board, titles held by no other diving facility or center in Israel.

Geographically, the IUI is fortuitously located on one of the northernmost reefs in the world, in a bathymetrically steep zone, with very high average visibility. In layman's terms, to travel from sea level to -100 m depths is a matter of a few kicks of the fins from shore, and it is usually possible to see your destination. For researchers, these circumstances present an unusual opportunity to conduct comparative depth research and explore the less-visited twilight zone depths without requiring the aid of a research ship.

Figure 1. Aerial view of IUI.

The amount of research conducted in the deeper zones of the Gulf of Eilat has been limited. Observations from submersibles and remotely-operated vehicles (ROVs) demonstrated that the coral growth extended beyond the 30 m depth zone, and suggested continuation beyond 90 m water depth. Despite this, the last published study of coral in these depths was in 1983 (Fricke, 1983). This dearth of information is not only unfortunate, it is dangerous. The data used to inform scientific studies and conservation studies is primarily derived from the shallow (less than 30 m) zone without any consideration of the condition of deeper areas. Until recently, very little was known about the biological communities in the deep coral reef.

Researchers at the IUI aimed to change this state of affairs by studying firsthand the deeper reef. It also is possible to approach the deeper reef with the use of ROV or submersible technology. However, these means are costly, and while improvements and advances are made regularly, direct firsthand human observation, and the convenience and dexterity of human hands has yet to be matched with those tools. With this in mind, the Marine Twilight Research and eXploration (MTRX) center was established in 2003 at the IUI dive facility (Figure 2).

Building the MTRX

The MTRX was first established with a generous private contribution which supported the purchase of three complete open-circuit technical diving sets. The DSO of the facility was trained through trimix instructor and in turn began training a pair of the more experienced graduate student divers to create the seed of the MTRX diving group. trimix blending capabilities were installed at the dive center allowing the IUI to be completely self-sufficient and independent. Within a year, hundreds of dives were completed by members of the group collecting material for the graduate students own research as well as providing deeper water collection material for others. In 2006, the MTRX added four megadelon rebreather systems (one donated by Shahar Segal) to the facility and four IUI MTRX divers were trained by Leon Scamahorn. After completing about 200 hours of diving on the Megadalon rebreather the DSO began instructor training for the megadelon to teach more students. Today the MTRX is housed within the recently renovated dive center and a storage caravan on the campus, future development plans include a new 'hanger' to house MTRX equipment, plan dives, prepare and maintain gear.

Figure 2. IUI dive center.

The Work

A variety of techniques have been used by MTRX divers to conduct research in the Red Sea. In the deep reef, line transects and video transects were used for community studies of corals fish and invertebrates, macroalgae and seagrass. Many dives included collecting samples of various organisms, translocating corals between shallow and deep reefs and vice versa, light measurements, in situ photosynthesis measurements of corals, macroalgae and seagrass. Marine geological researchers have used the technology to expedite sediment coring, collecting rock samples, and surveys of deep reefs of the region. The work was done in depths between 39 to 92 msw, and in some cases the technical diving gear was used to greatly extend diving time limits and safety margins during shallower work. Throughout this period, the MTRX also engaged in training new technical divers and making skill proficiency practice dives on a regular basis.

Results

There are multiple ways to assess the success of the MTRX dive program at the IUI, and in every aspect it has reached its goals and will continue to set new ones. Quantified from a purely diving perspective in terms of training and dives, it has been a great success. Over 1,000 technical deep (>42 m) scientific research dives have been completed since its inception in 2003. More than 30 students have completed at least one level of technical training, and six have completed training through trimix diver or higher. From a scientific perspective the program has also exceeded expectations. The materials, collections, recorded observations and studies carried out by the MTRX has contributed to five master and doctoral theses, over 10 peer-reviewed scientific papers, book chapters, and conference papers and poster presentations. The technology was used for a resident researcher's sediment core collections and highlighted in the National Geographic special 'Herod's Lost Tomb.' Video footage of the deep reef and damage caused by anchors, traps, fishing nets, and other marine garbage is being used to lobby for greater protection and conservation of these areas.

Conclusions

Today's deep-diving technology allows marine scientists to enter and carry out work safely in depths beyond recreational limits in a manner more cost-effective and accessible than ever before. The IUI has chosen to embrace these tools and add them into the overall dive training and capabilities of its dive center, making it the only such facility in Israel, and one of a handful of centers with the capability to research these depths worldwide. The awards reaped from this have been great in the form of better understanding the deeper environment, contributing to scientific knowledge, providing more information for environmental policy makers, and improving methodological approaches in underwater research.

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Field Programmable Gate Array (FPGA)-Based Fish Detection Using Haar Classifiers

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Abstract

The quantification of abundance, size, and distribution of fish is critical to properly manage and protect marine ecosystems and regulate marine fisheries. Currently, fish surveys are conducted using fish tagging, scientific diving, and/or capture and release methods (*i.e.,* net trawls), methods that are both costly and time consuming. Therefore, providing an automated way to conduct fish surveys could provide a real benefit to marine managers. In order to provide automated fish counts and classification we propose an automated fish species classification system using computer vision. This computer vision system can count and classify fish found in underwater video images using a classification method known as Haar classification. We have partnered with the Birch Aquarium to obtain underwater images of a variety of fish species, and present in this paper the implementation of our vision system and its detection results for our first test species, the Scythe Butterfly fish, subject of the Birch Aquarium logo.

Keywords: automated fish classification, Haar classifiers, FPGAs

Introduction

The quantification of abundance, size, and distribution of fish is critical to properly manage and protect marine ecosystems and regulate marine fisheries. Currently, fish surveys are conducted using fish tagging, scientific diving, and/or capture and release methods (*i.e.,* net trawls). All of these methods require many man hours and ship time which is costly and time consuming. Therefore, providing an automated way to conduct fish surveys could provide a real benefit to marine managers.

Automated fish surveys could be conducted using computer vision, where a computer can process underwater video images, counting and classifying fish species of interest. Some work on automatic fish classification using computer vision has already been done. These fish classification methods are based on shape (Cadieux *et al.*, 2000; Tillett *et al.*, 2000; Lee *et al.*, 2003; Lee *et al.*, 2004), texture (Rova *et al.*, 2007) or color (Strachan, 1993; Semani *et al.*, 2002; Chambah *et al*., 2004) and are used for various applications such as guiding fisheries management, evaluating the ecological impact of dams, managing commercial fish farms, improving fish migration monitoring or enabling educational interactive displays for aquarium visitors. More recent methods focus on object detection to enhance the productivity of human annotators (Cline *et al.*, 2008). However, none of these methods provide a framework for rapidly classifying 'any' fish species of interest.

Therefore, to provide a framework that can classify 'any' fish species of interest rapidly in parallel, we have designed an automatic fish detection system based on the Viola and Jones Haar-like feature object detection method on a field programmable gate array (FPGA). Haar-like features can be applied to any fish species of interest, and FPGAs are well known for their ability to process computations rapidly in parallel.

In this paper we describe our method for generating fish classifiers as input to our FPGA framework and describe how the FPGA framework uses these classifiers to perform real-time fish detection. We present our detection results for our first test species, the Scythe Butterfly fish, and report the potential performance capabilities of our framework based on face detection experiments. We conclude with a discussion on future work.

Methods

This section describes the method we use to generate Haar classifiers for our FPGA framework and describes how the FPGA framework uses these classifiers to perform real-time fish detection.

Generating Haar Classifiers

Our method to generate Haar classifiers for different fish species makes use of OpenCV's (an open source computer vision library) Haar Training Code based on the Viola-Jones detection method (Viola and Jones, 2004). This code allows a user to generate a Haar classifier for any object that is consistently textured and mostly rigid (Bradsky and Kaehler, 2008). A good classifier only needs to be generated once and then can be loaded into a classification system whenever that object of interest needs detection. OpenCV's Haar Training technique has been successful for face (Viola and Jones, 2004; Cho *et al.*, 2008), car (Hakan, 2005), and pedestrian (Montiero *et al.*, 2006) detection and we now extend this method to fish detection.

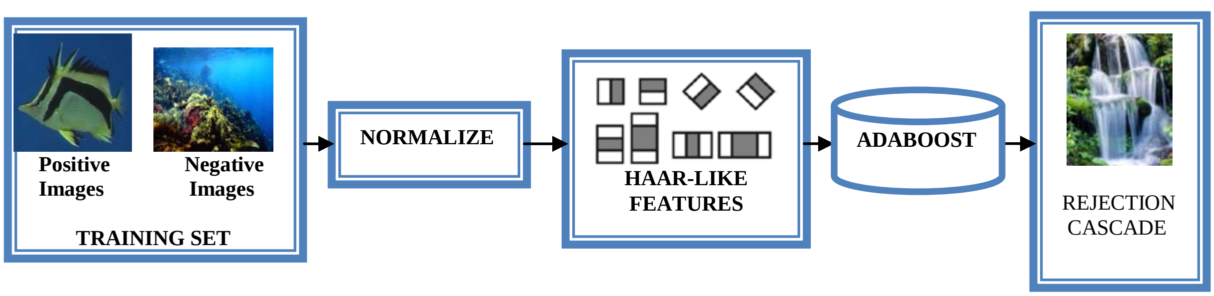

Figure 1. Haar training procedure.

Figure 1 shows OpenCV's Haar Training procedure. Haar Training takes in a set of positive and negative images as inputs – the positive images containing cropped images of the fish species of interest and the negative images containing images of the fish's environment and images of fish of other species. These images are then converted to gray-scale and normalized to a user-specified window size (in our case, 20 x 20 pixels). The training code calculates Haar-like features (sums and differences of 2-3 rectangular image regions denoted by the *(x,y)* coordinator of their upper left corner and their width and height) within the normalized images to find the Haar-like features that best distinguish between the positive and negative samples. Figure 2 shows an example of a Haar-like feature used for detection of the Scythe Butterfly fish. It consists of 2 rectangles (the white rectangle interpreted as "add that area" and the dark rectangle interpreted as "subtract that area").

Figure 2. Example of a 2-rectangle Haar-like feature used for detection of the Scythe Butterfly fish.

Once the Haar-like features have been calculated, the Haar Training procedure uses a form of AdaBoost (Freund and Schapire, 1997; Viola and Jones, 2004) to organize these features into a 'rejection cascade' consisting of *n* stages as shown in Figure 3. The stages are ordered from least to most complex so that computations will be minimized (simple stages are tried first) when rejecting non-fish regions of a test image. A fish is only detected if the Fish candidate passes through all stages of the rejection cascade.

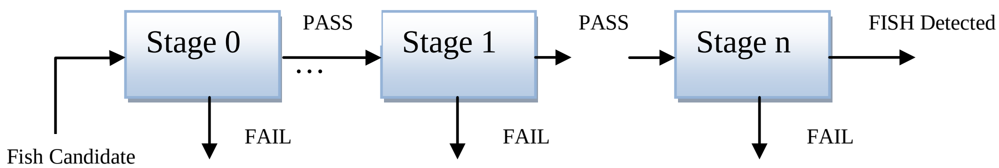

Figure 3. Rejection cascade.

Each stage consists of an Alternating Decision Tree (ADTree) (Freund and Mason, 1999) that represents an AdaBoosted set of *m* features. Figure 4 shows an example of an ADTree for one stage.

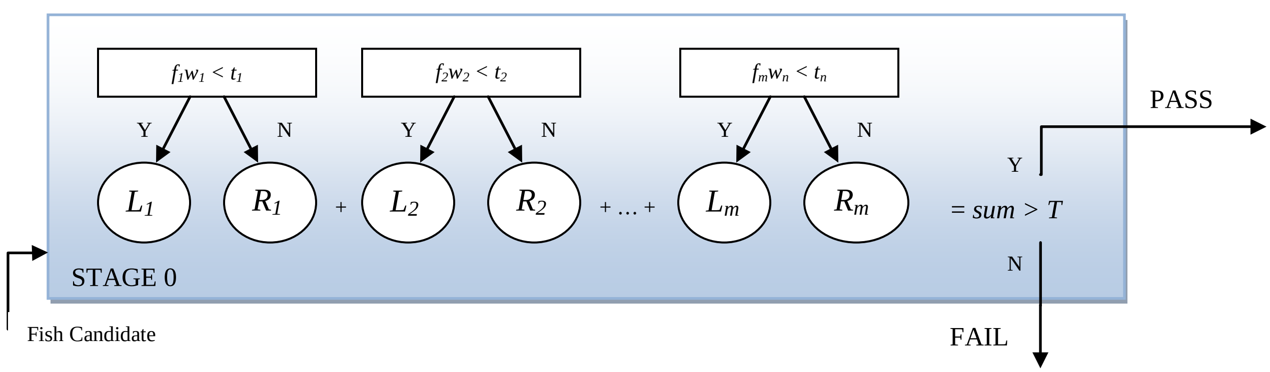

Figure 4. An alternating decision tree (ADTree) representation of one stage of the rejection cascade.

For each stage, AdaBoost selects *m* features f_i, feature weights, w_i, feature thresholds, t_i, left values, L_i, right values, R_i, and the stage threshold *T* that achieve a user specified hit rate of 99% and false positive rate of 50% when all training images are applied to the tree. A training or test image passes the stage if the sum of its selected left or right values (depending on the outcome of the feature threshold inequality), *sum*, is greater than the stage threshold *T*.

OpenCV represents the rejection cascade, the resulting Haar Classifier, as an xml file that contains the features, feature weights, feature thresholds, left values, right values, and a stage threshold for each stage in the cascade. This Haar Classifier achieves an excellent overall hit rate of 0.99^n and false alarm rate of 0.5^n on the training data. We use the generated xml file as input to our FPGA framework to provide real-time fish detection (described in the next subsection).

FPGA Framework

An FPGA is a semiconductor device that can be configured by the designer after manufacturing – hence the name "field programmable." FPGAs can be programmed to perform an application specific task (such as fish classification) through using a hardware description language to specify how the chip will work. Because the designer can create dedicated hardware to perform a specific task and can create duplicate sets of the same hardware to perform operations in parallel, FPGAs often offer higher performance than a software solution.

We implemented an FPGA framework for fish detection based on the Viola and Jones object detection method on a Xilinx Virtex-5 FPGA. Figure 5 shows the overview of this framework.

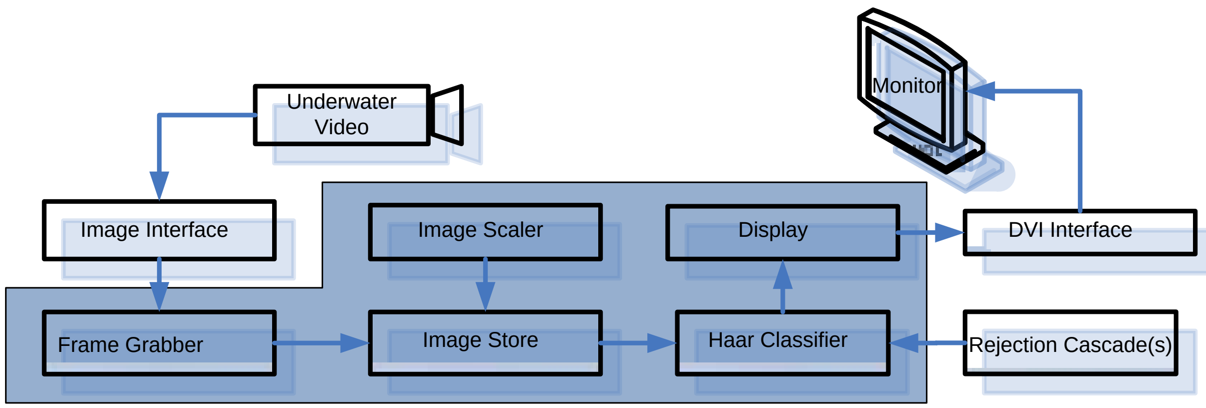

Figure 5. FPGA framework.

The underwater video is fed to the FPGA framework through an image interface which digitizes the analog image. The frame grabber module then grabs frames from the video to be processed individually. The image store module stores the image data arriving from the frame grabber module and transfers the image data to the Haar Classifier module based on the scale information from the image scaler module. The image scaler module scales the frame to various sizes to provide the capability for the framework to detect fish of various sizes within the video image. The Haar Classifier module performs the classification for the fish detection on each scaled frame based on the Haar Classifier Rejection Cascade generated as described in the previous subsection. The Haar Classifier module is the critical module of the whole fish detection system and thus will be described in more detail below. The display module stores the information of the detected fishes and displays white squares on the detected fish in the image sequence. The processed image is displayed on a monitor through the DVI interface.

The Haar Classifier module begins by computing the integral image of the input scaled frame. The integral image is the summation of the pixel values of the original image. The value at any location *(x,y)* of the integral image is the sum of the original image's pixels above and to the left of location *(x,y)*. Figure 6 illustrates the integral image generation.

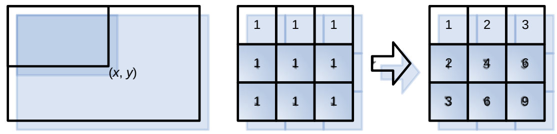

Figure 6. Integral image generation.

The integral image allows for rapid computation (constant time) of the Haar-like features. By using each corner for a Haar-like feature rectangle, the area of the rectangle can be computed quickly as shown in Figure 7. The area of the rectangle *R* can be computed using the integral image values in the positions L_1, L_2, L_3, and L_4 as L_4-L_3-L_2+L_1. Since the area of L_1 is subtracted off twice by areas L_2 and L_4, it is added back on to get the correct area of the rectangle.

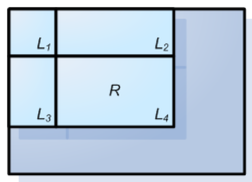

Figure 7. Calculating the area of a rectangle R using the integral image values as L_4-L_3-L_2+L_1.

Once the integral image has been computed, the Haar Classifier module scans the integral image by a 20x20 pixel window (a fish candidate), searching for a fish. Each fish candidate goes through the rejection cascade. Thus the Haar-like features in Stage0 are computed (using the integral image calculation), weighted and compared to the feature threshold (shown in Figure 4). If the sum of the selected left and right values, *sum*, is less than the stage threshold, *T*, the fish candidate is rejected and the Haar classifier module moves the scanning window over one pixel to process the next 20x20 fish candidate. If the *sum* is greater than the stage threshold, *T*, the fish candidate passes Stage0 and continues to Stage1, 2,…n until the fish candidate either fails at a stage or passes all stages. A fish candidate is only marked as containing a fish if the fish candidate passes all stages in the rejection cascade. To provide the ability to locate multiple fish in one frame, the Haar Classifier module processes the next scaled frame only after the entire integral image has been scanned. By processing frames of various scales, fish of various scales can be detected.

Results

Using the methods described in the previous section, we generated a 16 stage Haar classifier with 83 features for the Scythe Butterfly fish using 1077 positive images and 2470 negatives images. All positive images were obtained by grabbing frames of a video of one Scythe Butterfly fish with a blank blue background (as shown in Figure 8). All positive images contained the fish's side profile while swimming left as earlier work has shown a separate classifier is needed for different profiles of the same object (Horton *et al.*, personal communication). The negative images consisted of various gray scale underwater scenes of the Scythe Butterfly's natural environment.

Figure 8. Frame of Scythe Butterfly video used to generate one positive image.

Using the OpenCV performance metric and 100 test images (also obtained from the Scythe Butterfly video), we obtained 92 hits, eight misses and three false positives with the generated 16 stage classifier. We were unable to obtain hit/miss results from the FPGA Framework at the time of this publication as OpenCV includes tilted Haar features in its rejection cascade that are currently not handled by our FPGA framework.

Thus to obtain performance measurements of our FPGA framework, we used the OpenCV frontal face rejection cascade that consists of 22 stages and 2135 features (and no tilted features) (Bradski and Kaehler, 2008; OpenCV, 2008) and tested the performance of our framework for face detection on five images containing faces. Since the system performance of face detection depends on the number of faces in the images and the size of the image, we scaled the test images to two different sizes (320 x 240 and 640 x480) with the five test images of each size containing 1, 3, 6, 9, and 12 faces respectively. Table 1 shows the average performance of the face detection system with varying levels of parallelism. The level of parallelism denotes how many Haar-features can be computed simultaneously within the framework. For a detailed description of the parallel implementations (Cho, personal communication). The table shows the performance improvement of using the FPGA framework over an equivalent software solution (written in C++) on a PC; in this case using an Intel Core 2 Quad CPU (2.4 GHz), 8 GB DDR2 SDRAM (800MHz), Microsoft Windows Vista Business (64-bit), and Microsoft Visual Studio. The table shows the face detection system on the FPGA framework has the performance improvement of up to 84.5 times the software solution with the 320x240 resolution images and up to 37.39 times the software solution with the 640x480 resolution images. All faces in the five images of each image size were accurately detected with zero false positives.

Table 1. Performance of FPGA framework for frontal face detection.

Level of Parallelism	320×240 images	Improvement	640×480 images	Improvement
S/W 1	1,373ms (0.72 fps)	1.00	2,319 ms (0.43 fps)	1.00
FPGA 1	54.735 ms (18.26 fps)	25.36	190.541 ms (5.24 fps)	12.18
FPGA 2	38.997 ms (25.64 fps)	35.61	146.033 ms (6.84 fps)	15.90
FPGA 4	24.405 ms (40.97 fps)	56.90	81.499 ms (12.27 fps)	25.20
FPGA 6	21.053 ms (47.49 fps)	65.95	62.154 ms (16.08 fps)	28.53
FPGA 8	16.387 ms (61.02 fps)	84.75	62.154 ms (16.08 fps)	37.39

Discussion

The hit/miss rate results of the Scythe Butterfly fish Haar Classifier and the performance results of the FPGA framework on face detection are encouraging. The results provide evidence that the FPGA based fish detection system we described may provide a good way to perform rapid fish classification in underwater images. However, a large amount of future work must be performed to evaluate the effectiveness of this method on fish detection and the improvement it may provide over other existing fish classification methods mentioned in the introduction.

Future work includes modifying the OpenCV Haar Training code to generate Haar classifiers without titled features so that the classifier can be tested on our FPGA framework, obtaining images of the Scythe Butterfly fish in a natural background to see if the framework can accurately pick out the fish from the natural background, obtaining images of the Scythe Butterfly fish with other species of fish to see if the framework can accurate distinguish the Scythe Butterfly in the presence of other species, and generating classifiers for other profiles of the fish so that it can be detected in more than one position. If all of these future tests prove successful, we intend to develop a method or tool to allow scientists to generate their own classifiers of different fish species that can be added to a large database of classifiers and used in the FPGA framework for rapid detection of the scientists' species of interest.

Acknowledgments

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Science of the National Association for Cave Diving (NACD): Water Quality, Hydrogeology, Biology and Psychology

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Abstract

The NACD is committed to the exploration and conservation of underwater caverns and caves. This commitment has produced a variety of studies from explorations, mapping surveys, biometric assessments, water quality analyses, to the psychology of cave divers and public perceptions of cave diving. Old cave systems have been explored into new regions revealing new information regarding cave connections, extent of the systems, and the historical processes involved in development of the systems. New systems have been discovered and partially surveyed, providing insights into local aquifers. Population counts of various species have been conducted, revealing potential new species. The NACD is committed to conservation and education and has developed a water quality test kit, along with protocols for sampling, conducting the tests, counting flora and fauna (in and out of the cave), and reporting the findings to the public. Training workshops are conducted often so that members may test the waters they dive and contribute data to the public. The psychology of cave divers is also of interest to the NACD. Understanding the motivations, the personality, and the minds of these extreme environment explorers, may lead to improved selection of personnel for extreme environment missions; improved training of those selected, and improved safety of those who dare to go where no one has gone before.

Keywords: caves, cave species, scuba personality, springs, water quality testing

Introduction

The National Association for Cave Diving (NACD) was the first cave diving organization in the United States, founded in 1969, 23 years after the formation of the British Cave Diving Group. Its founding purpose was to train safe cave divers, primarily in reaction to the 48 cave diver deaths from 1959 to 1964. By 1970, NACD members had placed signs and gold line in the more popular Florida caves. The signs were "stop" signs, placed at the entrance to the underwater caves to warn the untrained not to enter. The gold line was placed as a safety feature to ensure that cave-trained divers could find their way out of the cave systems, especially in the event of silt-outs or light failures, in which visibility can be reduced to zero without warning (cave divers are trained to be aware of the line at all times and in techniques to find lost lines in the event of sudden reduced visibility, and to then follow it out by feel).

In 1973 the NACD published Tom Mount's "*Safe Cave Diving*," the same year that the National Association of Underwater Instructors (NAUI) released "*The Complete Guide to Cave Diving*." Also in 1973 the first commercially available dual-outlet manifold was introduced, thus allowing safer use of doubles or twin tanks for longer penetrations. The Cave Diving Section of the National Speleological Society was established in 1974 by Sheck Exley; that same year NAUI and the YMCA began offering cave diving certifications.

The NACD was involved in science diving since its inception, but it was not until 1975 that they published the research papers from the proceedings of the 6th and 7th annual seminars. Still with an emphasis on training safe cave divers, the NACD participated in the first cave diving search and recovery seminar in 1982, and helped sponsor Wes Skiles' 1984 revision of Exely's accident analysis outlining the major causes of cave diver deaths. In 1987 Wes Skiles published "*The Scientific Future of Cave Diving*" covering survey and cartography, dye tracing, water chemistries, photography, biological sampling, and geological sampling.

Over the next ten years cave diving became much more heavily equipment intensive, with Hogarthian configurations hotly debated (1990), the formation of new cave diving and technical diving training agencies (Technical Diving International was formed in 1994), the use of Do it Right (DIR) equipment configurations (1996), and the first explorations of iceberg caves by Wes Skiles, Jill Heinerth, and Paul Heinerth using closed-circuit rebreathers (CCR) in 2001. The National Science Foundation refused their grant request on the grounds of using the rebreathers (Heinerth and Oigarden, 2008). They eventually found support from New Zealand and the National Geographic Society. Their explorations revealed a wealth of data concerning icebergs, water chemistry, and many new species, including ice cave dwellers never before seen; indeed the very notion of life in an iceberg cave was not imagined prior to their discoveries.

In 2006, the NACD began a new emphasis on science and charged the Science Committee with investigating water quality issues and what could be done to enhance cave divers' awareness of the quality of the springs, sinks, and siphons. By 2007, we had developed a water quality testing kit and begun training cave divers, and the general public, on how to test water using the kit. In 2009, the first bio-team training workshop trained a dozen divers in how to conduct population counts of cave species. Today, as always, the NACD is committed to advancing our knowledge of underwater caves. With committees on conservation, exploration and survey, equipment technology, and accident advisory, the science of the NACD now includes: water quality, hydrogeology, biology, and psychology.

Water Quality

The NACD developed a water quality testing kit in order to provide a web-accessible database of spring water (cave water) quality for cave divers and the general public. The test kit is self-teaching so that community groups can borrow the kit and test waters of their choice as a teaching tool or to monitor local waters. Results are available online at http://www.safecavediving.com. The NACD has also trained over two dozen cave divers in seven states as Rapid Response Team members. Anyone can call, email, or post on the website a request for someone to come test the water and we will dispatch the nearest team.

The tests are eight of the nine tests needed to calculate the water quality index (WQI) that is recognized by the Federal EPA and most State EPAs. The tests are fecal coliform, phosphates, temperature, pH, nitrates/nitrites, turbidity, dissolved oxygen, and total dissolved solids. Biological oxygen demand (BOD), the ninth test needed, requires sending samples to a lab or involves complex equipment and chemicals. The primary goal of the testing kit is to ensure that twelve-year-olds can read the instructions and conduct the tests in the field, right at the site.

The WQI does not require the BOD for a category estimate, because made up values for BOD (within the range of possibility) indicate that only extreme values are sufficient to alter the WQI. In addition to the water tests, the test kit includes identification manuals and date recording sheets to count the flora and fauna of the surrounding landscape and the spring basin and run. The identification manuals include drawings and photographs for easy ID, but also categorize the life-forms as pollution-tolerant, pollution-sensitive, and pollution-intolerant as bioindicators of water quality. Measurements of water flow are also possible (instructions provided).

Hydrogeology

Research and Exploration
The purpose of the Exploration and Survey Committee is to promote and support exploration and documentation of underwater caves and to improve the quality and quantity of underwater cave maps available to cave divers. In pursuit of these goals, the NACD provides funding for exploration and survey projects by NACD members both internationally and throughout the United States. Survey workshops are hosted periodically where members can learn basic techniques for surveying, processing data and drawing cave maps. The NACD has provided support for a variety of projects, both in terms of cave divers and equipment, but also as small grant donations to various groups (such as Karst Underwater Research). Recent and current projects include exploration of Indian Springs, near Tallahassee, FL and Weeki-Wachee Spring, which has now been surveyd to 6,700 ft (2,042 m), and is the deepest submerged cave in the USA, at 407 ft (124 m), requiring mixed gasses in technical diving. In Tennessee, the NACD sponsors exploration and research in Guy James Spring, in Rutherford County and Cow Crap Sink, also in Rutherford County, both locations are also home to the rare Southern Cavefish (see below). In the Turks and Caicos Islands, the NACD supports exploration in Cottage Pond, an inland blue hole 255 ft (78 m) deep with a sulfer zone and fresh water on top of saltwater.

Survey Projects
The NACD supports the survey work being done in Lafayette Blue Cave System, in Lafayette County, Florida. A re-survey of the Lafayette Blue Spring / Green Sink / Snake Sink cave system is currently underway by Kelly Jessop and Jim Womble. This system contains some 25 known openings, and literally thousands of feet of passage. The goal is to add detail lacking in the original map by Exley's earlier team and to survey new tunnels discovered since the original map was published. In Manatee Springs in Levy County Florida surveying work is being done by Brett Hemphill, Andrew Pitkin, Michael Poucher, and Marc Singer with the help of NACD support divers. The goal is to obtain a complete survey of all the known passages in Manatee with details on passage configuration and flow patterns. Ruth Walker Spring, also in Lafayett County Florida, has been survyed by Jackie Clark, Joel Clark, and Cory Mearns with a detailed map produced as well.

Maps
The NACD works with the Florida Geological Survey to house its collection of maps and data on underwater caves so that the information is available to the scientific community. In addition, the NACD offers underwater cave maps for purchase on their website and the proceeds help the organization to provide additional services to its membership and the general public (like maintaining the supplies in the water quality test kits).

Biology

New Species
In September 2004, Dr. Stefan Koenemann from the Institute of Biodiversity and Ecosystem Dynamics in the Netherlands, identified a remipede specimen that belongs to an entirely new genus found nowhere else in the world. Taken from the Greek word *kalos* (beautiful) and *ketos* (sea monster), *Kaloketos pilosu*, the Beautiful Sea Monster, represents the fourth genus to be added to the remipede family Speleonectidae, literally the "cave swimmers." In Tennessee, NACD cave divers discovered two systems with populations of the Southern Cavefish. Previously only one specimen had been discovered in the county (pumped up from a well); we now know of several hundred in two

different populations. We also have the first and only video recordings showing the Southern Cavefish in its natural habitat (or any habitat for that matter). NACD is also supporting the capturing of live specimens for laboratory studies.

Bio Team Training

There have been few studies of the aquatic fauna of submerged caves and almost no long-term assessments based on population counts. The NACD has recently begun the training of cave divers in "bio teams" to conduct reliable animal counts. By systemizing the protocol, and the placement of markers every 100 ft (30 m) in a cave system, the location and number of various species can be accurately determined. The basic protocol was developed by Keith Mille and refined by Jim Womble and Kelly Jessop of the National Speleological Society's Cave Diving Section. An example of some of the data from a 2006 survey is shown in Figure 1. With continued monitoring and extension of the data collection to other systems in Florida and other states, a database of population densities will make it possible to track long-term changes.

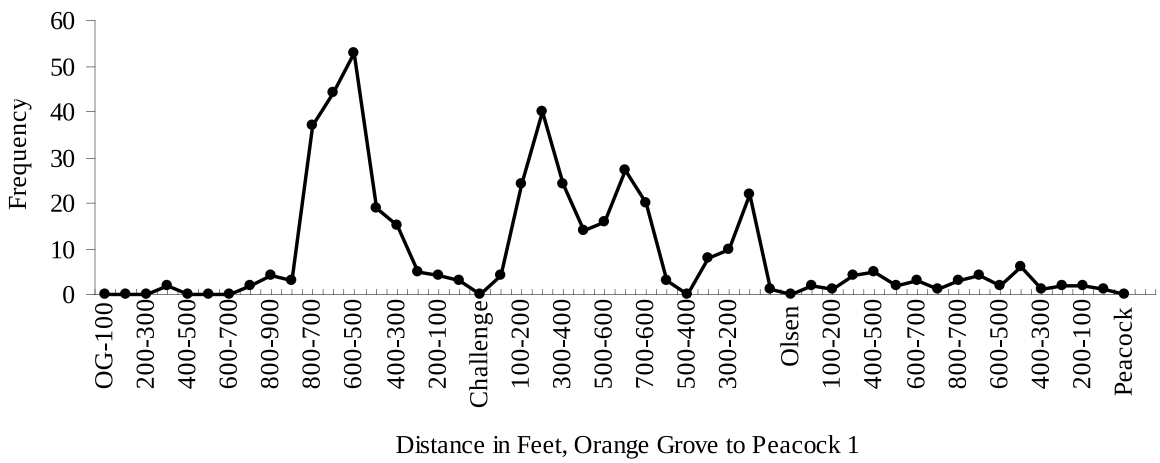

Figure 1. Amphipods and isopods in Peacock Springs, December, 2006. From Kelly Jessop.

Educational Articles

The journal of the National Association for Cave Diving publishes original articles on the history and presence of aquatic cave life to educate cave divers and the general public. Articles on a single unique species as well as cave life in general have been published. The NACD encourages authors to submit articles for review in all areas that may be of interest to cave divers.

Psychology

Accident Analysis for the New Millennium

Cave and other technical divers have long realized the benefits of analyzing accidents to determine the causes as a means of preventing those accidents in the future. Sheck Exley, one of the original cave divers first published "Basic Cave Diving: A Blueprint for Survival" in which he discussed the reasons cave divers died and how the deaths could have been prevented (Exley, 1979). From his list we learned that guidelines were needed, that reserving two-thirds of the air supply for the exit is required, and that it is too easy to violate maximum operating depths (MOD) in caves. Wes Skiles extended the list in the 1990s to include lack of cave training (open water divers were entering caves) and the lack of proper lights (cave divers carry three lights for redundancy). Recently Jeff Bozanic analyzed death statistics in technical diving and added several new items to the list: inappropriate gas mixtures, new technologies (*e.g.*, rebreathers, DPVs), medical problems (the aging diver population), equipment maintenance, solo diving, and skill maintenance (Bozanic, 2008). The identification of these new causes of diver deaths can now be addressed in training, seminars, and refresher courses.

Team Dynamics
Researchers at the University of Florida have teamed up with the NACD to conduct studies on team interactions and their relationship to performance. To date there are no data available, however, this example further demonstrates the role that the NACD can play in helping with scientific research.

Personality Profile of Cave Divers
The NACD is also supporting research into personality characteristics of cave divers, open water technical divers, beginning divers, and nondivers. These groups are compared on a variety of traits such as sensation seeking, the 'big five' personality inventory, extraversion, etc. These studies have resulted in a number of presentations and publications furthering our understanding of the psychology of divers and extreme environment explorers. Figure 2 shows an early finding resulting from this research. Scuba divers and students learning to scuba both score higher than the general nondiving public on sensation-seeking, and while student divers and the general nondiving public do not differ on trait anxiety, scuba divers score much lower on this trait. This suggests that although those who take scuba classes are the more adventuresome personalities, the ones who continue on to become experienced divers are the subset of student divers with unusually low trait anxiety.

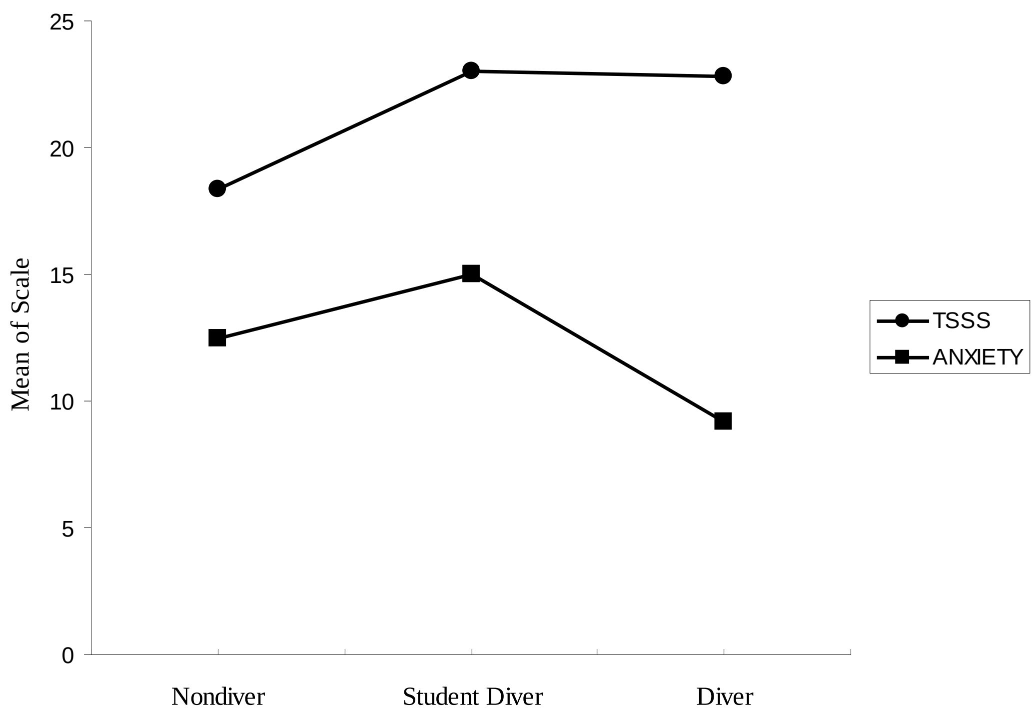

Figure 2. Trait anxiety and total sensation seeking scale for three groups of college students.

Attitudes about Solo Diving
One of the new items in accident analysis is solo diving. Although solo diving has long been condemned in the recreational and scientific dive communities, it continues to flourish. How can this

be? Surveys of the attitudes of divers have shown that most divers do not consider solo diving unsafe. There seems to be a disconnect between what divers are trained to do (the buddy system) and their beliefs about the need to do it.

Into the Future

The NACD is committed to continuing its emphasis on training safe cave divers, conservation, exploration and survey, and basic research in water quality, hydrogeology, biology, and psychology. Training safe cave diving has always been the primary purpose of the NACD, which today includes the maintenance of safe skills. Recently, the NACD has launched its new program in refresher training workshops offering a day for certified cavern and cave divers to join with instructors for a free day of skills assessment and improvement. Additionally, the NACD, with Jill Heinerth, offers workshops in the use of closed-circuit rebreathers and other new technologies in diving. These workshops are planned biannually. The NACD has plans to reach out to more government agencies to promote common goals in conservation by continuing to expand its water quality testing program to include more springs in Florida and other states. To date a half-dozen water quality workshops have been held in three states with more planned for 2009 and 2010. These will contribute to the growing database located on the website (www.safecavediving.com). Surveying known systems and providing detailed maps is another continuing goal, with more maps produced in the last three years than during any other period, and more surveying projects slated for the future. The NACD is most interested in expanding into science diving with an eye to joining the American Academy of Underwater Sciences (AAUS) and to thus encourage even greater cooperation among universities and other research institutes and agencies. With interests in building the largest data base of species and population counts in underwater caves and in continuing studies of the psychology of cave divers, the NACD is looking to the future by observing and measuring the present.

Conclusion

The NACD welcomes proposals from the scientific diving community. We can provide trained cave divers and equipment. We are also planning to train cave divers in scientific diving under the auspices of the AAUS in the future. The NACD can also provide charts and maps from the USGS and those created by members at nominal or no charge (submit a proposal; forms are available on the website - www.safecavediving.com). The NACD also provides line and signage to aid in exploration and survey of underwater caves. And, finally the NACD supports all underwater scientists, whether involved in submerged caves or open water, and will provide whatever support (small grants, divers, equipment) possible.

Acknowledgments

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Health of Coral Reefs: Measuring Benthic Indicator Groups and Calculating Tipping Points

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Abstract

Human population growth has always been accompanied by changes in land/sea use and increased exploitation of coastal resources, which continue to cause broad alterations in the structure of coral-reef communities. A basic objective in management ecology is to determine the mechanisms by which natural and anthropogenic factors maintain or alter structure and interactions in biotic communities. Protocols for determining and monitoring the status of coral-reef ecosystems are suggested and include assessment of: 1) standing stocks of key functional indicator groups (*i.e.,* reef-building corals, crustose coralline algae, low-growing turf algae, and frondose macroalgae); 2) herbivore populations; 3) grazing rates; and 4) nutrient levels. The first two measurements indicate the health of a given system; whereas, the last two can reveal the status of quantitative tipping-point levels beyond which resilience to and recovery from undesirable phase shifts become critically reduced. Indicator groups are elaborated and evaluated in detail, along with tipping-point approximations, which are reviewed and posited for both herbivory and for inorganic nutrients. The indictor-group and bioassay approaches provide powerful perspectives and essential measurement criteria to enable resource managers to protect coral reefs and similar coastal systems from eutrophication, destructive overfishing, and undesirable biotic phase shifts.

Keywords: coral reefs, eutrophication, herbivory, indicator groups, nutrients, tipping points

Introduction

Because of the long history of environmental stability within tropical zones, coral reefs have evolved astounding levels of biological diversity. Turbulent water motion and the many uniquely specialized benthic algae and photosynthetic symbionts dominating tropical reefs are responsible for some of the most productive natural ecosystems known. Four major space-occupying groups of benthic primary producers combine to create the bulk of coral-reef primary production (Figure 1): hermatypic corals (containing symbiotic algae), crustose coralline algae, algal turfs (fleshy filamentous and low-growing forms <3 cm high), and frondose macroalgae. Of these, photosynthetic corals create much of the structural heterogeneity/complexity and, with coralline algae, are primarily responsible for accretion of carbonate into the reef matrix, making them the most desirable functional groups from a management perspective.

A fundamental objective in management ecology is to understand the mechanisms by which natural and anthropogenic factors maintain or alter structure and interactions in biotic communities. Anthropogenic eutrophication and destructive overfishing (*i.e.,* herbivore removal by trapping, netting, poisoning, blasting) are the most frequently cited tractable factors correlated with the marked global decline in tropical-reef communities over the past two decades (see reviews in Ginsburg [1994] and Birkeland [1997], and papers in Szmant [2001]).

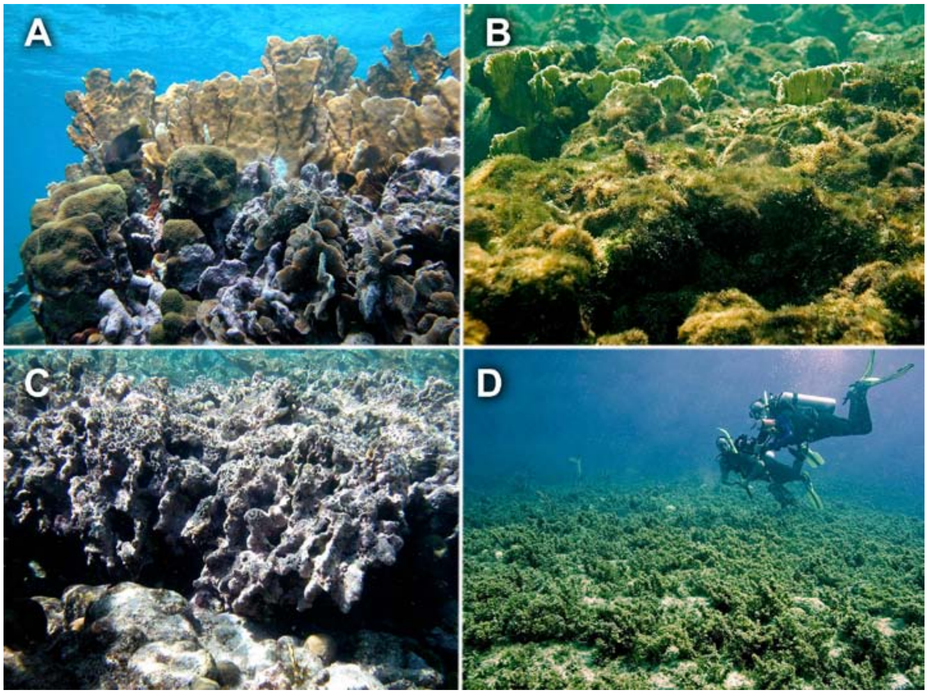

Figure 1. Dominant functional indicator groups of benthic primary producers. A: Corals and coralline algae. B: Low-growing and turf algae. C: Coralline algae. D: Fleshy macroalgae.

The concepts of 'top-down' and 'bottom-up' controls have been used (*e.g.*, Atkinson and Grigg, 1984) to describe mechanisms where either the actions of predators or resource availability regulate the structure of coral-reef communities; such interacting concepts can be useful in understanding coral-reef ecosystems. These factors provide a valuable perspective to assess and manage the human activities that affect the interactive mechanisms controlling stable-states and phase-shifts (*e.g.*, destructive overfishing, eutrophication) among the dominant functional groups of primary producers on tropical reefs. In healthy coral-dominated reefs, nutrient concentrations are extremely low and attachment space is occupied by a broad diversity of overgrowing organisms. Fleshy macroalgal blooms, irrespective of how they are induced, decrease the growth and reproductive capacity of the more structurally complex reef-building corals (Tanner, 1995; Miller and Hay, 1996), as well as inhibit coral larval recruitment (Birkeland, 1977; Tomascik, 1991; Ward and Harrison, 1997) and survival (Lewis, 1986; Hughes *et al.*, 1987; Hughes, 1989; Wittenberg and Hunte, 1992).

Methods

It is essential that assessment/monitoring methods be both uncomplicated and expeditious. Some of the following protocols are well known and require minimal elaboration; whereas several are new and, therefore, are described in more detail. The frequency of assessment/monitoring is entirely dependent on the system in question, but should document the time and scale of significant changes.

Biotic Indicator Patterns

Multiple, photographic (digital images or, preferably, HD video), randomly located transects on compass headings 90˚ to biotic zonational patterns are taken perpendicular to the substrate (Littler *et* *al.*, 1986). Simultaneously, voucher specimens of dominant macrophytes and turf algae are collected for taxonomic purposes. In the laboratory, HD digital images are randomly selected and scored for percentage cover (see Littler and Littler, 1985). To describe the predominant indicator-group assemblages along transects in an unbiased manner, the cover data of each functional group for all quadrats are subjected to hierarchical cluster analysis (flexible sorting, unweighted pair-group method) using the Bray and Curtis (1957) coefficient of similarity. The resultant dendrogram of similar quadrat groupings, based on the dominant biota and environmental affinities, is used to characterize zones of functional indicator groups (community types, see Littler *et al.*, 2006). As examples, an abundance of palatable macroalgae indicates declining natural populations of herbivorous reef fishes. Corals and members of the calcified-crustose and jointed-calcareous algal forms have evolved anti-herbivore defenses (*e.g.,* toughness, structural inhibition, low calorific content, or low palatability), and show the greatest resistance to herbivory by generalist grazers with a gradient of increasing palatability from the more fleshy thick-leathery forms toward the coarsely branched, sheet-like, and filamentous algal forms (see Littler *et al.*, 2006 for functional-morphological characterization).

Herbivore Abundances

Herbivore abundances are enumerated by counting numbers of individuals, from mid-morning to mid-afternoon throughout a typical day for weather, at fixed distances on either side of random replicates of standardized transect lines or on compass headings (Figure 2). HD Video transects are quick, high-quality still images can be extracted later for enumeration in the laboratory, and they provide a permanent record of the target species (Littler *et al.*, 1986). For coral-reef systems having healthy levels of herbivory, grazer abundances and diversity will be high (see Results and Discussion) and palatable test plants will show the kinds of losses posited below.

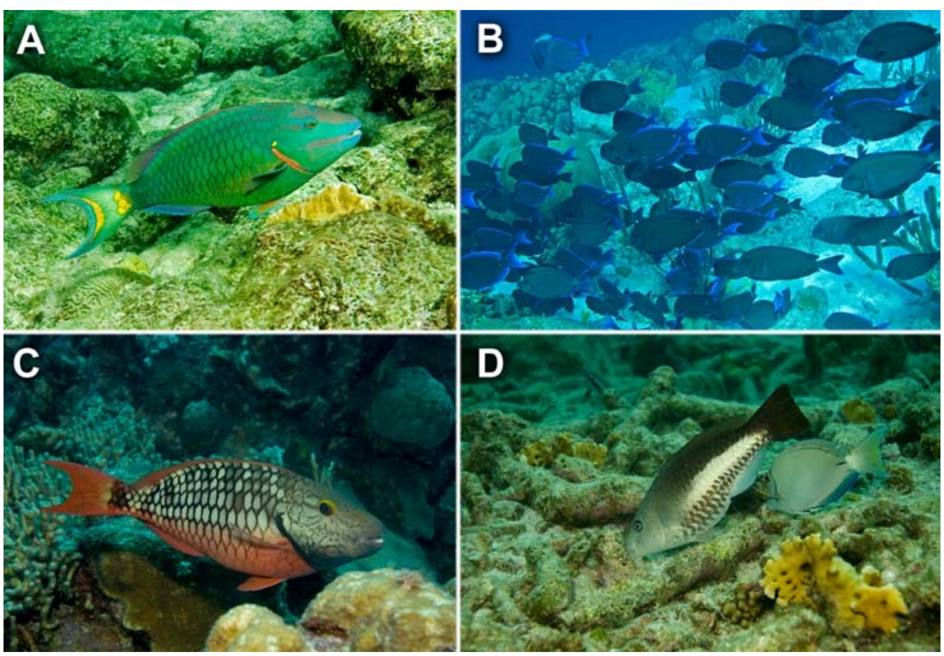

Figure 2. Examples of major herbivorous fishes. A, C & D: Parottfishes. B: Surgeonfish.

Herbivory Tipping-Point Assays

Tipping points for herbivory, where decreasing grazing reaches critical levels that begin to reduce resilience to and recovery from phase shifts, are assayed (Figure 3) using any highly palatable cosmopolitan test alga such as *Acanthophora spicifera*. We define resilience as the ability of a system to absorb disturbance while remaining essentially ecologically unchanged. The ubiquitously abundant red alga *A. spicifera* is a preferred food item for both parrotfishes and surgeonfishes (Lewis and Wainwright, 1985), as well as sea urchins (Littler *et al.*, 1983b). The alga is cut into measured segments (*e.g.,* 7.0 cm lengths) and attached to dead coral-rubble fragments by thin rubber bands. Replicates are placed haphazardly in each reef zone of interest for up to 6 h at midday, collected, and again measured (*i.e.,* length, area, or wet weight). At first, herbivore activity is generally lower but increases with each early trial, so assays are repeated until narrow confidence limits are attained. Also, trials are closely monitored and terminated when about 50% of the test plants have been consumed. Additionally, blades of the palatable red alga *Gracilaria* spp., the brown alga *Padina* spp. (Lapointe *et al.*, 2004), or the seagrass *Thalassia testudinum* (Hay, 1981) can be substituted in the above assay or used to further augment the data. This technique avoids novelty effects (*i.e.*, artifactual conspicuousness) that bias grazing patterns and rates. Gaudy markers, or materials such as colored rope and surveyor's tape, alarm herbivorous fishes in areas where they are intensively harvested and, conversely, attract them in protected (no-take) reserves (personal observations).

Figure 3. Dead coral fragments containing *Acanthophora spicifera* segments used to assay for herbivory.

Macroalgal Tissue-Nutrient Levels (C:N:P ratios)

Collections of dominant macroalgae are analyzed for tissue C, N, and P contents. These data are useful to assess the long-term nutrient history within any given environment, since antecedent nutrient events will have been recorded via uptake by the plants themselves (Figure 4). Tissue samples are usually sent to laboratories that contract for analytical services (*e.g.,* University of Maryland Chesapeake Biological Laboratory).

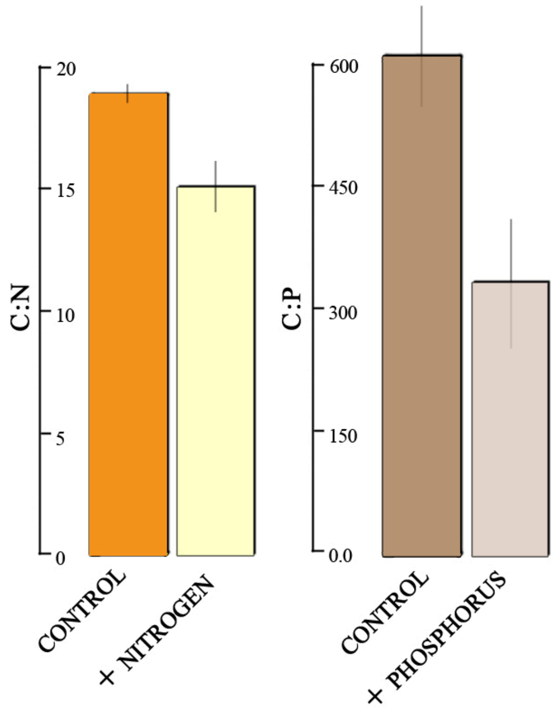

Figure 4. C:N and C:P ratios in *Acanthophora spicifera* from low (~1.0 µM DIN and 0.1 µM SRP) and elevated (~4.0 µM DIN and 0.4 µM SRP) DIN and SRP habitats, respectively. Data shown as mean±standard deviation.

Water-Column Nutrient Levels

To further characterize the nutrient environment, replicate water samples are collected, filtered, and quick-frozen from each target site. Dissolved inorganic nitrogen (DIN = NH_4^+ + NO_3^- + NO_2^-) and soluble reactive phosphorus SRP = PO_4^{3-}) analyses usually are contracted with laboratories that provide these services (*e.g.*, University of Maryland Chesapeake Biological Laboratory).

Results and Discussion

Functional Indicator Groups

The fast growth and turnover rates of fleshy algae compared to other reef organisms suggest their value as early-warning indicators of reef degradation. Representatives of ubiquitous algal form/function indicator groups (from Littler and Littler, 2006) are increasingly encountered as dominants on reefs, particularly those subjected to human activities (see Figure 2 in Littler and Littler, 2006).

- **Reef-building Corals (Cnidaria):** A predominance of diverse corals and calcareous coralline algae (Figure 5) are generally accepted as the most desirable components of biotic reefs because of: 1) their three-dimensional architecture, which provides habitats for myriad other reef organisms (largely responsible for much of the heterogeneity/high biodiversity); 2) their roles in producing the massive carbonate structure of reefs; and 3) their aesthetic qualities. The vertical structure and horizontal canopies of branching forms allow abundant populations of shade-dwelling crustose coralline algae to co-occur. Reef-building corals, while preyed upon by a few omnivorous fishes and specialist invertebrates (*e.g.*, crown-of-thorns sea star), generally achieve dominance under the top-down control of intense herbivory (Lewis, 1986; Lirman, 2001) and extremely low nutrient concentrations (Bell, 1992; Lapointe *et al.*, 1993). Massive corals are resistant to grazing at the higher levels of herbivory (Littler *et al.*, 1989). Hard mound-shaped forms show relatively little colony mortality under high grazing pressure, even though severely rasped by parrotfishes. Contrastingly, some delicately-branched corals such as *Porites porites* are quite palatable and readily decimated by parrotfishes (*e.g., Sparisoma viride*, Littler *et al.*, 1989; Miller and Hay, 1998). Nutrient increases are sometimes associated with coral diseases (Harvell *et al.*, 1999, 2002; Bruno *et al.*, 2003). As mentioned, numerous corals tolerate elevated nutrients (*e.g.*, Atkinson *et al.*, 1995; Steven and Broadbent, 1997; Bongiorni *et al.*, 2003), but diversity suffers. Conversely, others are physiologically inhibited by increases in nitrate (*e.g., Montastrea annularis* and *Porites porites*: Marubini and Davies, 1996), ammonium (*e.g., Pocillopora damicornis*: Stambler *et al.*, 1991; Muller-Parker *et al.*, 1994), and orthophosphate (*e.g., Porites compressa*: Townsley cited in Doty, 1969; *P. damicornis* and *Stylophora pistillata*: Høegh-Guldberg *et al.*, 1997). Nutrient inhibition of coral larval settlement also has been shown for *Acropora longicyathis* (Ward and Harrison, 1997). During the extensive ENCORE program on Heron Island, all increases in nutrient levels adversely affected coral reproduction (Koop *et al.*, 2001).

Figure 5. Healthy coral-dominated, highly-structured reef habitats.

- **Macroalgae:** With an increase in nutrients, the growth of harmful fleshy algae (Figure 6) is favored over the slower growing but highly desirable corals (Genin *et al.*, 1995; Miller and Hay, 1996; Lapointe *et al.*, 1997) and the latter become inhibited by competition for space and light, increased diseases, and physiological inhibition. On healthy oligotrophic coral reefs, even very low nutrient increases may exceed critical levels that can shift relative dominances by stimulating macroalgal production, while inhibiting corals. Interestingly, large biomasses/standing stocks of slow-growing perennial macroalgae (*e.g.*, rockweeds) can develop over time under low inorganic nutrient concentrations (McCook, 1999), and *Sargassum* spp. can co-exist with corals in oligotrophic waters by utilizing particulate organic sources of nutrients (Schaffelke, 1999). Therefore, in this context, large plant biomasses do not necessarily indicate detrimentally abundant dissolved nutrients. Filamentous and frondose macroalgae can outcompete corals (Birkeland, 1977; Bellwood *et al.*, 2006; but see McCook *et al.*, 2001), many of which are inhibited under elevated nutrient levels (reviewed in Marubini and Davies, 1996). Fast-growing algae are opportunists that benefit from disturbances that release space resources from established longer-lived populations, but also can become the superior competitors (Birkeland, 1977) when provided with sufficient nutrients. As a result, frondose macroalgae as a group are now generally recognized as harmful to the longevity of coral reefs due to the linkage between excessive blooms and coastal eutrophication (ECOHAB, 1997). Potential competitive dominance of fast-growing macroalgae is inferred from their overshadowing canopy heights, as well as from inverse correlations in abundances between algae and the other benthic producer groups (Lewis, 1986), particularly at elevated nutrient concentrations (*e.g.*, Littler *et al.*, 1993; Lapointe *et al.*, 1997). Macroalgae, such as *Halimeda* spp. (Figure 7), also gain competitive advantage by serving as carriers of coral diseases (Nugues *et al.*, 2004). The fleshy macroalgal form group has proven to be particularly attractive to herbivores (see Hay, 1981; Littler *et al.*, 1983a, 1983b) and only becomes abundant where grazing is lowered or swamped by excessive algal growth (chemically-defended forms such as Cyanobacteria [Figure 8] are exceptions). High levels of overcompensation by herbivory may explain some of the reported cases (*e.g.*, Crossland *et al.*, 1984; Szmant, 1997; Smith *et al.*, 2001) of specific corals surviving high-nutrient reef environments.

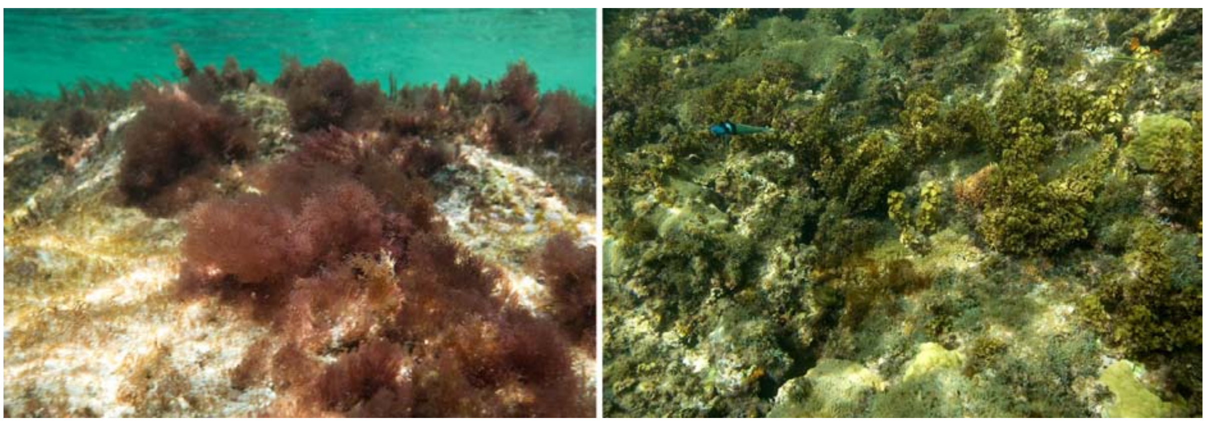

Figure 6. Undesirable harmful macroalgal blooms indicative of reduced herbivory (top-down) and elevated nutrients (bottom-up).

Figure 7. *Halimeda opuntia* colonizing coral-dominated communities. *Halimeda* is a vector for coral diseases, which may facilitate its outcompeting coral populations.

Figure 8. Cyanobacterium (blue-green alga) overgrowing a coral colony (left) and killing it (right).

- **Crustose Coralline Algae:** The predominant members of this indicator group tend to be slow-growing competitively inferior taxa abundant in most reef systems (Littler, 1972). However, they span a spectrum of morphotypes from thin sheet-like crusts to thick massive pavements to upright branched and columnar coral-like heads (Figure 9) that contribute to both cementation and bulk. This functional group is highly resilient and is able to recover/restore the coral-reef system relatively quickly, given that some crustose coralline algae accelerate colonization and chemically attract/facilitate the survival of coral larvae (Harrington *et al.*, 2004), while the other two fleshy algal functional groups tend to inhibit larval settlement. Because crustose corallines continually slough-off upper surface layers, they play a key role, as do filter-feeding corals, in physically preventing the settlement and colonization of many undesirable fleshy fouling organisms on coral reefs (Littler and Littler, 1997). Crustose corallines, because of their slow growth rates, tolerate low nutrient levels and generally are conspicuous, but not dominant, under low concentrations of nutrients and high levels of herbivory (Littler *et al.,* 1991). Accordingly, they do well under both low and elevated nutrients [*i.e.*, most are not inhibited by nutrient stress and many are maintained competitor-free by surface cell-layer shedding (Johnson and Mann, 1986), even at lower levels of grazing (Littler and Littler, 1997)]. Therefore, crustose coralline algae do not require elevated nutrients (as might be inferred); instead, their rise to dominance is largely controlled indirectly by the factors influencing the abundances of the other groups, primarily corals and fleshy macroalgae. The key point is that crustose corallines predominate mainly by default (*i.e.*, under conditions of minimal competition), where either corals are inhibited by elevated nutrients or fleshy algae become removed by intense herbivory. A gradient of frondose- to turf- to coralline-algal groups was closely correlated with escalating herbivory on coral reefs (Steneck, 1989).

Figure 9. Crustose coralline algal communities indicative of high herbivory and elevated nutrients.

- **Low-Growing Turf Algae:** These ubiquitous forms (Figure 10) are mostly dense filamentous and low-growing fleshy members of all four algal phyla that tend to become predominant under minimal inhibitory top-down and stimulatory bottom-up controls. Domination by turf algae suggests desirably low nutrient levels, but an inadequate herbivory component. Their relatively small size and rapid perennation results in moderate losses to herbivory at low grazing pressures. They have opportunistic life-history characteristics, including high surface areas and the ability to maintain substantial nutrient uptake and growth rates under low-nutrient conditions (Rosenberg and Ramus, 1984). Turfs also contain an abundance of nitrogen-fixing Cyanobacteria (Adey and Goertemiller, 1987; Adey, 1998) that can enrich other low-growing members of the dense turf community. Algal turfs have been shown to be favored under reduced nutrient-loading rates (Fong *et al.,* 1987) or infrequent nutrient pulses (Fujita *et al.,* 1988) and can form extensive horizontal mats.

Figure 10. Low-growing turf algal communities characteristic of low herbivory and low nutrient levels.

Herbivory

Herbivore abundances, enumerated by counting numbers of grazers, from mid-morning to mid-afternoon throughout a typical day for weather, are given below (from Littler *et al.*, 2006; see their Table 1). These data provide typical baseline data contrasting natural herbivorous fish densities and grazing intensities for typical Belize Barrier Reef (Carrie Bow Cay, CA) back-reef flat zones of low-herbivory and high-herbivory. The high-herbivory site was characterized as having an average of 145-fold more surgeonfish and 148-fold more parrotfish than the low-herbivory site. In agreement, bioassays for the healthy high-herbivory site averaged 80% *Acanthophora spicifera* loss · 6 h^{-1} and 100% *Thalassia testudinum* loss · 3.2 h^{-1}; compared with 5% (16-fold lower) and 3% (62-fold lower) losses, respectively, for the low-herbivory site. Based on similar experiments conducted worldwide on coral reefs by a range of workers (*e.g.*, Hay, 1984; Lewis and Wainwright, 1985; Paul *et al.*, 1987; Sluka and Miller, 2001; Littler *et al.*, 2006), Littler and Littler (2006) posited that less than a 6-h half life (>50% mean loss per 6-h for palatable algae, Figure 11) during a series of *in-situ*, mid-day, assay periods is indicative of a healthy level of herbivory for the particular coral-reef habitat(s) tested.

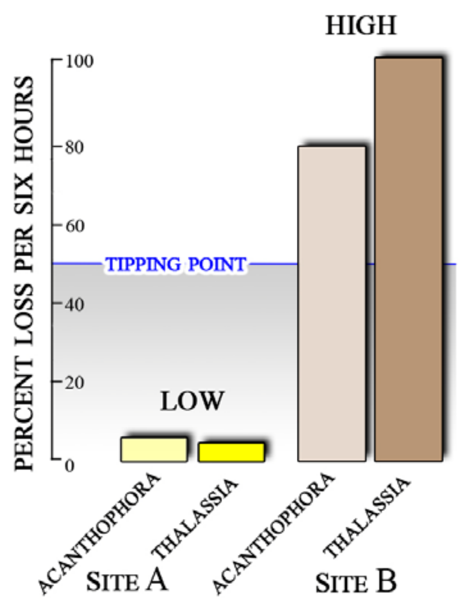

Figure 11. Experimental herbivory during a series of assays at two sites on the Belize fringing reef at Carrie Bow Cay. World-wide and experimental values indicate a mean tipping point half-life of >50% loss per 6-h for palatable plants as characteristic of a healthy level of herbivory.

Tissue Nutrients

At present, C:N and C:P ratios can be calibrated to the range of values reported (*e.g.*, Lapointe *et al.*, 1992, 1994, 1997, 2005) for a wide variety of macroalgae throughout a spectrum of systems, ranging from eutrophic to oligotrophic. From the extensive data of Lapointe *et al.* (1993), tissue C:N ratios below ~30 and C:P ratios below ~600 correlate with eutrophic environments (DIN = 4.8 μM, SRP = 1.6 μM, N:P = <17); whereas, ratios above ~36 and ~800, respectively, suggest more oligotrophic conditions (DIN = 0.2 μM, SRP = 0.01 μM, N:P = >24). In the future, tissue nutrient ratios should be experimentally calibrated to growth rates for cosmopolitan indicator algae to provide even greater utility (see values reviewed in Larned (1998).

Water-Column Nutrients

To interpret water-column nutrient data, it must be emphasized that both delivery rates and concentrations are important (Atkinson *et al.*, 2001), but concentrations are paramount. Once diffusion gradients are eliminated by the levels of water motion typically present on most coral reefs, concentration becomes the issue. Also, water-column nutrient concentrations represent the net sum of internal cycling, algal assimilation, and external inputs, relative to macroalgal growth demands (Lapointe, 1997), and, therefore, offer the most direct method to assess nutrient excesses. Consequently, a nutrient threshold model based on concentrations (rather than on fluxes) is not only valid, but is probably the best index of nutrient status.

Low-nutrient tipping points (Figure 12), where increasing nutrients reach hypothetically critical levels that begin to reduce recoverability from phase shifts (*i.e.*, ~1.0 µM DIN = Nitrogen @ 0.014 ppm N, or 0.040 ppm NO_3^- and ~0.10 µM SRP = Phosphorus @ 0.003 ppm P, or 0.007 ppm PO_4^{3-}), have been broadly corroborated [in developing the Nutrient Threshold Hypothesis (NTH), Bell, 1992; Lapointe *et al.*, 1993; Bell *et al.* 2007)] for sustaining macroalgal overgrowth of both coral reefs and seagrass beds. As examples, low-nutrient tipping points also have been correlated for macroalgal overgrowth of coral-reef communities at Kaneohe Bay in Hawaii, fringing reefs of Barbados, inshore reefs within the Great Barrier Reef lagoon, and the reefs of the Houtman Abrolhos Islands, Western Australia (Crossland *et al.*, 1984). The physiological/kinetic basis for such low-nutrient tipping points is the hyperbolic Monod relation (Droop, 1985; Bell *et al.*, 2007), which is also supported by controlled, high-flux, continuous-culture, laboratory experiments (Caperon *et al.*, 1971; DeBoer *et al.*, 1978; Lapointe and Tenore, 1981). In our experience, if modern analytical instruments can detect measurable nutrient levels, so can growth-limited macroalgae.

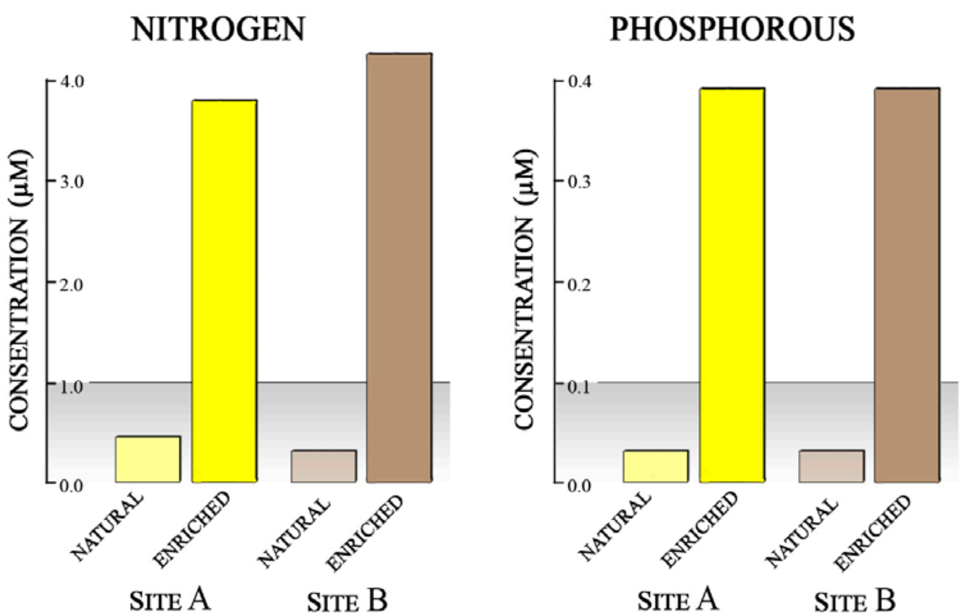

Figure 12. Experimental nutrient enrichment concentrations at two sites on the Belize fringing reef at Carrie Bow Cay. World-wide and experimental values indicate tipping points for DIN and SRP to be approximately 1.0 µM and 0.1 µM, respectively.

Additionally, a wealth of *in-situ* coral-reef studies carried out in areas characterized by nutrient levels only moderately above the 1.0 μM DIN and 0.1 μM SRP NTH levels (Larkum and Koop, 1997; Miller *et al.*, 1999; Thacker *et al.*, 2001), reported minimal algal stimulation following experimental nutrient enrichment – further documenting the low natural nutrient concentrations required for ample algal growth and their widespread applicability. Moreover, the macroalgal overgrowth experimentally stimulated (Smith *et al.*, 2001; Littler *et al.*, 2006) in reduced-grazing/elevated-nutrient treatments demonstrates that ambient nutrient concentrations inhibitory to growth under the natural turbulence levels found on coral reefs are extremely low, but universally similar to those reported above for other tropical marine algae. Some corals can tolerate high levels of DIN and SRP; however, nutrient tipping points not much above present analytical limits of detectability represent a universal level of resource availability at which resilience begins to be reduced (Scheffer *et al.*, 2001), such that stochastic or other disturbances/stresses can shift coral-reef ecosystems towards dominance by macroalgal stable states.

Conclusions

The indictor-group and bioassay approaches provide powerful perspectives and essential measurement criteria to enable resource managers to protect coral reefs and similar coastal systems from eutrophication, destructive overfishing, and initiation of harmful algal blooms. Human population growth, accompanied by changes in land/sea use and increased exploitation of natural resources, will continue to cause broad alterations in the structure of coral-reef communities. Unless curbed, anthropogenically induced phase shifts will expand geographically at an accelerated pace. However, workable solutions are available that include the designation of Marine Protected Areas and regulations banning the taking of critical herbivorous fish species (*e.g.*, Figure 2, Parrotfish, Surgeonfish; and also Rudderfish, Rabbitfish and Batfish) from market exploitation. Fisheries controls must be backed up by strategies to regulate the effects of pollution (*e.g.*, governmental-mandated seawater nutrient standards, Advanced Wastewater Treatment), along with the long-term international commitments to reduce the emissions of greenhouse gases.

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Collaborative Diving for Science: A Report on the Diving Equipment, Techniques and Collaborative Approach Used to Conduct Subtidal Shellfish Surveys in Coos Bay, Oregon

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Abstract

Oregon's estuaries are legend for recreational clamming. In the 1970s, the Oregon Department of Fish and Wildlife (ODFW) conducted a comprehensive natural resource survey of Coos Bay. In 2008, ODFW repeated the 1970s study in intertidal mudflats of Coos Bay and collaborated with the Oregon Coast Aquarium to conduct similar sampling in comparable subtidal habitats of Coos Bay. The primary focus of this paper is on diving methods. This paper will describe the equipment and techniques that were used to provide a safe and effective diving expedition. It will also provide an overview of the collaboration between ODFW and the Oregon Coast Aquarium for this project.

Keywords: aquarium, dive safety, interagency collaboration, shellfish survey

Introduction

This was a contracted scientific diving expedition initiated by the SEACOR (Shellfish and Estuarine Assessment of Coos Bay, Oregon) project of ODFW. The Oregon Coast Aquarium provided a Dive Safety Officer and a team of volunteer scientific divers. Their mission was to conduct sub-tidal shellfish surveys in Charleston/Coos Bay during the week of September 29th to October 2nd, 2008, and to identify the effectiveness of methods for future application. The SEACOR team provided scientific methods protocol and topside support for the operation. All diving operations were conducted in compliance with scientific diving safety standards promulgated by the American Academy of Underwater Sciences (AAUS). Sixty-six dives were conducted in the areas of Pigeon Point and Clam Island. All data collected were provided to the SEACOR team.

Methods

The Oregon Coast Aquarium's Dive Safety Officer (DSO), Vallorie Hodges, was initially contacted by Caren Braby of ODFW's Charleston office, asking for advice on how SEACOR might be able to organize sub-tidal data collection in a safe, scientifically valid and effective manner, using non-ODFW divers. In the absence of an ODFW dive program, ODFW staff members were not currently authorized to dive on research projects. SEACOR's project goals were to assess and describe the habitat of Coos Bay, map the distribution and densities of four main clam species and generate a biomass estimate. The study design included sampling areas throughout Coos Bay. Braby and her team had already conducted rapid and detailed assessments of the intertidal areas, but were very interested in conducting a sub-tidal assessment. Braby and Hodges discussed the basic research methods that were intended to be used, the equipment, tasks and techniques required of the divers, the number of dive sites/data collection points (waypoints), the location of the general diving area, conditions, and other logistical considerations.

From these discussions, it was clear that a team of appropriately trained and certified scientific divers from the aquarium could be deployed for this purpose. Braby sought and received approval from ODFW to offer the Aquarium a contract to provide the diving services. Hodges sought and received approval from the Aquarium to agree to the contract, which included the services of the Aquarium Dive Safety Officer and a team of volunteer divers. The contract was a relatively standard State of Oregon Personal/Professional Services Contract that established the contractual relationship between ODFW and the Aquarium, including elements such as the contract period, statement of work, consideration (compensation/expenses), required documents (including insurance and worker's compensation), tax and withholdings, representation/warrantees, ownership of work product, indemnity and other legal issues.

Prior to the diving in Coos Bay, Hodges scheduled a Scientific Diving training course which provided a ready avenue of completing Scientific Diving certification training and mission-specific skills training. Divers were recruited from the Aquarium's volunteer diver corps, provided they were a volunteer in good standing, and held a current Aquarium Scientific Diver certification. The course also provided an excellent platform for putting the SEACOR research methods into practice in a controlled environment. During the course, divers built and tested several styles of quadrats, practiced the intended sampling methods, and worked with the suction dredge. Divers also received training on the identification of the shellfish and algal species targeted by the SEACOR project. Shellfish species included gapers (*Tresus capax*), butter clams (*Saxidomus giganteus*), cockles (*Clinocardium nuttallii*), and littlenecks (*Protothaca staminea*). Algae included *Ulva intestinalis*, *Ulva lactuca*, *Fucus* spp., *Laminaria* spp., and *Chondracanthus* spp.

The primary equipment for this project included a quadrat, a suction dredge, a collecting bag, and a hand rake. The 9 m^2 quadrat (3 m on each side) was constructed of 1 inch polyvinyl chloride (PVC) (see Figure 1). Rather than a fixed rigid square, it was constructed using four L shaped corner sections, each of which could be press-fit to join its neighboring corner and was held in place via shot cord (like that used for tent poles) or collapsed for easy retrieval at the end of the dive. This design also allowed for easy stowage. On one corner of the quadrat was a fixed 0.25 m^2. Each quadrat was also fitted with a large clip and a section of line, so it could be tethered to a marker buoy. To deploy the equipment, the vessel was navigated to a global positioning system (GPS) waypoint, an anchored waypoint buoy was dropped into the water, and the quadrat was opened and the press-fit pieces guided together (if necessary). It was then clipped to the buoy line, where it would sink to the bottom. Divers then entered the water, swam down the buoy line to the bottom, and commenced collecting data. This facilitated the random nature of the data collection, since divers did not choose where to position the quadrat underwater, they simply collected the data inside the quadrat where they found it, already on the bottom.

Figure 1. Quadrat and detail.

The suction dredge was powered by a Honda 4.0 hp, 75 gal·min^{-1} gasoline-driven pump (Figure 2). The inflow consisted of a section of pool vacuum hose long enough to extend over the edge of the boat into the water and was fitted with a strainer basket to prevent debris entering the flow loop. The outflow consisted of a lightweight fire-hose which attached to the dredge array. The dredge was made up of several sections. The main dredge body was constructed of 6 inch diameter PVC (approximately 8 ft long) with an angled neck, to which a 6 inch diameter flexible black plastic hose was attached (approximately 6 ft long). The end of the flex hose was fitted with a 6 inch diameter aluminum collection nozzle and handle, which made directing and handling the dredge much easier. A 3 ft long wire mesh collection basket was attached to the other end of the dredge body.

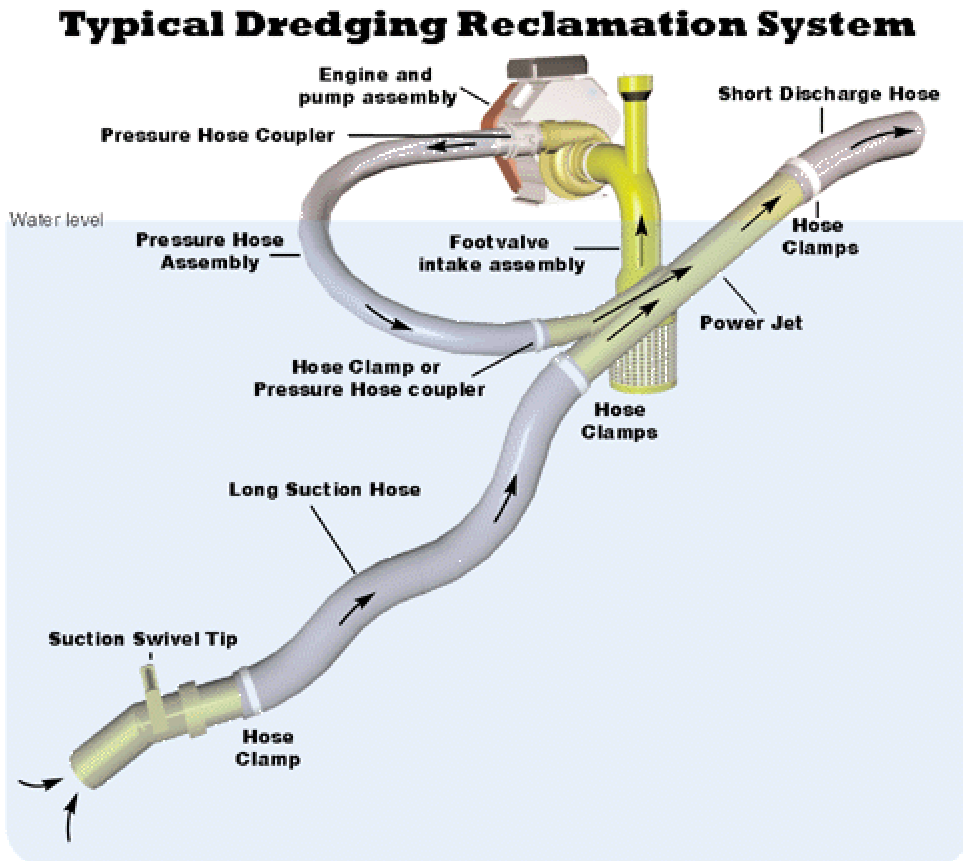

Figure 2. Dredge.

The data collecting methods included three tasks. The first task was the "gaper grope" which was a visual and/or tactile count of the number of gaper siphons within the 9 m^2 quadrat (excluding the 0.25 m^2). The second and third tasks utilized only the 0.25 m^2. The second task was to record the bed-type (bivalve, shrimp or other), the substrate (sand, sand/mud, mud, shell, cobble, or bedrock), and an estimate of the percentage and species of algal cover. All data were recorded on waterproof data sheets designed specifically for that purpose. The third task was to collect specimens within the 0.25 m^2 to a depth of 35 cm. Divers were instructed to first use the hand rake in two directions to locate and remove any existing cockles or littleneck clams. These were to be placed in the diver's collecting bag. Then the divers were to use the dredge to collect any specimens inside the 0.25 m^2. At the conclusion of the dive, the divers were to fold and retrieve the quadrat. The topside personnel were to retrieve the dredge (which was tethered to the vessel via two lines attached to the fore and aft sections of the dredge) along with any collected samples that were captured in the basket attached to the end of the dredge. Signaling and safety protocol was developed to assure diver safety during the dredge removal.

During the training and practice sessions with the dredge there were mixed results. In most substrates it was found to be a bit slow, but effective. It was clear that a slightly more powerful pump would improve the effectiveness of the design. In somewhat softer substrates cave-in made it more challenging to assure that specimens collected came only from the 0.25 m^2 area. Also of interest was the experience of one diver who simply hand-dug the 0.25 m^2 and placed collected specimens in the diver's collecting bag.

Results

Nine volunteer divers and the aquarium's DSO traveled to Charleston and provided diving and topside dive safety support. In addition to the ODFW R/V *Saxidomus*, one volunteer provided a small rigid hull inflatable boat (RHIB) to serve as a highly maneuverable diver retrieval vessel.

The team met with ODFW staff for a pre-operations briefing before setting out for the first several sets of randomly chosen target sites in the general area of Pigeon Point and Clam Island in Coos Bay. On the first site bedrock rendered the dredge not useable. Given the additional logistics that were involved in deploying the dredge, it was decided to trial the hand-digging method on some of the sites. Since most of the dives were in areas with soft substrate, and were conducted in conditions of moderate current, this method actually worked fairly well. The sediment was rapidly carried away from the resulting hole, and divers found they could readily feel the presence of even very small specimens with their hands.

Several things were learned over the process of the next three days. One was that the divers could operate in considerably stronger current than was first expected; however, skill was needed to assure that the quadrat was not moved by the divers or dragged by the buoy. Additional scope on the marker buoys was called for and better anchors that would hold securely to the bottom, even in the current. Diving within some restrictions of the tides and currents and the desire to get as many waypoints as possible meant that the ability to quickly deploy divers and equipment greatly aided in the efficiency of the project. We quickly found that divers could get several waypoints on a single cylinder of air, however, due to the design of the vessels it was necessary to remove dive gear before boarding. A vessel better equipped for diving would certainly facilitate such operations. It was also noted that simple scuba equipment configurations with quick donning/doffing capability clearly worked better for these operations than some of the more technical configurations commonly used by some of our cold-water divers. Another finding was that liveboating was of considerable assistance both in terms of time efficiency and in terms of diver safety (*e.g.,* quick diver retrieval in current), but this requires more boat handling skills and good vessel maneuverability. We found that a combination of anchoring the R/V *Saxidomus* and keeping the RHIB mobile worked well for diver retrieval and safety. Another skill that proved worthwhile was the ability of the divers to deploy surface marker buoys, using line and reels. The divers carried the marker buoys and reels and used them during the drift dives, making it far easier for the RHIB to monitor the diver positions. Since we were operating in a shipping channel, we were also able to have a contingency plan for the RHIB driver to signal to the divers (by line pull signals on the buoy) if it were necessary to recall the divers due to shipping traffic. Reel quality (and the reel and line-handling skills among the divers) were not equal, and it became clear that a good quality, easily deployed and retrieved reel in the hands of a skilled diver was an asset. It was also clear that not all marker buoys work well for this purpose. Some are better used on the surface by the diver as an emergency signaling device (*e.g.,* safety sausage), while others retained air and floated high on the surface, proving to be very suitable locating buoys for the submerged divers. As mentioned earlier, the dredge design worked adequately for most substrates, but did require more logistical support and safety protocol, and on most substrates the divers experienced reasonable success manually digging for samples. It should also be noted that post-project, the divers experimented with some additional dredge designs, including a very simple diver-carried air lift constructed of PVC that can be attached to a scuba cylinder. Results were promising but testing was incomplete.

During the first three days of the project, sampling dives were made on a series of waypoints, however, very few live clams were found. After the dives on the third morning, ODFW staff convened a meeting to discuss alternative sampling methods. For the next two days, drift dive transects were conducted. Divers reported very few target species of clams, but did see quantities of piddocks (*Zirfaea pilsbryi*) as well as a considerable number of sea pens, crabs, shell debris and lost anchors. The lack of sighted and/or collected target clams was a concern for the ODFW scientists. There was some expectation that there would be a positive correlation between the intertidal densities found in the earlier mudflats sampling by ODFW staff and sub-tidal densities found by the divers. Divers did observe large quantities of gaper mortalities at the Clam Island waypoints, but few to none were found alive at any of the sites. The team discussed the lack of sightings and questioned variables that included recent dredging activity, water quality issues, skill of the divers in identifying gaper siphons and siphon holes, the effect of tides and currents, and the behavior of the clams. It is possible that the clams were there but they were not seen due to behavior. Most of the dives were done on outgoing tides, and this may have impacted the results, but even a drift dive done on an incoming tide that covered a considerable distance yielded only one gaper siphon sighting. It was clear that additional diving would need to be done to further evaluate these variables and results.

Recommendations

This was a highly successful project in terms of being able to provide SEACOR with divers to collect valuable sub-tidal data for their project and to evaluate the effectiveness of methods for future application. It was also a highly successful project in terms of providing Oregon Coast Aquarium volunteer scientific divers with an opportunity to put their science diving skills to valuable use. The opportunity to work cooperatively on this project was a positive outcome for both organizations. This mission was completed with a high level of safety and confidence for both our divers and ODFW staff.

The primary difficulty with this mission was the lack of authorization for the ODFW scientists to dive. The entire team found it frustrating that the principle investigator and her staff could not participate in evaluating first-hand the data collection methods and the underwater environment, equipment, and techniques. It certainly helped that one of our divers took some underwater photos and video, which could be reviewed by the SEACOR team, but the extent/scope of these images was limited, photography/videography was not the primary task of this diver, and first hand experience is typically superior to photographs, regardless of their quality. It is somewhat time-consuming to train/orient volunteer divers to these types of research techniques, though worthwhile if these same divers can participate in future projects of similar design. To that end, we have recommended to our scientific diver volunteer contingent to continue building their skills and experience by applying the research methods developed during this project to a few target areas in Yaquina Bay. The group will use this as a trial project to collect data and to continue revising the techniques and equipment used to better suit this purpose, including working with several other dredging techniques and designs, such as the diver-carried air lift mentioned earlier. It is of considerable interest to the Aquarium to continue to make these kinds of scientific diving opportunities available to our volunteer scientific divers to *assist* ODFW scientists and other agencies with underwater research projects. It should also be made clear that the Aquarium management and the Aquarium's Dive Control Board agreed to this project as a one-time operation, and that these resources were not to be considered a proxy or surrogate for an ODFW dive program. It would be of significant benefit to ODFW to put in place a safe, effective and legally compliant dive program that provides the needed in-water oversight and control over the science for the resource they have the duty to manage. The Aquarium has offered support and assistance in the establishment of an ODFW dive program, including a number of resource-sharing ideas.

The concept of collaborative/cooperative projects is not new to scientific diving, but it is perhaps more relevant than ever in today's economy. The current economic environment has impacted the scientific diving community, resulting not only in tighter budgets, but also concerns over the closure or suspension of some research projects and even entire dive programs. It may be worth examining how a collaborative approach to scientific diving projects could (even temporarily) allow some projects to continue. And what about applying this model to more permanent relationships? There are a number of programs that have combined resources to their mutual benefit, such as dive program consortiums. Perhaps it is time to look more critically at both these short-term and long-term approaches and evaluate their merits, as well as the potential negative aspects of these relationships, with the goal of providing the scientific diving community with some guidance on how they might be successfully introduced.

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Oxygen and Hydrogen Isotopes Suggest Two Sources for Little Salt Spring

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Abstract

Water samples collected by scuba diving and analyzed for oxygen and hydrogen isotopes suggest that vents are feeding Little Salt Spring from two distinct sources. One source has oxygen values of -0.96±0.12‰ and hydrogen values of -0.80±2.27‰. The other source has oxygen values of -1.31±0.12‰ and hydrogen values of -2.35±2.27‰. Furthermore, for one of the sources, the stable isotopes of oxygen vary between the months of October to November 2009 by 0.79±0.12‰, possibly related to the seasonal changes in water flow and chemistry that have been observed by divers in the spring. This work has implications for stable isotope-based paleoclimate records constructed for Little Salt Spring based on the assumption of a single water source and well mixed water column. Additionally, continued preservation and exploration of the early prehistoric human remains and artifacts of Little Salt Spring are tied to understanding the site's hydrology and chemistry.

Keywords: decompression diving, hydrology, isotopes, Little Salt Spring

Introduction

Little Salt Spring is a shallow, water filled basin above a deep, underwater cavern located near Charlotte Harbor in Sarasota County, Southwest Florida (Figure 1). In terms of karst geomorphology it is a cover-collapse sinkhole. Its water flow rate is in the range of 40-50 $L \cdot s^{-1}$ (Clausen *et al.*, 1979), so it is on the boundary between a third and fourth magnitude spring. It is slightly saline (3‰), and has an average annual temperature of 28°C and a pH of ~7.5 (Alvarez-Zarikian, 2005). At then end of the Pleistocene epoch the site was apparently a freshwater cenote, an oasis in a large, dry Florida peninsula, and now holds organic artifacts and other evidence of Paleo-Indian and Archaic stage use ranging in age from 12,000 to 9000 and 6800 to 5200 radiocarbon years before present (Clausen *et al.*, 1979). It is the unique anoxic water that fills the sinkhole below five meters depth that has allowed organic materials such as wood, textile fragments, hair, skin and brain tissue, which normally decompose within a few years, to be preserved (Gifford, pers. comm., 2009). The excellent preservation potential of the site may be the key to solving the long raging debate over the origin of the first colonizers of the Americas. DNA from a 9000+ year-old human burial might reveal if the first Americans came from Europe or Asia (Gifford, pers. comm., 2009).

Ongoing research in Little Salt Spring has aimed to relate Late Quaternary human occupation of the site with climate patterns during the last 11,000 years as determined by ostracod assemblages and stable isotopes. Although the end of human occupation of the site around 5000 radiocarbon years before present (rcy BP) was originally thought to be related to a switch to a wet-mode climate with freshwater readily available everywhere on the Florida peninsula (Clausen *et al.*, 1979), based on isotopic work, Alvarez-Zarikian *et al.* (2005) suggest the alternative hypothesis that site abandonment was related to the deterioration of water quality as the spring became more mineralized and saline due to lateral salt water intrusion (Alvarez-Zarikian *et al.*, 2005). Isotope-based climate modeling, however, was based on the assumption of one source of water for the spring and a well-mixed water column.

Decompression dives to the 75-m bottom of the spring between 2006 and the present have led to the discovery of at least two separate vents feeding the spring, one at the contact between the southwest wall and abutting bottom sediments, and one on the bottom sediment floor in the northwest quadrant. Stable isotope analysis of water obtained from the throats of both vents was conducted to determine if the vents tapped the same or two different water sources. The results have implications for both preservation of this significant archaeological site and the reconstruction of its paleoclimate history.

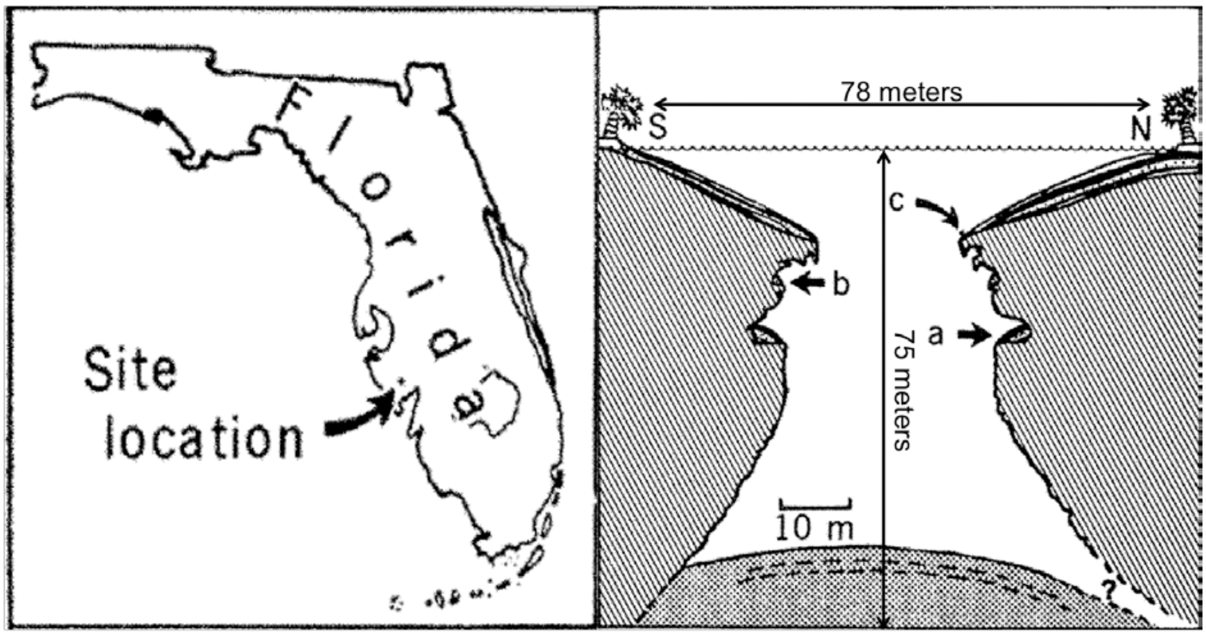

Figure 1. Site location and vertical cross-section of Little Salt Spring, (a) 27 m ledge, (b) 18 m ledge, (c) 13 m edge of basin. Modified from Clausen *et al.* (1979).

Methods

Decompression Diving

Dives to collect water samples from the two bottom vents were conducted approximately 28 days apart in October and November 2008. Maximum depth was 74.7 m with a bottom time of 20 minutes. Back gas was 15% O_2 and 55% helium. Decompression (deco) schedules were calculated with DecoPlanner software using deco gases of 50% nitrox and 100% O_2. Water samples were collected by hand from the vent throats using plastic syringes that were flushed three times before collection and capped immediately after collection to minimize contamination by ambient water or evaporation (Figure 2). Water samples were also collected at intervals up the water column and at the surface. For comparison, local tap water and water from Warm Mineral Springs, located 3.5 km from Little Salt Spring, were also obtained. Due to a visibility problem, no water was collected from the floor vent in October 2008. Bottom observations from March 2007 to November 2008 chronicle a seasonal occurrence of biofilms in the dry season and disappearance of the films by May. Divers also report that the floor vent is always flowing warmer and stronger than the wall vent.

Figure 2. Rick Riera-Gomez collects water samples in plastic syringes from the throats of the floor vent (left) and wall vent (right) at a depth of 75 m on November 20, 2008. Biofilms were present in November but not in October.

Geochemical Analysis

The stable isotopic composition of oxygen and hydrogen ($\delta^{18}O$ and δD) in the water samples was determined by mass spectrometry following the modified methods of Epstein and Mayeda (1953) and Coplen *et al.* (1991), respectively. The analysis was conducted using a Europa Geo 20-20 equipped with autosampler-equilibration unit (Europa WES) at the Rosenstiel School of Marine and Atmospheric Sciences' Stable Isotope Laboratory. Precision of these methods as determined by replicate analyses of the standards within each run was 0.12‰ for $\delta^{18}O$ and 2.27‰ for δD of the Little Salt Spring (LSS) floor vent (FVnov), both wall vent (WVoct and WVnov) and the 100-ft samples run in December 2008 and 0.19‰ for $\delta^{18}O$ and 2.56‰ for δD. According to convention, standard delta notation (δ) is used to report all isotopic results for water relative to standard mean ocean water (SMOW) in parts per thousand (‰ or ppt) or parts per million (ppm).

Results

Oxygen isotope values vary from -0.90‰ to -2.82‰. The most enriched value is for the Warm Mineral Springs sample and the most depleted is for rainwater. Hydrogen isotope values vary from -12.90‰ to 2.19‰. Rainwater is the most depleted and the FVnov samples is the most enriched with respect to hydrogen. Little Salt Spring has more negative (lighter/depleted) oxygen values and more positive (heavier/enriched) deuterium (^{2}H) values than its neighbor, Warm Mineral Springs (Table 1). The data cluster around the Meteoric Water Line (MWL) with no apparent trend. As seen in Figure 3, the wall and floor vents have distinct isotopic values for November 2008 with the wall vent plotting below the MWL and the floor vent plotting above it. In October 2008; however, the wall vent plotted above the MWL with a lighter $\delta^{18}O$‰ value.

Table 1. $\delta^{18}O$ and δD values for Little Salt Spring.

Sample Name	Month	Depth (m)	$\delta^{18}O$ (‰)	δD (‰)
Average Error	-	-	±0.19	±2.56
Rainwater*	-	-	-2.82	-12.90
Surface	Oct	0	-2.34	-2.35
50-ft	Oct	15	-1.49	-2.11
100-ft	Nov	30	-0.99	-1.30
150-ft	Oct	46	-1.52	-7.31
200-ft	Oct	61	-2.11	-4.60
Wall Vent oct	Oct	72	-1.75	-1.79
Wall Vent nov	Nov	72	-0.96	-0.80
Floor Vent nov	Nov	72	-1.31	2.19
Warm Mineral Springs	Oct	-	-0.90	-3.64
LSS tapwater	Oct	-	-2.08	-11.04

* value obtained from Price *et al.*, (2008)

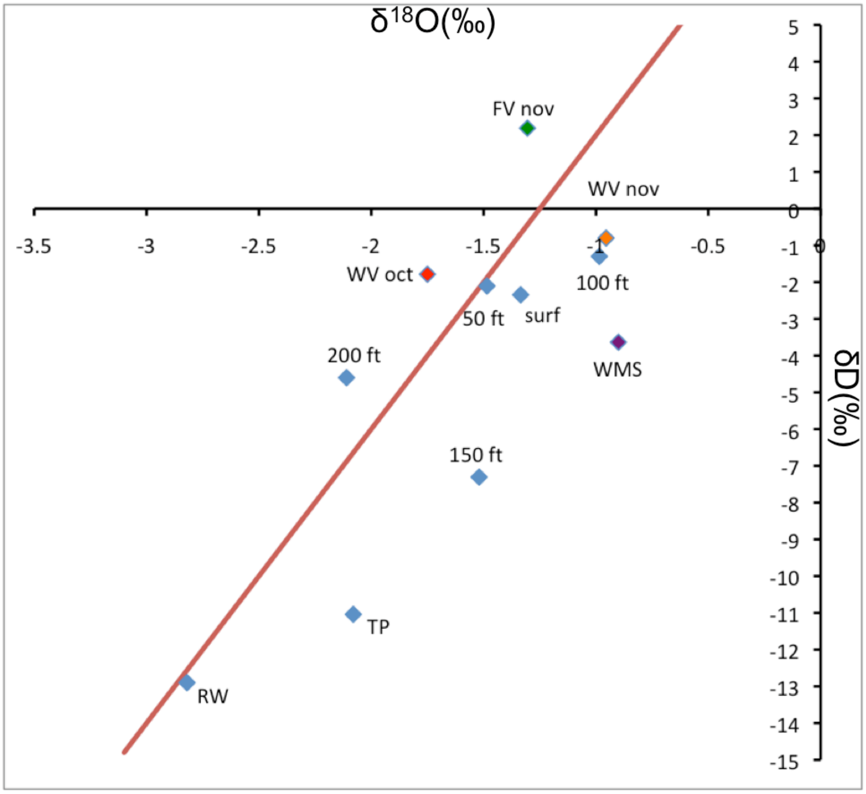

Figure 3. Relation between δD and $\delta^{18}O$ values in water from Little Salt Spring, Warm Mineral Springs, regional rainfall, and tap water plotted with the Meteoric Water Line. Rainwater (RW) value is for the Everglades from Price *et al.*, (2008).

Discussion

Background

All elements have both stable and unstable isotopes. While unstable or radioactive isotopes decay with time, the ratios of stable isotopes in a substance are only changed by processes that cause fractionation (discussed further below). Isotopes are forms of elements with different masses caused by variability in the number of neutrons in an atom's nucleus. Although the chemical properties of a given element's isotopes are the same, the differences in mass allow mass spectrometry to be used to determine the ratio of different isotopes present in a substance, such as water.

Fractionation

Fractionation of isotopes occurs when there is a change in the proportion of one isotope with respect to another. Isotopic ratios of hydrogen and oxygen in the hydrological cycle are controlled by two main factors: temperature and source (Epstein and Mayeda, 1953). Water sourced from the ocean will have very different isotopic values rainwater over the middle of continents. This is caused by the fractionation that occurs with the processes of condensation and evaporation in the hydrological cycle. For example, ocean water by definition has an oxygen isotopic value of zero ppt. As the ocean is evaporated, the lighter isotope (^{16}O) is preferentially removed into a cloud and the heavier isotope (^{18}O) is left behind. The amount of fractionation that occurs is controlled by temperature: the lower the temperature, the greater the fractionation. At higher temperatures, so much energy is available that the process does not need to discriminate between heavy and light isotopes. As the cloud moves over the continent, toward higher latitudes, or up a mountain, it cools and begins to condense. The first droplets to rain out of the cloud are the heaviest isotopically, leaving behind a more and more isotopically light cloud vapor (Figure 4). This process is known as Rayleigh Distillation. MWL represents the isotopic values of hydrogen and oxygen found in rainwater worldwide (Craig, 1961). Values plotting below this line have been evaporated.

The isotopic composition of water can also be affected by fluid interactions with rock; however this process is often insignificant compared to the amount of water flowing through an open system such as a Florida aquifer.

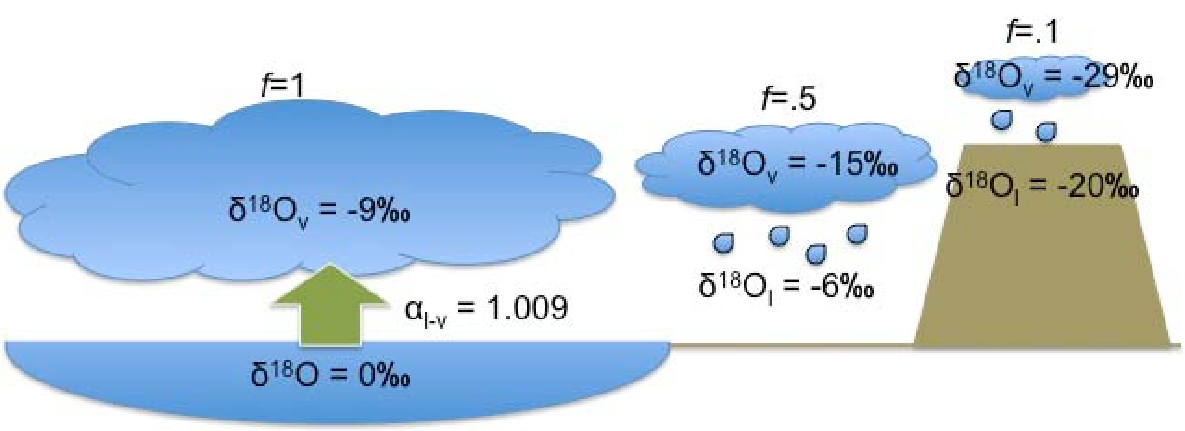

Figure 4. Fractionation of oxygen isotopes in the hydrological cycle. Ocean water is fractionated during evaporation according to the alpha value α. As the cloud moves inland, to higher latitudes, or to higher altitudes, the fraction (*f*) of the original vapor is reduced and the delta values (δ) of the ^{18}O vapor (v) become more negative. When vapor from the cloud condenses, the heaviest water rains out first into the liquid (l) and the remaining cloud vapor becomes progressing more isotopically light or negative.

Little Salt Spring

Hydrogen and oxygen-18 values can help identify waters that have undergone evaporation, recharge under different climatic conditions than present, and mixing of waters from different sources (Sacks and Tihansky, 1996). The differences between WMS and LSS samples suggest that these neighboring springs are fed by different sources. Likewise, the values of the wall vent and floor vent samples are different enough to suggest that they are fed from distinct sources or at least have distinct pathways through the aquifer system from source to spring.

The majority of the values measured in this paper are offset below the MWL, indicating that the water has undergone evaporation prior to recharging the source aquifer systems of the springs. Interestingly, FVnov and WVoct plot well above the MWL. This could be the consequence of isotopically light rainfall with respect to oxygen in the respective recharge areas or watersheds. These depleted values could be caused by winter storms bringing rainwater down from higher latitudes and the continental interior. The wall vent values also shift from above to below the MWL between October and November, becoming more positive in its oxygen isotopes toward the end of the year. This may be a reflection of a seasonal shift to drier, more evaporative conditions in the Florida winter. This change occurs in conjunction with the appearance of biofilms covering the wall near the vent, suggesting a strong relationship between water chemistry and biology on the bottom of the spring. These biofilms are currently under investigation by a group from Pennsylvania State University. This group is interested in the biofims as potential sources of biomarker compounds and because of their likely role in sulfuric acid production and limestone dissolution (speleogenesis) (Yang *et al.*, 2008).

As expected, the Everglades rainwater sample plots on the MWL. Reflecting the influence of rainwater on the shallow basin's water chemistry, the surface sample and 50-ft sample plot near the MWL as well.

These results have implications for the past, present and future of Little Salt Spring. First, although Alvarez-Zarikian *et al.* (2005) assumed otherwise, isotopic evidence indicates more than one source for Little Salt Spring and variable chemistry with respect to depth. Not only is depth variation apparent in our data, a depth trend is also seen in the pH and sulfate concentrations reported for the surface, 6.0 m and 24 m water samples in Alvarez-Zarikian *et al.* (2005). Although their methods state that water samples were collected at 65 m as well, these values are not reported. Based on this paper's contribution to understanding the hydrology and chemistry of the spring, it seems probable that the trends seen in the upper portion of the spring continue to 65 m and beyond. Because of the wrong assumptions on which the Alvarez-Zarikian *et al.* (2005) paleoclimate interpretation is founded, their data needs to be re-evaluated in light of recent advances in understanding the hydrology of Little Salt Spring. Second, current work on the geomicrobiology of the spring appears intimately tied to its water chemistry, which, in turn, appears to experience seasonal changes. Continued monitoring of the bottom vents for changes in isotopic composition will aid the study of the unique microbial communities these vents support. Finally, continued preservation of the significant artifacts and human remains of Little Salt Spring, many of them still waiting to be discovered, is dependent on the water chemistry of the site. There is a need to determine the recharge region of Little Salt Spring in order to protect this area from groundwater contaminants that may make their way into LSS and damage its unique archaeological assemblage before divers can sample it. Future work should aim not only to determine the recharge region of the spring, but also if the changes in isotopic values are seasonal and related to other important chemical parameters such as sulfate and oxygen concentrations. Decompression dives to the bottom of Little Salt Spring have enabled characterization of the entire spring system, which aids understanding the ancient climatic conditions and protecting the record of early human history and migration in the Americas.

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Approaches for Analyzing Behavioral Interactions of Fishes Using Time Series Video Observations at an Ocean Observatory off the Coast of Georgia

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Abstract

Remote underwater video produces replicate visual observations of species composition, behavior and interactions with habitat under the most natural conditions possible. Previous video-based studies are associated with adequate spatial coverage but poor temporal coverage of particular habitats, due to limited bottom time for divers and other underwater vehicles. However, time series data from a single long-term study site reveals fine scale variations in species composition and behavior. We used time series video from an ocean observatory site in the South Atlantic Bight (SAB) off the coast of Georgia to quantify patterns of species interactions and group foraging in a sub-tropical fish community. Six cameras mounted centrally with outward looking fields of view recorded 10-second video clips every hour during daylight. Video clips from November 2002 were examined to evaluate multivariate techniques for distinguishing patterns in behavioral interactions between species.

Keywords: behavior, foraging, species interactions

Introduction

Species interact within communities in multiple ways with positive, neutral or negative outcomes for individuals involved in such interactions as a consequence (*i.e.*, predation, competition, parasitism, mutualism, and commensalism). Much of the focus in the ecological literature has been on predation, competition and parasitic relationships with one or more species experiencing a negative outcome. However, there has been relatively limited attention given to facilitative interactions between species (mutualisms or commensalisms with one or both species experiencing a positive or neutral outcome) and the associated affects on populations and in communities (Bruno *et al.*, 2003). Some interactions are long-term on the order of months to years. For example, clownfish (subfamily Amphiprioninae) generally live in a host anemone throughout their lifetime (Buston, 2004). Other relationships are shorter-term and may change at time scales as small as seconds to minutes while still resulting in facilitated changes in predator avoidance and prey acquisition (*e.g.*, Barber and Auster, 2005; Auster *et al.*, 2009). These relationships are common among predators on reefs and in other coastal habitats (Parrish, 1993; Sazima *et al.*, 2003; Auster *et al.*, 2005; Auster, 2008; Auster *et al.*, 2009; Auster and Lindholm, in press).

Many fish species that are small in size and serve as prey for multiple piscivorous fishes occur in schools to increase their individual chances of survival. However, when groups of predators locate aggregations of prey, their abundance can be greatly reduced. In response to predation pressure, prey aggregations may change location or behavior in an attempt to reduce risk (Crowder *et al.*, 1997, Auster *et al.*, 2009), although outcomes from such responses are not consistent and multiple studies demonstrate both decreases as well as increases in rates of predation (Sih *et al.*, 1998). Multiple predator species with variable search and attack strategies can facilitate capture of prey and have an additive affect on mortality rates of prey. For example, wading birds (multiple heron species) appear to facilitate predation on prey by smallmouth bass *Micropterus dolomieu* by driving prey to deeper water (Steinmetz *et al.*, 2006). Alternatively, multiple predators may interfere or cause shifts in prey distributions that reduce predation rates (Crowder *et al.*, 1997; Safina, 1990). If the predator-prey interactions of fishes are commonly mediated by the behavior of co-occurring species, such behavior webs may be important in terms of population processes (*e.g.*, prey consumption and growth rates) of multiple species (Lukoschek and McCormick, 2002; Bruno *et al*., 2003).

Our understanding of the ecology of reef fish communities has benefited greatly from the ability of scientists to make direct observations underwater. While direct data collection by divers is common, time underwater is limited by depth and the physiological constraints of breathing gases on human observers. Furthermore, the presence of divers during data collection efforts may bias the data recorded; however, re-breathers may reduce the severity by which data collected during human presence is skewed (Lobel, 2001). Most studies of reef fishes in deep water are also generally on the scale of days to weeks, even when remotely operated data collection devices are utilized. Even decadal scale time series studies in shallow water (<20 m depth) are based on data sets produced from collections of short forays onto the reef.

Remote video recording is a powerful tool for collection of data on the distribution and abundance of fishes as well as their associated behaviors. Video records can be reviewed by multiple observers (*i.e.*, to validate species identifications and counts) and repeated at multiple speeds to dissect elements of behavior. Imagery can be collected throughout the daylight period and with specialized lighting it is possible to obtain video records throughout the diel cycle. Video has been used extensively by divers and on mobile underwater vehicles (*i.e.,* occupied submersibles, remotely operated vehicles) for what are essentially snapshots of species composition, abundance, patterns of habitat use and other ecological metrics. However, long time series imagery from single sites (*i.e.*, from underwater observatories) is relatively rare despite the lack of understanding of variation in species composition, patterns of habitat use, and species interactions that occur at particular sites on the scale of days to weeks. For example, Smith and Tyler (1973) conducted one such study using a closed-circuit television at 17 m depth off Bimini in the Bahamas. The authors studied patterns of diversity and the functional role of species within a community of reef fishes and used long time period observations to define an assemblage of fishes that were transient through the study site but were functionally important higher trophic level predators. Few studies have examined such variation at short but ecologically relevant time scales over long temporal periods.

As part of a larger project we conducted an analysis of video records collected over multiple years at a seafloor observatory in the South Atlantic Bight off the coast of Georgia. Our objective was to assess variation in patterns of species interactions in a subtropical reef fish assemblage. A related objective was to develop a set of approaches for quantifying behavioral attributes of foraging from time series video at fixed emplacements. Here we review our approach for producing data from video imagery and subsequent analytical approaches related to these objectives.

Analytical Approach

Video imagery was collected in a systematic manner at a site 72 km off the coast of Georgia in <35 m depth as a component of the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON). Barans et al (2005) provides a full description of the camera system, installation on the seafloor, and data handling. Briefly, six wide angle video cameras were mounted in single camera housing at the center of a 15 m diameter circle containing concrete artificial reef structures. Although the site was located in an area where fishing was allowed, the location of the small reef was kept secret to evaluate fisheries recruitment and retention patterns. The reef structures provided a substrate for colonization by encrusting organisms found throughout the region. Two to three reef structures were situated within the view field of each camera. Samples were recorded sequentially for 10 s once an hour between the hours of 1200 and 2200 GMT. The cameras had 460 line resolution, which is relatively low, but allowed for rapid digitization of files at the site and transmission of files to an onshore station via microwave link. Each file contained the camera number, date, time and a ten second monochrome video clip.

In order to assess the utility of time series video for studies of behavioral facilitation in fish communities, we made the *a priori* choice to analyze video records from November 2000, 2002 and 2004, although we report only on analyses for 2002 here as we discuss methodological approaches. The month of November for each year contained the most continuous sequential files (*i.e.*, versus breaks in the record due to file corruption) as well as had the greatest continuous period of good horizontal visibility underwater. Topaz Movement software (Version 3.5; Topaz Labs LLC, Dallas, Texas) was used to view video clips, sharpen images for species identification purposes, count individuals and classify behavior (Figure 1). For each file we recorded species composition (SC) based on taxon and abundance as well as those species exhibiting two classes of behavior: multi-species associations (MSA) defined as species exhibiting coordinated and directed movements in multi-species groups as well as group foraging (GF) defined as those multi-species groups actually exhibiting foraging behavior based on stalking or biting prey. Species exhibiting GF were subsets of species observed in MSA groups.

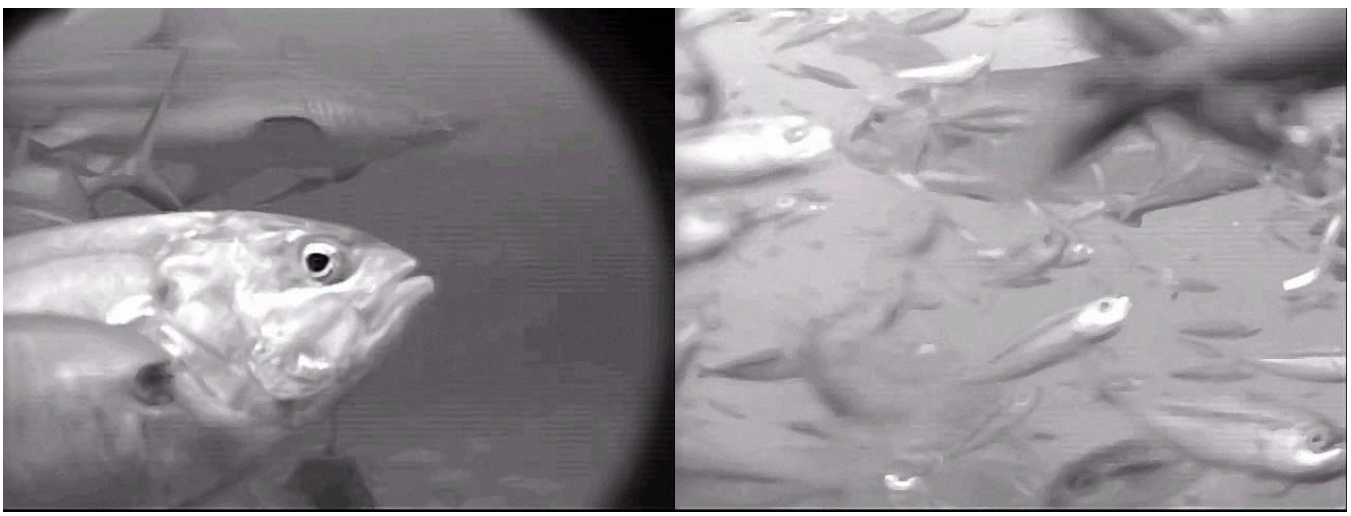


Figure 1. Examples of frame grabs from video samples.

Species accumulation curves were plotted to ascertain the adequacy of sample size based on species composition and the two behavior categories. To determine the relative strength of species co-occurrences in samples, Bray-Curtis similarity coefficients were computed for all species pairs observed per sample based on a presence-absence matrix. (Presence-absence versus species-abundance data were used due to the extreme dominance of several species of small sized schooling species.) Results of a hierarchical clustering procedure based on the Bray-Curtis matrix were used to illustrate the variation in strength of these relationships (Clarke and Gorley, 2001) such that the probability of the species occurring together in samples (*i.e.*, SC), and based on the probability of the species engaging in the same behavior together (*i.e.*, MSA and GF). Community changes for SC, MSA and GF were determined using the Analysis of Similarity (ANOSIM) procedure to test for similarity between years. Each species was classified as one of six trophic groups: browsers, herbivores, microinvertivores, macroinvertivores, piscivores, and planktivores based on assignments in Bohnsack *et al.* (2002) and Auster *et al.* (2005) in order to assess variation in the functional role within the reef fish community. Abundance data were transformed using the square root standardization procedure to reduce the influence of the dominant species.

Examples of Results from the 2002 Data Set

The scientific and common names of the 46 taxa observed in our samples from 2002, as well as abbreviation codes used in our analyses, are listed in Table 1. Note that it was not possible to positively identify some individuals to the level of species, thus genus or other descriptor was used to ensure all individuals observed were accounted for in the data set.

Table 1. List of all taxa observed in all 2002 video samples by scientific name, common name and an abbreviation as used in analyses.

Scientific Name	Common Name	Abbr.	Scientific Name	Common Name	Abbr.
Alueterus schoepfi	Orange filefish	Alsch	*Holocanthus bremudenis*	Blue angelfish	Holbr
Anchoa sp.	Anchovy	Anchoa	*Lutjanus griseus*	Grey snapper	Lutgr
Apogon pseudomaculatus	Two-spot candinalfish	Apopse	*Lutjanus sp.*	Unidentified snapper	Lut
Archosargus probactocephalus	Sheepsheead	Arpro	*Mycteropercta microlepus*	Gag grouper	Mycmic
Balistes capriscus	Grey triggerfish	Balcap	*Mycteroperca phenax*	Scamp	Mycph
Caranx crysos	Blue runner	Carcry	*Pagrus sp.*	Porgy	Pargus
Caranx ruber	Bar jack	Carru	*Paralichthys sp.*	Flounder	Paral
Caranx sp.	Unidentified jack	Cara	*Pareques umbrosus*	Cubbyu	Parum
Carcharinus limbatus	Blacktip shark	Carli	*Pomacentrus sp.*	Damselfish	Pom
Canthidermis sufflamen	Ocean triggerfish	Cansu	*Rachycentron canadum*	Cobia	Racan
Carcharinus taurus	Sandbar shark	Cart	*Remora remora*	Remora	Remrem
Centropristis striata	Black seabass	Censt	*Scombridae sp.*	Mackeral	Scomb
Chaetodipterus faber	Atlantic spadefish	Chafa	*Selar crumenopthalmus*	Bigeye scad	Secru
Chaetodon ocellatus	Spotfin butterflyfish	Chaoc	*Seriola dumerili*	Greater amberjack	Serdu
Chloroscombrus chrysurus	Atlantic bumper	Chlchr	*Seriola rivoliana*	Almaco jack	Seriv
Cnidaria	Jelly	Cnid	*Sphyraena barracuda*	Great barracuda	Sphbar
Dasyatis sp.	Stingray	Dasy	*Stegastes leucostictus*	Beaugregory	Stleu
Decapterus sp.	Scad	Deca			
Echeneis sp.	Shark sucker	Ech		Larvae	Larvae
Epinephelus sp.	Rock hind	Epine		Misc small finfish	Schooling
Euthynnus alletteratus	Little tunny	Eual		Unidentified finfish	Unid fin
Giglymystoma cirratum	Nurse shark	Gigcir		Unidentified shark	Unid shark
Haemulon aurolineatum	Tomtate	Haeauro			
Halichoeres bivittatus	Slippery dick	Halbi			

Sample effort for 2002 and the number of samples within each behavior category are summarized in Table 2. All video samples collected during November were not viewable. However, the number of viewable files is indicated for the SC category. A low percentage of files were corrupted during the digitization and transmission phases of data acquisition.

Table 2. Summary of sample effort and files attributed to behavior categories for each year.

Year	Data Type	No. Video Samples	Total Species
2002	All samples[1]	1767	
	SC	1730	46
	MSA	484	29
	GF	191	22

[1] The category of "All samples" indicates total effort but includes files that were corrupted during the acquisition process.

Species richness and the shape of species accumulation curves varied as a function of sample size in each behavior category (Figure 2). A clear asymptote for species richness was reached for all samples used for assessing species composition. The same pattern emerged for taxa observed in multi-species associations (Figure 2b) and group foraging (Figure 2c).

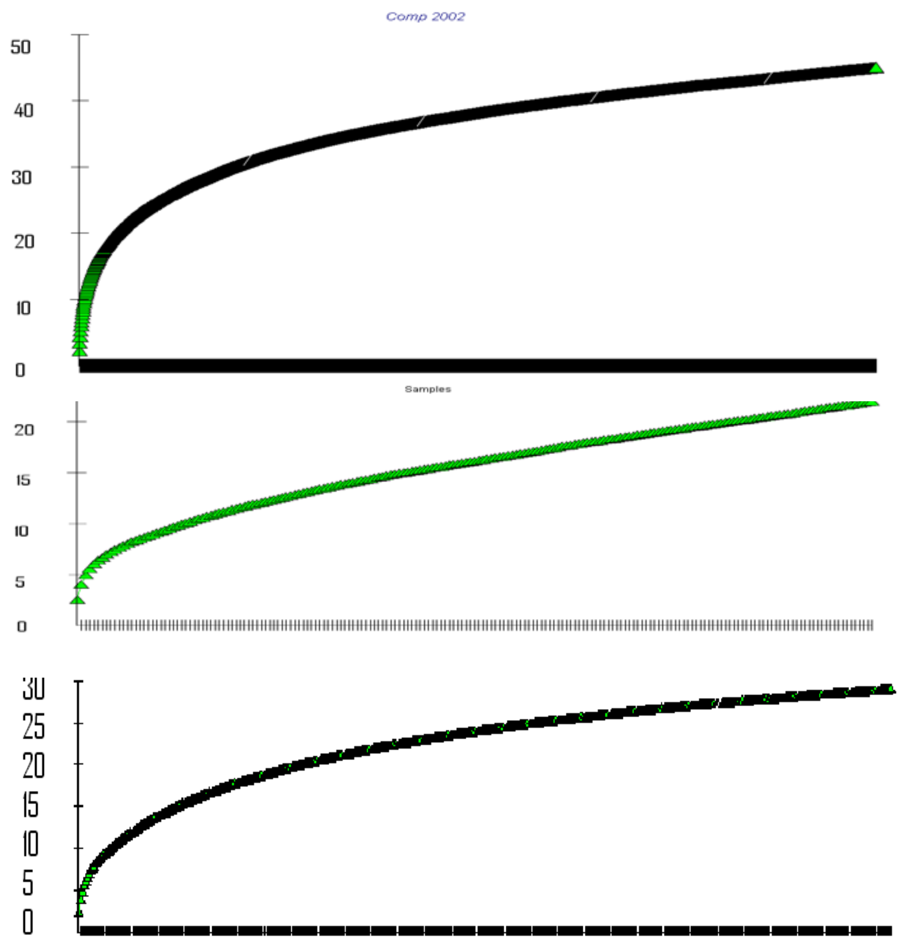


Figure 2. Species accumulation curves based on species presence-absence data for SC (a), MSA (b) and GF (c) in 2002. The datasets contained 1730, 484 and 191 samples respectively. The number of samples is on the x-axis and the number of cumulative species per sample set is on the y-axis.

Based on abundance data, planktivores dominated all behaviors, which comprised over 95% of the total individuals observed (Figure 3). However, piscivores dominated when using only species richness data (Figure 4), indicating the importance of this functional role from a species diversity perspective.

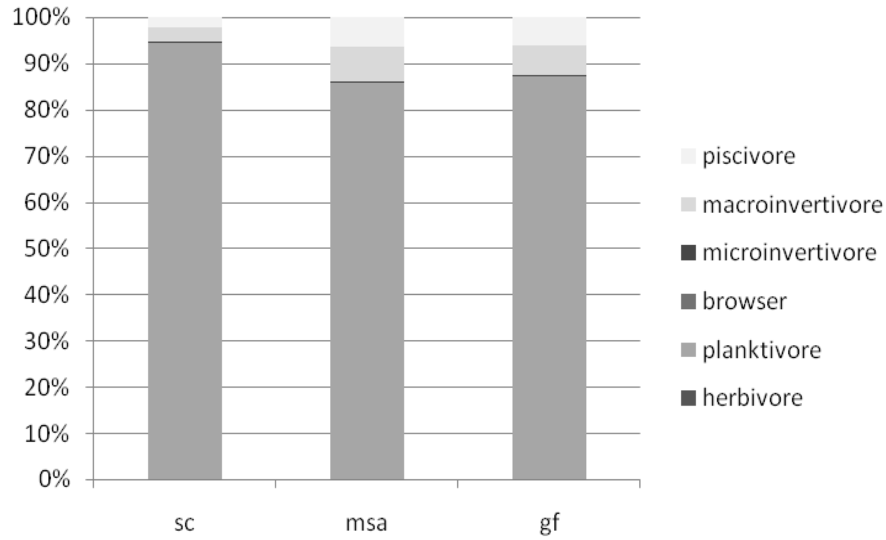


Figure 3. Trophic guild composition in 2002 for community composition and each behavior category based on species abundance data. Values are a percentage of the total number of individuals in each category of each year.

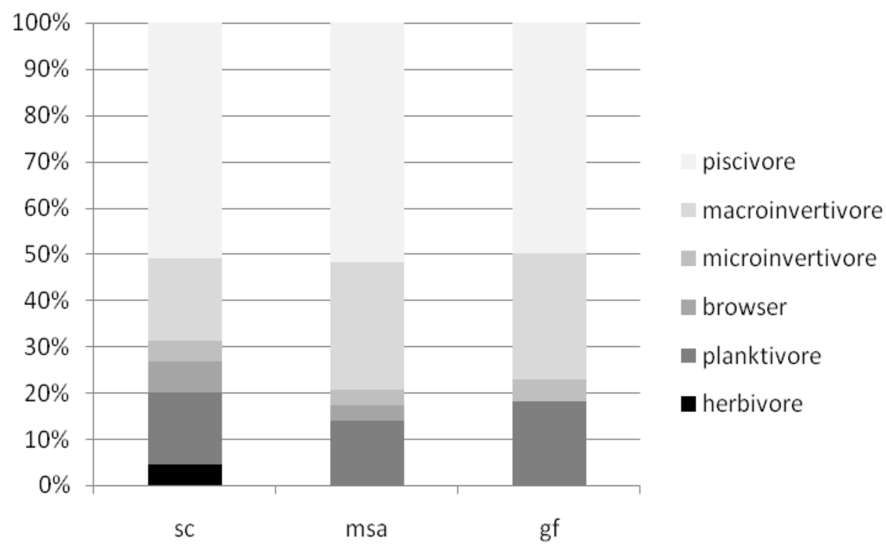
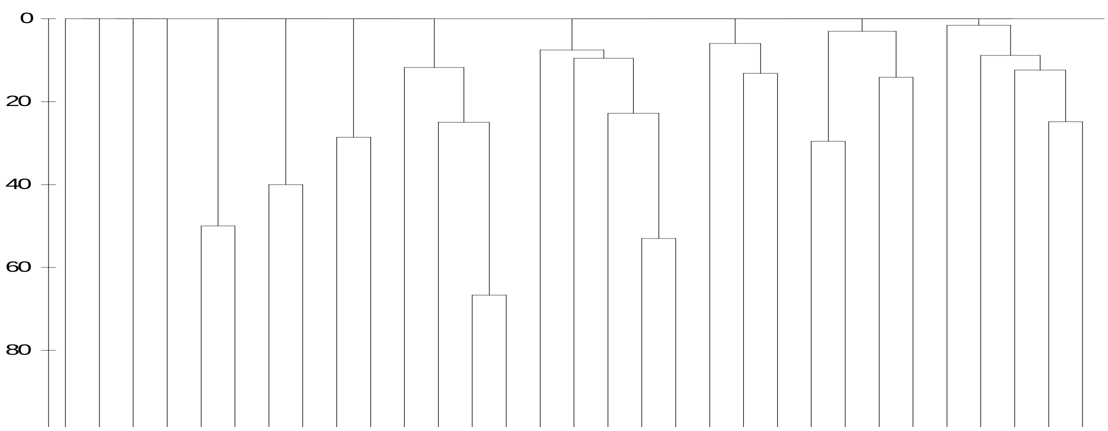


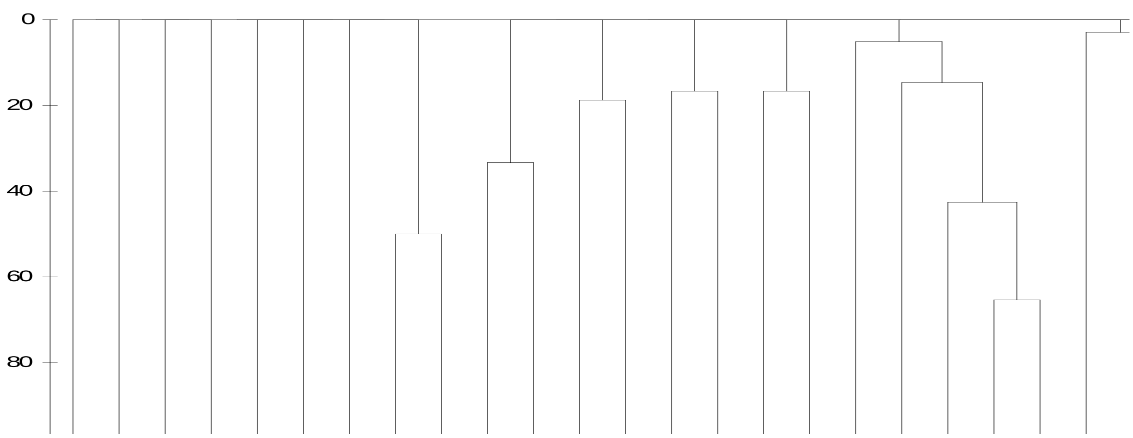
Figure 4. Trophic guild composition in 2002 as a percentage of species richness data. Values are a percentage of the total number of individuals in each category from 2002.

The relationships between species varied; however, many of the same species engaged in consistently strong relationships. In the time frame of the study, several strong relationships between species were apparent. For example, blue runner and greater amberjack were strongly associated based on both MSA and GF behaviors (Figure 5). Tomtate were generally strongly associated with other schooling fishes (*i.e.*, those classified as unidentified finfish and schooling fish). Gag grouper and scamp were strongly associated in MSA (Figure 5b), but not in GF samples. While it is clear that the strengths of some relationships vary, there are consistent patterns of associations between species.

a



b



c

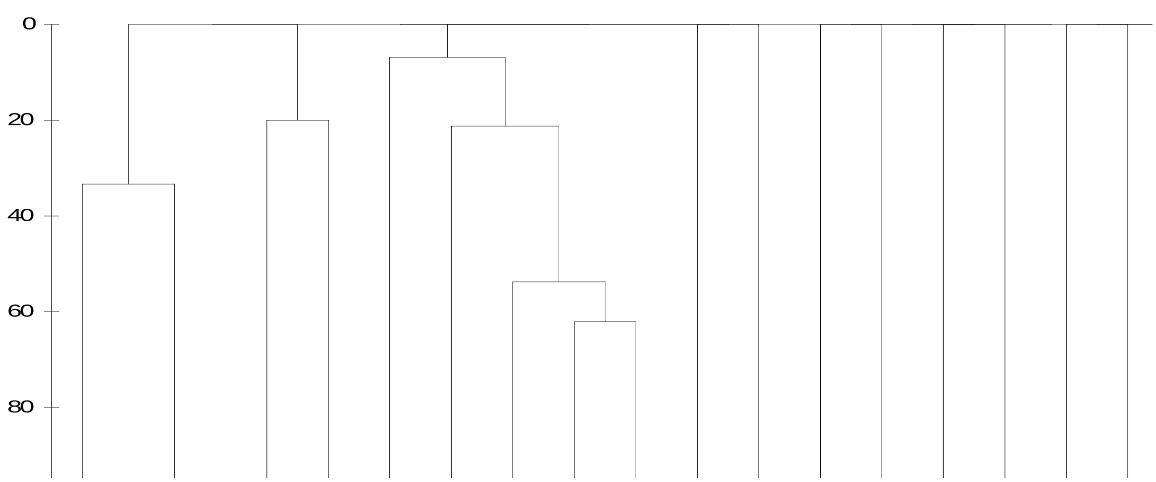


Figure 5. Strong relationships or high probabilities of the species occurring together in the same sample have values closer to 100. Weak relationships are close to zero. These are derived from presence/absence of species in the community from 2002 based on (a) SC, (b) MSA and (c) GF.

Discussion

Overall our results demonstrate that time series video can adequately sample the local fish community on the scale of days to weeks, within the constraints of video resolution, and record rare events evidenced by the limited number of direct foraging behaviors observed in comparison to sample size. Video observations from November 2002 revealed a total of 46 taxa in the local community with 40 identifiable to genus or species level. All species were found in previous studies in the region and are considered reef dominants, with few small benthic and cryptic species observed (*e.g.,* Sedberry and Van Dolah, 1984; Barans *et al*., 2005). We suspect that variation in sample size between years could have an effect on the outcome of analyses, although general patterns will certainly emerge, as differences in sample size are known to confound patterns of species richness and composition. Such variation can be accommodated by using bootstrap approaches for producing estimates of diversity and comparisons of community composition.

The species accumulation curves for November 2002 indicate that there were also sufficient samples to describe community composition, multi-species associations and group foraging. However, an increased sampling rate (*i.e.,* more samples per hour) or longer sampling period (*i.e.,* >10 s) would increase the probability of capturing group foraging bouts on video. It is important to note that planktivores accounted for approximately 95% of the total individuals observed. This is due to the large schools and aggregations of juvenile stages of fish species (*i.e.,* tomtate) and mid-water species that attain relatively small size at maturity (*i.e.,* scads and anchovies). The dominance of these few species would have masked the patterns we wanted to discern in the analyses so we made the *a priori* decision to use presence/absence data rather than abundance in our multivariate analyses.

We used Primer software to analyze MSA and GF data sets in an attempt to 'map' the behavioral interactions of species (sensu Auster *et al.*, 2009) and illustrate the variation in strength of these relationships (Clarke and Gorley, 2001). Primer software calculates the probability of the species occurring together in the samples (*i.e.*, SC), based on the probability of the species engaging in the same behavior together (*i.e.,* MSA and GF). ANOSIM can test for similarity of such relationships between years. Such an approach to visualize the relationships between species and groups of species can yield insights about the stability of such relationships over space and time. It is important to realize that choice of linkage and distance measures in hierarchical clustering can produce different results so interpretation of dendrograms and quantitative distance measures should be viewed in a relative sense. In our case we computed Bray-Curtis similarity coefficients for all species pairs. Presence-absence versus species-abundance data were used due to the extreme dominance of several species of small sized schooling species.

Classification of species into three primary trophic categories (*i.e.*, benthivores, planktivores, and piscivores) versus more refined classifications simplifies data structure in order to ascertain changes in the proportionality of feeding guilds and meet the statistical limitations of the chi-square procedure. Tests of guild proportionality between years using Chi-square tests of homogeneity of distribution on both presence-absence and species abundance data will be used to compare trophic composition in overall community structure with MSA and GF species over time. Transformation of abundance data using the square root standardization procedure will reduce the influence of the dominant species on analyses.

The video camera system proved useful in the observation of species composition, multi-species associations and group foraging behavior. There are advantages and disadvantages that are important to note for considerations of future use. In general, underwater video camera systems are temporally sufficient. The cameras record video clips over a time period that could not be sampled by divers. When considering diving operations, one must consider weather conditions, depth and other factors that limit human exposure to the ocean environment. Financial constraints for ship time and personnel also limit sampling using diving methods. The presence of diver also may have an effect on species behavior.

On the other hand, large video sample sizes require more time to extract data from the images. The cost of the system itself and underwater maintenance (*i.e.*, sending divers to clean the lens) is also time-consuming. In addition, the detail in video files is constrained due to limits on file size, as well as variation in visibility. There were several instances where drifting objects or fish blocked the view field of the camera. The cameras recorded at 460 horizontal lines of resolution, which is relatively low compared to other systems. This allowed fast file transfer but restricted the ability to accurately identify the species at times. In fact, most identifications to species level were limited to fish observed in the foreground.

Temporally, the SABSOON underwater video camera provided insight on the characteristic composition of the local community. When everything functioned properly, the system recorded over 60 samples daily. However, this particular configuration prevented sufficient observations to address spatial variability. The use of similar underwater video observatories in adjacent areas would also help determine if the behavioral patterns are site specific or if the observed patterns are widely applicable.

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Tourist Charge Capacities for Recreational Scuba Diving in Marine Protected Areas and Establishment of Interpretative Underwater Paths

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Abstract

This project was developed with the goal of establishing Charge Capacities of scuba diving in two reef sites in the west coast of Mexico, in the state of Jalisco and Nayarit. This is the first project of this kind in Mexico and an important effort to save the ecosystem in both marine protected areas (MPAs) which have an important for year round recreational diving activity. The study areas were the 'Los Arcos de Mismaloya' and 'Islas Marietas' MPAs. The goal was to establish Interpretative Underwater Paths for divers visiting the area. First, we evaluated the study area including topographic aspects, maximum depths and GPS referenced marks, as well as compiling an inventory of the living organisms. The research team then designed an underwater path based on the length of the diving site, itinerary type, points of interest and estimated air supply time. This information was converted into a description of the underwater path to be used by divers, with particular characteristics of the site mentioned, attraction issues, typical flora and fauna and recommended diver experience. The formula was established as 'calculation of touristic charge capacities' (CCT) proposed by Gallo *et al.* (2003), and some considerations of Borrie *et al.* (1998) and include the calculation of three capacities: Physical Charge Capacity (PCC), Real Charge Capacity (RCC) and Effective Charge Capacity (ECC) and these three have a relationship where each value is the equal or less than the precedent: PCC≥RCC≥ECC. An important factor used for the final determination was the touch frequency of divers observed and recorded in their dives.

Keywords: diving activities, ecological protection, touch frequency

Introduction

Environmental interpretation is a tool of environmental education that seeks to develop the sensitivity of people with respect to the atmosphere. It mainly deals with the subject, the nature systems and the human impact. Putting it into practice constitutes an act of education, reinforcing the importance of conservation of natural resources. In order to make an educational practice through the environmental interpretation a route outline is designed to make a series of learning units to address the subject. This outline of route is also called an *interpretative footpath*, essentially a guided route. This procedure allows not only to approach the subjects related to nature and their preservation, but also to involve social, political, economic and cultural aspects (Bedoy-Velazquez *et al.*, 2005).

This study provides planning tools to obtain an approach to the intensity of use of the established submarine areas like Marine Protected Areas (MPAs) (Cifuentes, 1992; Acevedo-Ejzman, 1997). First, determination of the environmental charge capacity (EnCC), which is defined as the capacity of an ecosystem to maintain organisms while it maintains a certain productivity, adaptability and capacity of regeneration. It represents the limit of human activity: if exceeded the resource will deteriorate (Ceballos-Lascuráin, 1996). A specific type of EnCC is the Capacity of Tourist Charge

(CTC), which talks about to the biophysical and social capacity of the surroundings with respect to the tourist activity and its development (Ceballos-Lascuráin, 1996). Its calculation comes through a complex process in which factors to consider are ecological, physical, social, economic and cultural (Moore, 1993). The CTC represents the maximum indicator of visitor use which an area can sustain.

Study Area

The study was conducted in the 'Bahía de Banderas' area that it is located in the states of Jalisco and Nayarit (Figure 1). The two specific localities were highly frequented by tourist services providers: Islas Marietas (*Marietas islands*), located in the northwestern part of the bay, and Arcos de Mismaloya (*The Mismaloyaarcs*), located in the southeastern coastal region. Both sites were established as MPAs. Nevertheless, they do not count with environmental regulations that limit the entrance of tourism and the CTC in these diving zones has not been considered previously.

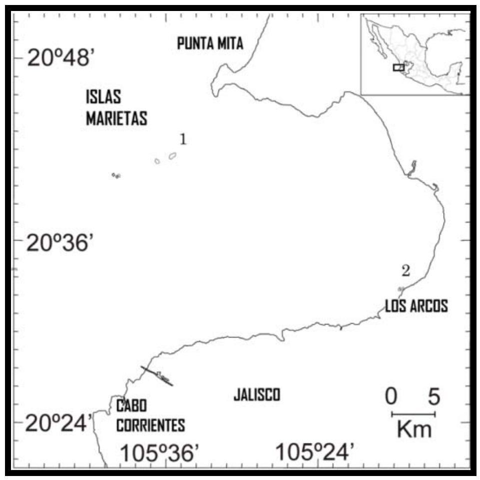

Figure 1. Study region.

Methods

Establishment of underwater paths

The criteria used for the establishment was:

1. Election of the appropriate tourist areas.
2. Creating an inventory of living resources (Ecosystem).
3. Design of an underwater path, including and considering:
   a) Length of the dive
   b) Planning of itinerary type
   c) Decision of interest points based on a specific theme
   d) Average air time according to experience of the divers
   e) Well known diving sites: shallow and calm places and easy to access.
   f) Important fauna concentration
   g) Topographic convenience and tracking: straight line, circular, rectangular, returning to the starting point, etc.

The guide for the underwater paths designed that we propose was edited from the interpretative paths established by the Secretaría de Turismo (2007) and developed for the creation of land pathways in protected nature areas. One of the main problems with this underwater methodology is communication; henceforth the surface briefing before the dives is basic to define all the points of interest.

The main points to consider for this study were:

- Geo-referenced localization of the sites and maximum depths
- Description of the underwater paths, including: distinctive and physiographic characteristics of the starting point, direction or bearing, distance and underwater geographic or physiographic description.
- Motive for visit: including the particular characteristics and attraction of the diving site as well as the recommended diver experience.
- Characteristic flora and fauna of the diving site.

Twenty dives were made for both the Los Arcos location and the Islas Marietas, with duration of 50 minutes each and a minimum and maximum deep of 20-90 fsw. The two first dives of each site were performed for general reconnaissance of the marine environment and the characteristic biota with the help of photographic and video cameras. This methodology allowed determination of the existing species and was compared with other studies made before in the area, so it was possible to detect resources and activities that join the tourist use respecting ecology protection rules defined by the MPA promulgation. Subsequent dives were used to collect data on substrate type and cover percentage.

A direct search method was used and consisted in the description and examination of the marine environment without the capture of organisms. A transect method was applied using a 150 ft long line and covering 300 ft^2. Data were recorded regarding substrate, hard coral cover, maximum and minimum depth, total distance and general description of the marine biota, taking special interest in large size fishes, hard and soft corals, echinoderms, crustaceans and mollusks, which are the more sought after species by amateurs divers and photographers. The identification was made *in situ* with the help of specialists in each marine group.

The calculation formula was established as 'Calculation of Tourist Charge Capacities reconnaissance' (TCC) proposed by Gallo *et al.* (2003), and some considerations of Borrie *et al.* (1998) and included the calculation of three capacities: Physical Charge Capacity (PCC), Real Charge Capacity (RCC) and Effective Charge Capacity (ECC). These three have a relationship where each value is the equal or less than the previous: PCC≥RCC≥ECC (Figure 2). An important factor used for the final determination was the touch frequency of divers observed and recorded in their dives.

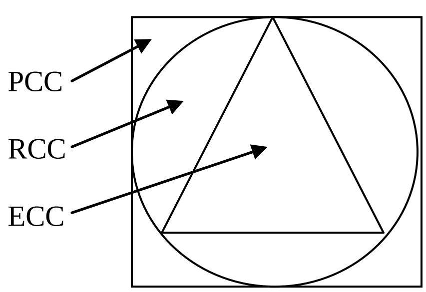

Figure 2. PCC≥RCC≥ECC.

Results

The length and time required for the underwater paths were based on a programmed calculation for each dive type with an expectation that the remaining air at the end of the dive was ~500 psi. The number of divers proposed for each group was limited (8:1, eight divers per guide) on a heavy tourism day in peak season. In low season the group usually is 2:1. The PCC in the underwater paths of Islas Marietas (519 divers per day) was lower than in Los Arcos (815 divers) (Table 1). This difference was primarily due to an 11 hour diving operation at Los Arcos, compared to a seven hour duration at Islas Marietas. The first site is more accessible and more frequented for night diving. ECC values are found in Table 2.

Table 1. Physical Charge Capacities (PCC).

	Islas Marietas			**Los Arcos**		
	La Pared	**El Amarradero**	**Bajo de la Manta**	**El Cañón**	**Arco Grande**	**Bajo del Cristo**
Surface in lineal meters (***S***)	250	250	250	250	250	250
Surface used by diver (***SD***)	4.5	4.5	4.5	4.5	4.5	4.5
Visitinghours (***Vh***)	7	7	7	11	11	11
Time spent in each visit (***ts***)	0.75	0.75	0.75	0.75	0.75	0.75
Number of visits per day (***NV***)	9.34	9.34	9.34	14.67	14.67	14.67
PCC	**519**	**519**	**519**	**815**	**815**	**815**

Table 2. Effective Charge Capacities (ECC).

Diving Site	**PCC**	**RCC**	**MC**	**ECC**
La Pared	592.8	71.92	0.70	**50.35**
El Amarradero	592.8	32.69	0.70	**22.88**
Bajo dela manta	592.8	65.38	0.70	**45.77**
El cañon	815	105.63	0.70	**73.94**
Arco grande	815	112.37	0.70	**78.66**
Bajo del cristo	815	112.37	0.70	**78.66**

PPC=Physical Charge Capacity; RCC=Real Charge Capacity; MC=management Charge; ECC= Effective Charge Capacity.

Discussion

The number of visitors to Bahia de Banderas was close to four million in 2007. In this year, Islas Marietas received almost 19,000 persons and Los Arcos 80,000 (Tourism Secretary, 2007).

Environmental interpretation is used as a conscious tool for the conservation of MPAs; promoting attitude changes that improve the relationship between society and nature. Planning the establishment of six underwater paths in these highly visited diving sites is a pioneer effort in the state of Jalisco and Central Pacific Area of Mexico.

The recommendation is to try that the divers visit only the underwater paths proposed (especially those that have only open water certification level, those who usually have less experience and water skills). Each under underwater path has different characteristics and makes it attractive for the visitors. Also the six of them have a marked seasonality that responds to water variation and visibility. The selected species were those easier to locate, gaudy and preferred by divers.

The results obtained suggest reducing the amount of divers that visit the diving sites to reduce the harmful effect to the coralline structures. The calculation formula for TCC showed to be appropriate:

$$TCC = \frac{\text{Total area used by tourists}}{\text{Percent of needed area for each one}}$$

The present studio was developed under the previously mentioned Gallo *et al.*, (2003) methodology; which represents an application for recreational divers and a consideration of important variables of the marine environment. After all we consider that it was more appropriate because it was different to other methodologies that only restrict the entry to the dive site and do not consider other human and physical factors.

The work made with the PCC determination that a pathway length of 800 feet was ideal. With the right weather and environmental conditions (tides, visibility, constant kicking and controlled breathing) the distance can be covered in 40 to 50 minutes, a common time for a typical dive. About the number of visits per day (*NV*), the higher was in Los Arcos, due the wider hours for visiting (eleven against seven for Islas Marietas) which increases the FCC for Los Arcos to 815 and 592 for Las Marietas.

In the calculation of the RCC the correction factors considered to limit the number of divers in each site was the Social Factor (SF), where the size of the groups are smaller than land groups (Cifuentes, 1992; 1999). The maximum ratio of underwater groups is eight divers per dive leader.

An interval of 20 minutes between groups allowed that the second group entering water and the first one to be half of the total path away, so the likelihood of accidental encounters with boats or other divers is reduced. It also helps the macrofauna to recover from any acute disturbance produced by a prior dive group.

The fragility factor obtained reduced the entrance of divers in those sites with more percentage of hard corals, like the Amarradero, in Islas Marietas, where the ECC calculated decreased as far as 3% of the FCC. This coincides with the Hawkins (1992) proposal which establish that those paths with more hard coral coverage must reduce the number of visitors.

Finally, the factor for touching damage (FTD) is important to grade the behavior of the divers underwater. In this case we used the Gallo *et al.* (2003) methodology that considers the number and intensity of touching in a typical dive. This factor was important to establish a recommendation for diving experience for each site considering its fragility condition.

The main recommendations for diving activities along interpretative paths are to avoid:

- Lifting any objects from the ocean bottom
- Touching anything
- Bothering or pursuing any resident species
- Uncontrolled buoyancy
- Kicking that affects stability of the bottom or fauna or flora residents
- Using equipment not attached to the body, especially in coral areas.

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Algal Garden Cultivation and Guarding Behavior of Dusky Damselfish on Coral Rubble and Intact Reef in Dry Tortugas National Park

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Abstract

In the past 30 years, cold events and disease have reduced branching coral reefs in Dry Tortugas National Park, USA to rubble fields. Damselfish constituted the main source of herbivory in branching coral habitat, but it is unclear how the equilibrium between territoriality and grazing resources has been affected by habitat change. In this study, the agonistic behavior and algal garden farming of dusky damselfish (*Stegastes adustus*) was compared between coral rubble and patch reef territories. Underwater observations showed no significant difference in mean numbers of antagonistic grazers entering both rubble and patch territories (p=0.12); however dusky damselfish showed a more conspicuous aggressive strategy in rubble territories (p=0.03). Gardens exhibited a clear higher species diversity (p=0.0001) in rubble (species=13) than in patch reef (species=7). It is plausible that dusky damselfish defending flat rubble territory are better able to detect possible intruders than damselfish guarding more complex patch reef. In a highly saturated living space, dusky damselfish successfully colonize live and dead coral areas and, while patch reef may offer a more concealed site, the newly created rubble fields represent bigger territories and the chance to cultivate a greater variety of algae.

Keywords: algal farming, coral reef, territoriality

Introduction

Damselfishes (family Pomacentridae) are important members of the Caribbean reef ichthyofauna and are considered to be 'keystone species' vital to healthy reef ecology (Hixon and Brostoff, 1983). Even though pomacentrids make up less than 5% of the herbivores' biomass (Williams *et al.*, 2001) and, could be considered less efficient algal grazers when compared to scarids and acanthurids, these fishes profoundly shape reef communities through their agonistic guarding behavior and selective algal farming. In fact, many damselfish confine their range to well-defined territories that include algal lawns. Damselfish gardens are characterized by high level of algal biomass (Lobel, 1980; Sammarco, 1983) and are strongly defended against intruders (Brawley and Adey, 1977; Robertson *et al.*, 1981; Foster, 1985; Letourneur, 2000). Their influence on coral reefs is far-reaching, as it impacts growth and survival of corals (Kaufman, 1977; Eakin, 1988), grazing activity by other herbivores (Foster, 1987; Williams *et al.*, 2001), and algal diversity (Hixon and Brostoff, 1982; Hata and Kato, 2003; Zemke-White and Beatson, 2005).

Healthy coral reefs are traditional damselfish habitat; however, many reef systems in the Caribbean and Florida reef track have been in a serious state of decline. Twenty years ago mass mortality of the long spined sea urchin, *Diadema antillarum*, resulted in a reduction in algae grazing on Caribbean reefs by up to 99% (Carpenter, 1990), and dramatically increased algal biomass. Nearly overnight Caribbean reefs were transformed from coral-dominated to algae-dominated system (Williams *et al.*, 2001). In the winter of 1976-77, a destructive cold front along the Florida strip wiped out 96% of branching coral within two meters of the surface (Porter *et al.*, 1982; Bohnsack, 1983). Staghorn coral, *Acropora cervicornis*, was especially hard hit by the cold event and experienced the most far-reaching decline (Davis, 1982; Wallman *et al.*, 2004). Subsequently, surviving staghorn coral was subjected to diseases and algal growth, and collapsed in most of the Caribbean (Aronson and Precht, 1997). Likewise, the once extensive branching coral formations in Dry Tortugas National Park (DTNP) have been reduced to rubble fields (Davis, 1982). Little is known about how damselfish have responded to changes in reef habitat or how the loss of traditional structure has affected algal farming in the group. In addition, it is unclear how changes in reef structure may have affected interaction between damselfish and their major competitors**.**

The purpose of our study was to compare algal garden attributes and assess agonistic behavior of the dusky damselfish, *Stegastes adustus*, on patch reef and branching coral rubble in DTNP. Specific objectives of our study were to determine 1) territory size, 2) number and diversity of intruder fishes defended against, and 3) algal garden composition, in both reef and rubble habitats. The DTNP was an ideal site for our study because it is a marine protected area relatively isolated from fishing pressure, and has abundant patch reef habitat in close proximity to recently formed rubble fields. A better understanding of defense strategies used by damselfish in disturbed and undisturbed reef habitats could provide useful insight into damselfish ecology, and possible changes in their role as keystone species on Caribbean reef environments.

Methods

Field observations of dusky damselfish were conducted between 0800 and 1700, in shallow water (1-2.5 m) on patch reef and coral rubble on the northwest side of Loggerhead Key, DTNP (Figure 1), in May 2008. Territory size, algal garden composition (algal type), and fish encounters of dusky damselfish not involved in nesting activities were recorded. Data were collected by five teams of two snorkelers. After a dusky damselfish territory was identified, the fish was allowed to become accustomed to the researchers' presence for 10 minutes (Wallman *et al.*, 2004). Following the 10 minutes pre-observation period, defended territory were delineated using eight weighted marker pins that were placed at 45° intervals around the approximate center point of the fish' territory. Pins were adjusted inward or outward of the center point as dictated by fish movement over the following 20 minutes. Territory size was measured (cm) from a selected point near the center of the territory extending out to each of the marker. All territory sizes were reduced to a 1:20 scale and plotted onto constant weight paper. Territories were weighted (g) and grams converted into territory area (m^2).

Following territory size determinations, fish entering a territory (*i.e.*, fish encounters) were observed over the subsequent 15-minute period and recorded using a digital Sony Handycam DCR-SR40 in a waterproof housing. A guarding encounter was considered to be an aggressive movement toward an intruder, *i.e.*, non site-bond herbivores (Ceccarelli, 2007), showing lateral display, chasing, or biting (Draud *et al.*, 1990). Fishes entering the damselfish home range that did not elicit a guarding response were also documented. Videos were reviewed later at the University of West Florida where the number of challenged and unchallenged fish was determined and each intruder fish identified to species. A list of intruder species encountered, challenged and unchallenged, was also compiled. At the end of each video period, algae within each garden were randomly scraped from the garden and preserved in 70% ethanol for later identification. Samples of algae were examined under a dissecting microscope and identified to at least genus (Taylor, 1960). One-way ANOVA was used to compare territory size, algal diversity and number of fish encountered (challenged, unchallenged and pooled), on rubble and patch habitat. Non-normal data were transformed prior to analysis. All statistical comparisons were based on α=0.05.

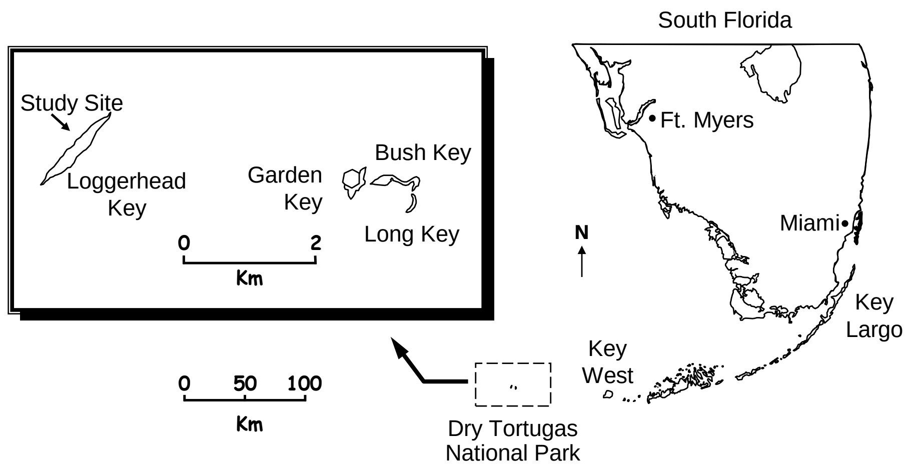

Figure 1. Patch and rubble study site off Loggerhead Key, Dry Tortugas National Park, Florida, USA.

Results

Dusky damselfish were abundant throughout the reef on the northwest side of Loggerhead Key, DTNP. A total of 50 h of underwater observations were made across 37 territories. Territory size was significantly larger for damselfish living on rubble versus patch reef (one way ANOVA $F=1.66$, $p<0.01$, $\alpha=0.05$; Table 1). Underwater observations revealed that dusky damselfish defended feeding areas against solitary herbivorous fishes, but virtually ignored long spine sea urchins found in dusky's territories. Grazing herbivorous and egg-eating fishes attempted to enter both rubble and patch territories with equal frequency (one-way ANOVA on transformed data $F=1.68$, $p=0.12$, $\alpha=0.05$). Yellowtail damselfish, *Microspathodon crysurus*, and redlip blenny, *Ophioblennius macclurei*, were tolerated in the territories by dusky damselfish, regardless of site type. Although antagonistic pressure of herbivorous and egg-eating fish was similar for the two types of reef, dusky damselfish in rubble territories chased out statistically more invader fish than than duskys on patch reef (one-way ANOVA on transformed data $F=2.04$, $p=0.03$, $\alpha=0.05$). Gardens exhibited significant differences in algae diversity between habitat types as well (one-way ANOVA $F=2.04$, $p=0.0001$, $\alpha=0.05$) with rubble gardens displaying nearly twice the diversity seen in patch territories (Tables 1 and 2).

Table 1. Mean territory size along with standard error. Number of intruders and number of challenges are presented as min^1, median^2, max^3. Algae diversity is represented as number of species.

Site type	n	Territory size (m^2)	Number of intruders	Number of challenges	Algae diversity
Patch	16	2.34±0.096	7^1, 14.5^2, 37^3	0^1, 2^2, 6^3	7
Rubble	21	2.75±0.109	5^1, 21^2, 68^3	0^1, 4^2, 14^3	13

Table 2. Algal species composition within *Stegastes adustus* territories in DTNP.

Algae species	Patch territory	Rubble territory
Anothricum spp	x	x
Ceramium spp	x	x
Cystoseira myrica	x	x
Dictyopteris delicatula		x
Dictyota bartayrensii		x
Dictyota dichotoma	x	x
Dictyota linearis		x
Halimeda spp	x	x
Lobophora variegate		x
Rhipilia tomentosa		x
Rosenvingea intricate	x	x
Rosenvingea sanctae-crucis		x
Wrangelia spp	x	x

Discussion

Staghorn coral — which constituted more than fifty percent of total coral coverage in DTNP until 30 years ago — has been remarkably slow to recover and has most likely affected damselfish distribution (Wallman *et al.*, 2004). Following the collapse of staghorn coral, competitive interactions among herbivores for shelter or feeding and nesting sites could have influenced space partitioning (Emery, 1973). In our study, dusky damselfish seemed to have adjusted to changes in reef structure and were abundant on both patch and coral rubble. Ferer *et al.* (personal communication) found that dusky damselfish in DTNP show significantly higher density ($p<0.05$) on patch reef ($0.785 \cdot m^{-2}$) than rubble ($0.596 \cdot m^{-2}$). A more complex structure, patch reef could provide refuge from predators and nesting sites that are more concealed (Chabanet, 1997; Almany, 2004). However, Nagelkerken *et al.* (2005) found dimensional complexity to be only one of many factors influencing coral reef fish distribution. Moreover, in our study dusky damselfish occupied larger territories on flat rubble field than on patch reef. Patch reef may be better suited for nesting; however the high competition for a concealed nesting space could push dusky damselfish to colonize two-dimensional rubble fields.

Territory size is, to a great extent, influenced by abundance and type of competitors, *i.e.*, conspecifics, and intruders. According to the optimal territory model, the benefits deriving from guarding behavior must surpass the costs of chasing intruders. Videos recorded on site illustrate approximately equal amounts of intruder pressure in both patch and rubble territories. However, dusky damselfish inhabiting flat rubble may have been better able to detect intruders, typically seeing them before they penetrated territory boundaries. It is plausible that flat territories are easier to patrol than complex patches, but perhaps the larger territories were more difficult to defend. Our video footage often showed intruder herbivorous fishes entering patch territories and picking on algae while the tenant dusky was busy controlling the other side of the area.

Dusky damselfish defensive behavior varied markedly depending on the type of intruder detected. For example, non-herbivorous fishes were attacked less frequently and with less vigor than herbivorous fishes. Egg-eating bluehead wrasses, *Thalassoma bifasciatum*, for example, were not always chased from territories, possibly because damselfish were not nesting. The wrasses were typically run off only if they became a disturbing presence by picking on algal mats to obtain invertebrates (Ogden and Lobel, 1978). Individual blue tangs, *Achanthurus coeruleus*, and parrotfishes, *Scaridae* spp, on the other hand, were chased off successfully at all times as they likely represented a constant threat to the algal garden. The only way these fishes could effectively graze in dusky territory was by invading as a group (Foster, 1985). Yellowtail damselfish and redlip blenny, both algal grazers, were never chased from dusky damselfish territory. Yellowtail damselfish are known to share a territory with dusky's (Foster, 1987); however, it is unclear why dusky damselfish would tolerate the constant presence of redlip blennies. It is possible that the belligerent demeanor of the small blenny combined with its probable low impact on algal mats, makes the fish an 'ignorable' intruder. Interestingly, neighboring duskys' were challenged more promptly than other herbivorous fishes. In a removal experiment, Jan *et al.* (2003) found that when dusky gregory, *Stegastes nigricans,* were removed from their territory, the adjacent dusky gregory immediately occupied the vacant area. These data suggest that conspecifics represent a greater threat to a territory tenant than other herbivorous fishes.

By keeping intruders outside territories, dusky damselfish likely influence algal diversity of their gardens. The responses of diversity to herbivory, however, vary among studies of site-bound fishes (Sammarco, 1983). For instance, Hixon and Brostoff (1983) observed that algal diversity is enhanced by farming behavior of Pacific gregory, *Stegastes fasciolatus*. Conversely, Hata and Kato (2003) found that dusky gregory in the North Pacific tend a monoculture of palatable algae. At the same time Zemke-White and Beatson (2005) described dusky gregory as farming up to ten species around Rarotonga, Cook Islands, and Fiji. Several factors may in fact result in increased algae diversity including species availability and palatability (Zemke-White and Beatson, 2005), differing levels of herbivory (Paine and Vadas 1969) farming behavior (Montgomery, 1980), and type of intruders (Lubchenco and Gaines, 1981; Sammarco, 1983). Whatever the cause, it is clear the recently formed rubble territories resulting from the collapse of staghorn coral in DTNP represent the chance for dusky damselfish to defend bigger spaces and cultivate a larger variety of algae.

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Population Analysis of an Introduced Coral Species, *Tubastraea coccinea*, in Florida

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Abstract

Marine biological invasions pose an increasing threat to the health of already-stressed coral reef ecosystems. Biological and ecological characteristics of the orange cup coral, *Tubastraea coccinea*, which has been introduced into the Florida Keys National Marine Sanctuary (FKNMS) suggest this species has the potential to negatively impact native reef communities through coral mortality due to overgrowth and allelopathic competition, decrease in recruitment of native species and reductions in biodiversity. This study documents and describes *T. coccinea* populations inhabiting artificial reefs in Florida, including two within the FKNMS, in an effort to assess this species' distribution and potential impacts on native reef communities. *T. coccinea* was found in abundance at all four study sites with the highest population density and percent coverage of this species observed on the USCG Duane in the FKNMS. The demographic and biological characteristics of this species suggest it should be considered a potential threat to native communities and efforts should be made to monitor this species in non-native environments.

Keywords: demography, introduced species, invasive, range cup coral

Introduction

At a time when marine communities are increasingly impacted by natural and anthropogenic disturbances, the threat of additional devastation due to invasive alien species is increasing. Invasions are now recognized as a major threat to marine and coastal ecosystems due to the potential of these species to locally or regionally reduce biodiversity, alter species interactions and directly or indirectly modify the habitat (Carlton and Geller, 1993; Vitousek *et al.*, 1996; Wilcove *et al.*, 1998; Sala *et al.*, 2000; Coles and Eldridge, 2002; Occhipinti-Ambrogi and Savini, 2003; Galil, 2007; Occhipinti-Ambrogi, 2007), which may result in severe economic costs (Pimentel *et al.*, 2000).

As is common with many marine biological invasions, the initial introduction of the azooxanthellate scleractinian coral, *Tubastraea coccinea*, into the Caribbean was probably human-mediated (Cairns, 2000; Figueira de Paula and Creed, 2004). *T. coccinea*, orange cup coral, was first documented at two Caribbean reefs (Curaçao and Puerto Rico) in 1943 (Vaughan and Wells). Over the last 60 years, range expansion of this coral from the initial introduced population(s) has extended to reefs throughout the Caribbean and more recently into the Florida Keys National Marine Sanctuary (FKNMS), most likely via episodic events of natural larval dispersal with surface currents (Fenner and Banks, 2004).

Tubastraea coccinea is a prolific hermaphroditic brooding scleractinian coral (Harrison and Wallace, 1990) capable of producing larvae through sexual and asexual means (Ayre and Resing, 1986) and commonly producing new asexual colonies through runner formation (Vermeij, 2005). The success of *T. coccinea*, in terms of colony growth, reproductive success and population size, in a non-native environment has not been investigated; however, preliminary observations of *T. coccinea* on the artificial reef, the former US Coast Guard vessel *Duane* within the FKNMS, demonstrate that this species can dominate with population sizes in the hundreds and thousands of colonies to the exclusion of native sessile organisms, likely reducing the species diversity and recruitment potential of native species within this community. Recent observations in Brazil demonstrate tissue necrosis and partial mortality of native corals due to contact with *Tubastraea* species (Creed, 2006). In addition, chemical extracts from a congener, *T. faulkneri,* which may also be present in *T. coccinea,* are toxic to coral larvae (Koh and Sweatman, 2000). This azooxanthellate species relies on suspension feeding and may impact food availability of other organisms, including sponges, ascidians, bryozoans and filter/particulate-feeding mollusks, annelids and echinoderms, positioned downstream of large *Tubastraea* populations. Because this fouling species competes with other sessile organisms for space and its natural predator, the gastropod *Epitonium billeeanum*, has not been documented in the Caribbean or Gulf of Mexico, natural reef communities may be negatively impacted if this invader thrives and outcompetes native Caribbean species.

This study documents and describes *T. coccinea* populations inhabiting artificial reefs in Florida, including two within the FKNMS, in an effort to assess this species' distribution and potential impacts on native reef communities. The study sites included in this investigation were four artificial reefs deployed between 1987 and 2002. This species was previously documented on two of these artificial reefs (USCG Duane and Port of Miami Mitigation Reefs). In 1999, numerous colonies were present on the Duane; however, only a single colony was observed on the Miami Mitigation reef (Fenner and Banks, 2004). Demographic data from *T. coccinea* populations will assist in determining if populations of this introduced species are expanding in size and geographic range.

Methods

Populations of *Tubastraea coccinea* were investigated at four artificial reef structures in the FKNMS and South Florida (Table 1, Figure 2). These structures were deployed between 1990 and 2002 and *T. coccinea* was previously documented at these sites (Fenner and Banks, 2004; and pers. obs.). In December 2008, these structures were visually inspected by scuba divers at depths between 12-27 m to locate colonies of this species. At the USCG Duane and the USS Spiegel Grove, density and percent coverage of *T. coccinea* were measured using 19-27 quadrats (1.0 m x 0.5 m) randomly located (<27 m depth) along the vertical surfaces of the artificial reef. *T. coccinea* colonies within each quadrat were counted and maximum colony diameter and diameter perpendicular to maximum were measured. Population surveys could not be conducted at the Port of Miami Mitigation Reef or the C-One wreck since the colonies were positioned on the underside of the substrate and could not be reached for measurement. Tissue samples were collected from 50 colonies at each site to be used for future genetic analysis.

Table 1. Artificial reefs surveyed for *Tubastraea coccinea* in the Florida Keys National Marine Sanctuary and South Florida.

Vessel	Type	Length (m [ft])	Year Deployed	Survey Depth (m [ft])
USCG Duane	steel ship	100 (327)	1987	~9 (30)
USS Spiegel Grove	steel ship	155 (510)	2002	~9 (30)
Port of Miami Mitigation Reef	limestone boulders	–	1996	~5 (15)
C-One wreck	steel tug	37 (120)	1990	~7 (23)

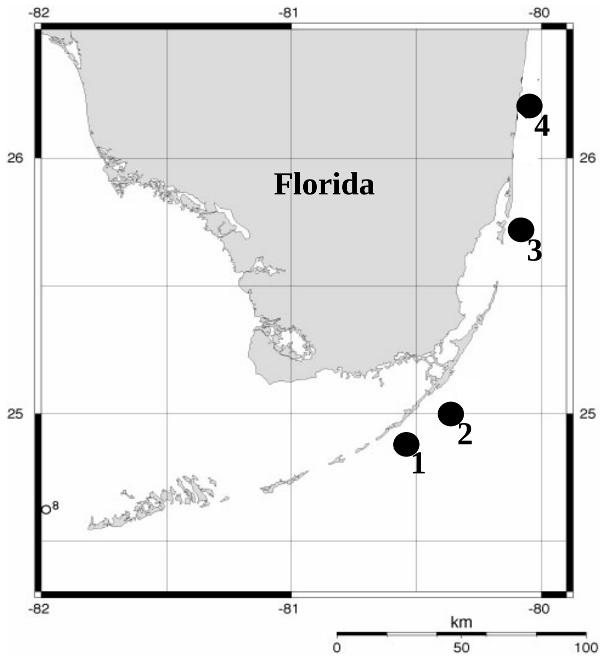

Figure 1. Study sites in the Florida Keys National Marine Sanctuary and South Florida: USCG Duane (1), USS Spiegel Grove (2), Port of Miami Mitigation Reef (3) and C-One wreck (4).

Results

Tubastraea coccinea was abundant at all four study sites. Visual estimates of overall population sizes across each artificial structure were in the hundreds of colonies across the USS Spiegel Grove, Port of Miami Mitigation Reef and C-One wrecks, and in the thousands of colonies across the USCG Duane (pers. obs). At the USCG Duane, *T. coccinea* colonies were present in 100% of quadrats (19/19), but only in 7% of quadrats (2/27) at the USS Spiegel Grove. Density of *T. coccinea* at the USCG Duane ranged from 2-42 colonies·m^{-2} with a mean of 22.3 colonies·m^{-2} across 19 quadrats, whereas the density at USS Spiegel Grove ranged from 0-10 colonies/m^2 with a mean of 0.6 colonies·m^{-2} across 27 quadrats (Figure 2). Percent coverage of *T. coccinea* within quadrats ranged from 1.3-30.3% with a mean of 10.6% coverage at the USCG Duane, whereas at USS Spiegel Grove, percent coverage ranged from 0.3-1.3% with a mean of 0.06% (Figure 3).

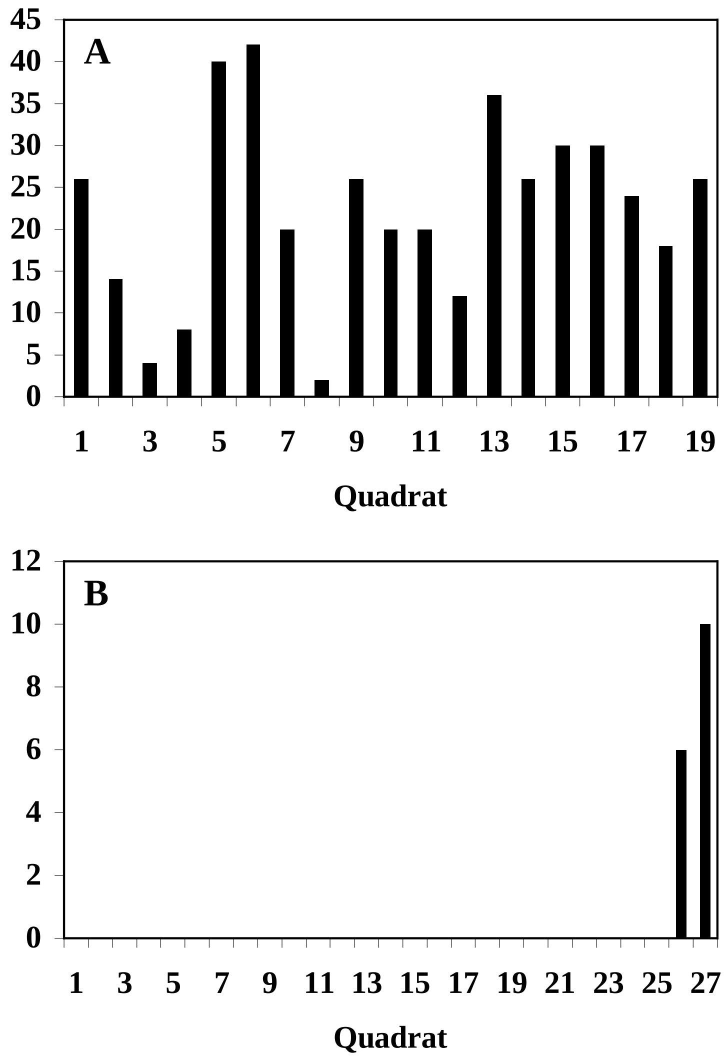

Figure 2. Density (colonies·m^{-2}; x-axes) of *Tubastraea coccinea* colonies in quadrats at (A) USCG Duane and (B) USS Speigel Grove.

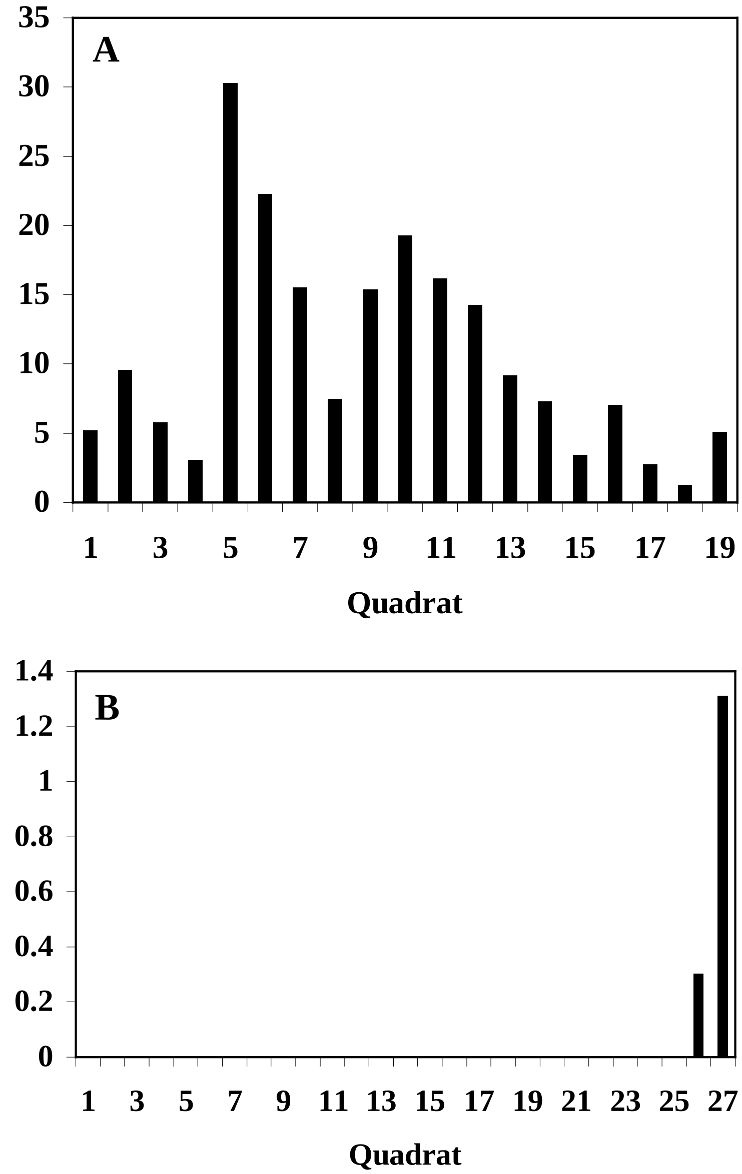

Figure 3. % coverage (x-axes) of *Tubastraea coccinea* colonies in quadrats at (A) USCG Duane and (B) USS Spiegel Grove.

Discussion

Despite the deterioration of the world's coral populations, it appears that *T. coccinea* is thriving at many sites in the western Atlantic, Caribbean and Gulf of Mexico as it continues to expand its geographic range. From previous observations at the Port of Miami Mitigation Reef, it appears that *T. coccinea* population size has increased significantly from a single colony (Fenner and Banks, 2004) to hundreds of colonies (pers. obs.) *T. coccinea* colonies (n=50) at this site were measured and sampled by our divers in 2008 and ranged in size from 0.5-8.0 cm. The relatively small size of the colonies suggests recruitment over the last two years based on published growth rates (Vermeij, 2006);

however colony size is not always correlated with age, so these colonies could be older. The hypothesis of recent recruitment is consistent with the virtual absence of the species during previous surveys followed by increasing population sizes.

The largest population size and highest percent coverage were observed at the USCG Duane. This was the oldest of the artificial reefs in this study and may suggest that if population size is correlated with time since deployment, it is likely that in several years each of the other sites could exhibit high population densities as well. The density and percent coverage estimates at the USCG Duane in this study are conservative estimates since areas with the highest abundance of colonies could not be randomly sampled due to maximum depths allowed for our divers. The hull at the bow of the USCG Duane approaches 100% coverage by *T. coccinea*; however, it rests at depths >30 m and could not be surveyed during this study. Thus, it appears that populations of this introduced species are healthy, reproductive and growing and that in the near future other artificial substrates will experience increasing population sizes.

T. coccinea is a prime candidate for invasion success throughout its expanded distribution and has been given "invasive" status in the Global Invasive Species Database (www.invasivespecies.net). The lack of a natural predator, the ability to proliferate sexually and asexually with local and widespread larval dispersal capabilities, freedom from microhabitat restrictions imposed by symbiotic relationships with zooxanthellae, evidence of competitive dominance over native corals and potential to inhibit recruitment of other species through allelopathy leading to high population densities are all characteristics that support the invasive nature of this species and illustrate the potential for negative ecological impacts of this species. Continued range expansion and establishment of new populations should be monitored, as should established populations to in order to understand the population dynamics of this species in a novel environment, to measure the impact of this species on native communities, including effects on recruitment and biodiversity and to document if and when this species becomes common on natural reef substrate. The existence of the species primarily on artificial substrate has minimized concern for its potential to impact reef communities. On the contrary, there is significant potential for *T. coccinea* to disturb communities on natural substrate, and establishment of *T. coccinea* populations on artificial reefs has already promoted its range expansion to natural reefs in some areas of the Caribbean, Gulf of Mexico and Brazil (Fenner and Banks, 2004; Sammarco *et al.*, 2004; Hickerson and Schmahl, 2005; Creed, 2006). One population of *T. coccinea* has been documented on natural substrate off Palm Beach County, FL but has subsequently been destroyed due to heavy sedimentation resulting from recent hurricane activity (J. Phipps, Palm Beach County Environmental Resources Management, pers. comm.). In 2002, this species was documented on reef substrate within the Flower Garden Banks National Marine Sanctuary (FGBNMS) and in 2004, on nearby Geyer Bank (Hickerson and Schmahl, 2005). The source(s) of these populations was likely oil and gas platforms in the northwestern Gulf of Mexico where this species has existed since 1991 (Fenner and Banks 2004; Hickerson and Schmahl, 2005). In Brazil, steps are currently being taken to achieve the goal of eradicating *Tubastraea* species from local habitats within the next 20 years (Projeto Coral-Sol; J. Creed, pers. comm., 2006). Possible sightings of this species have been indicated at Gray's Reef National Marine Sanctuary off the Georgia coast (G. McFall, pers. comm., 2009) and confirmation of this sighting will be conducted to assess the northward range expansion of this species. *T. coccinea* has not yet been observed in Bermuda (Fenner and Banks, 2004); however, if patterns of range expansion reflect water circulation patterns and populations in Florida serve as stepping-stone populations, colonization in Bermuda is expected in the future.

The characteristics of this species, as well as the efforts of other regions (*i.e.,* FGBNMS and Brazil) to manage and possibly eliminate *T. coccinea* are indications that this species is a potential threat to natural populations throughout its introduced range. An ecological monitoring program for *T. coccinea* and an assessment of the source and pathways of range expansion are necessary to develop practical solutions for minimizing ecological and economic losses that may result from this species' proliferation.

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Design and Evaluation of Cold Water Diving Garments Using Super-Insulating Aerogel Fabrics

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Abstract

Experimental cold water diving garments have recently been developed under sponsorship of the Office of Naval Research using super-insulation materials based on aerogel composites. These garments use a flexible, drapeable aerogel composite insulation which has the thermal performance equal to the best known solid insulation (brittle monolithic aerogels) in a much more practical form. Thermal manikin testing at the Naval Clothing and Textile Research Facility (NCTRF) in Natick, MA has verified that these prototype drysuit liners have inherent thermal insulation values up to 76% greater than commercially-available liners fabricated from 400-weight micro-fibrous polypropylene batts. Recent dive trials at the Navy Experimental Diving Unit (NEDU) in Panama City, FL with three prototype aerogel garments showed significant improvements in diver thermal protection when compared to baseline commercially-available drysuits. This paper gives an overview of the integration of aerogel fabrics in cold water diving garments, and summarizes the improvements in thermal performance documented during recent laboratory trials.

Keywords: aerogels, super-insulation, thermal protection

Introduction

An area of primary interest in diving safety and effectiveness is improving the ability of free-swimming and tethered divers to operate in thermal extremes (both hot and cold) through improved suit materials, insulating materials, heat exchangers, and heat storage devices. Unfortunately, few improvements in passive diver thermal protection have been seen since the introduction of foam neoprene wetsuits during the early 1950s (Penzias and Goodman, 1973). Early attempts to develop drysuits made of foam wetsuit materials showed improved thermal performance at shallow depths at the expense of excessive suit bulk and buoyancy. Unfortunately, these thermal improvements were found to rapidly degrade with increased depths as the foam crushed with increasing pressure (Wattenbarger and Breckenridge, 1978). To compensate for this thermal reduction with depth, additional undergarments were utilized, adding even further bulk and buoyancy. Attempts to incorporate heat-reflecting layers in these suit designs have proven to be mostly ineffective. Microencapsulated phase change materials (PCM) mixed into open cell foams were pursued as a drysuit liner material by the Naval Surface Warfare Center/Dahlgren Division under sponsorship by the Office of Naval Research (ONR). These materials were shown to offer good inherent thermal insulation qualities when dry, but suffered most of the same deficiencies as conventional foams and batts, *i.e.*, excessive bulk, excessive buoyancy and severe degradation in insulating quality when wet (Nuckols, 1999). Alternatively, bulk PCMs integrated into a suit composite were shown to provide sufficient stored energy to give only a short come home capability for composite diving suits (Nuckols and Grupe, 1997).

Recently, an experimental composite cold water diving garment was developed in partnership of Southwest Research Institute, Duke University, the Navy Experimental Diving Unit (NEDU), Diving Unlimited International (DUI), and Aspen Aerogels, Inc. under sponsorship of the Office of Naval Research. Preliminary thermal analyses, later confirmed by thermal manikin testing at the Naval Clothing and Textile Research Facility in Natick, MA, verified that the experimental liner had an inherent thermal insulation value 76% greater than commercially-available diving garments fabricated from 400-weight micro-fibrous polypropylene batts. The impact of this added thermal protection on diver mission capability was highlighted during a series of test dives conducted at NEDU during January 2005 in water temperatures of 35±2°F (1.7±0.5°C). The additional insulation provided by the experimental aerogel garment resulted in increased dive durations for all dive subjects, on average 43% greater durations than dives with the commercial liners. Divers' mean skin temperatures when wearing the experimental liner beneath a commercial dry suit likewise improved significantly (3°C on average one hour into the dive) when compared with skin temperatures for divers wearing the commercial liners. While dive durations were still predominately dictated by cold hands and feet, the prototype garment did provide significant improvements in thermal protection to the fingers and toes (approximately 4°C higher finger temperatures on average one hour into the dive, and approximately 5°C higher toe temperatures on average 30 minutes into the dive). Subsequent development efforts with aerogel fabrics have also led to the integration of these materials in divers' gloves and boots as well.

What Are Aerogel Fabrics?

Aerogel is a low density, open-celled nanopore structure having a void volume in excess of 99%. With an average pore size of approximately 10 nanometers—smaller than the mean free path of air molecules—ultra low thermal conductivities are achieved, approaching those found in a vacuum. Aerogel is manufactured through a sol-gel chemistry of which silica is the main solid residual component. As shown in Figure 1, precursor materials such as alkoxysilanes are mixed with water in a solvent. After alkoxysilane hydrolysis, a catalyst is added to start the polymerization reaction which yields a linked silica network in a wet gel form. The gel is then aged in order to strengthen the silica latticework. Hydrophobicity imparting agents are added during the aging process. The final step is to dry the solvent containing 'wet gel' by carefully removing the liquid phase so that only the silica structure remains. Aspen Aerogels, Inc. (AAI) uses CO_2 to dry the gels at super-critical pressure and temperature. If this drying process was performed at ambient temperatures the weight and capillary forces of the wet components would crush the silica structure. Supercritical CO_2 extraction allows the removal of the solvents without destroying the fragile silica network. The end result of this process is a dry hydrophobic, nano-porous solid structure with a density around 0.1 $g \cdot cc^{-1}$. This structure is delicate enough that it could not be practically used in the monolithic form in apparel applications. In order to provide a product with high durability, AAI infiltrates aerogel into fibrous substrates, which are usually composed of non-woven textile blankets. When aerogel is manufactured with this process, a flexible, drapeable aerogel composite insulation is produced which has exceptional thermal performance, approaching that of the brittle monolithic aerogels, but in a much more practical form. The fiber reinforcement provides structure and flexibility which allows the blanketed material to be rolled, cut, and shaped into numerous forms, as shown in Figure 2. Laboratory testing has verified that insulation improvements with panels of these aerogel infiltrated blankets can approach 2.5-3 times greater than the insulation of a comparable thickness of 400-weight Thinsulate[1]—a popular material selection for cold weather apparel—and over five times greater than foam neoprene used in wetsuits (see Figure 3). Integration of these aerogel fabrics into the design of a thermal undergarment for a diver's drysuit have been shown to provide an effective thermal advantage that is approximately 76% greater than a garment fabricated with a comparable thickness of 400-weight Thinsulate.

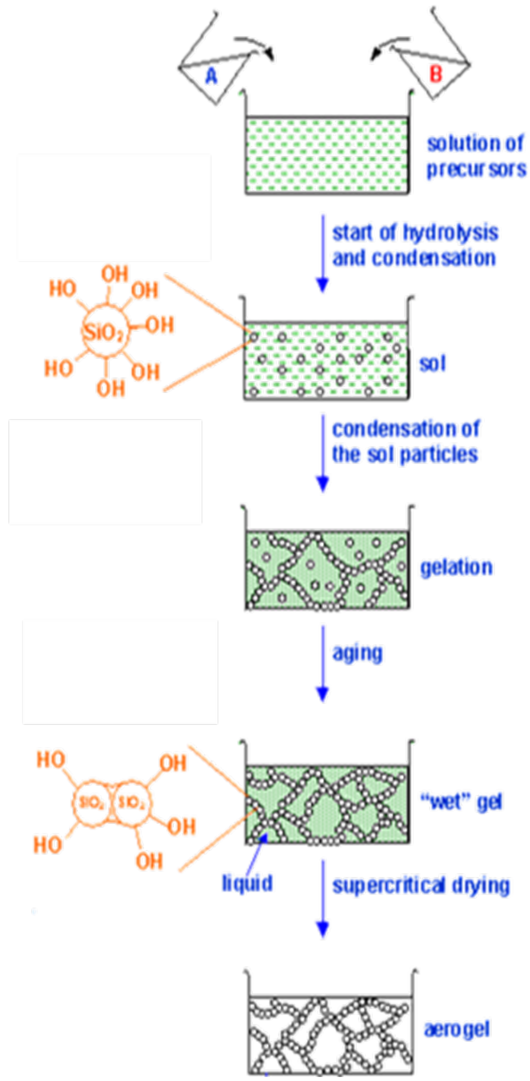

Figure 1. Manufacturing process of aerogel.

[1] Thinsulate is a registered tradename for a commercial, synthetic micro-fibrous insulation material manufactured by 3M Corporation.

Figure 2. Sample of aerogel infiltrated, flexible fabric possessing ultra low thermal conductivity.

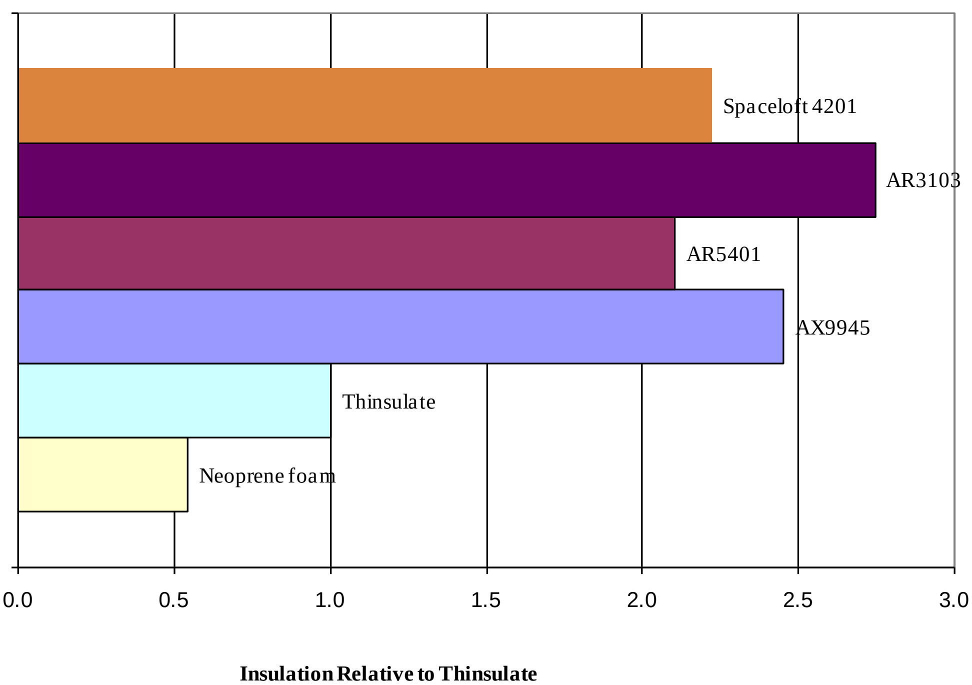

Figure 3. Relative thermal insulations of aerogel fabrics in comparison with 400-weight Thinsulate and closed-cell foam neoprene. The four top materials are different compositions of aerogel.

Assessment of Thermal Improvements With Aerogel Garments

Thermal images using infrared photography have been used to look for thermal shorts in prototype aerogel garments and for comparing their thermal performance with commercial garments. Figures 4 through 7 show infrared comparisons at various suit orientations. Prior to capturing these infrared photos, a human test subject stood in a dry test chamber conditioned to an air temperature of minus 10°C (14°F) for 30 minutes while wearing each garment. Note that color coding for surface temperatures is shown on the right bar in each photo in degrees Fahrenheit and localized surface temperatures are indicated for reference. Comparing Figures 4 and 5, it is evident that the outer surface temperatures for a garment constructed with micro-fibrous polypropylene batts are warmer in the frontal view, indicating a higher heat loss than the aerogel garment. In general, the surface temperatures for the commercial garment can be seen to be consistently higher in all views when compared to the aerogel garment.

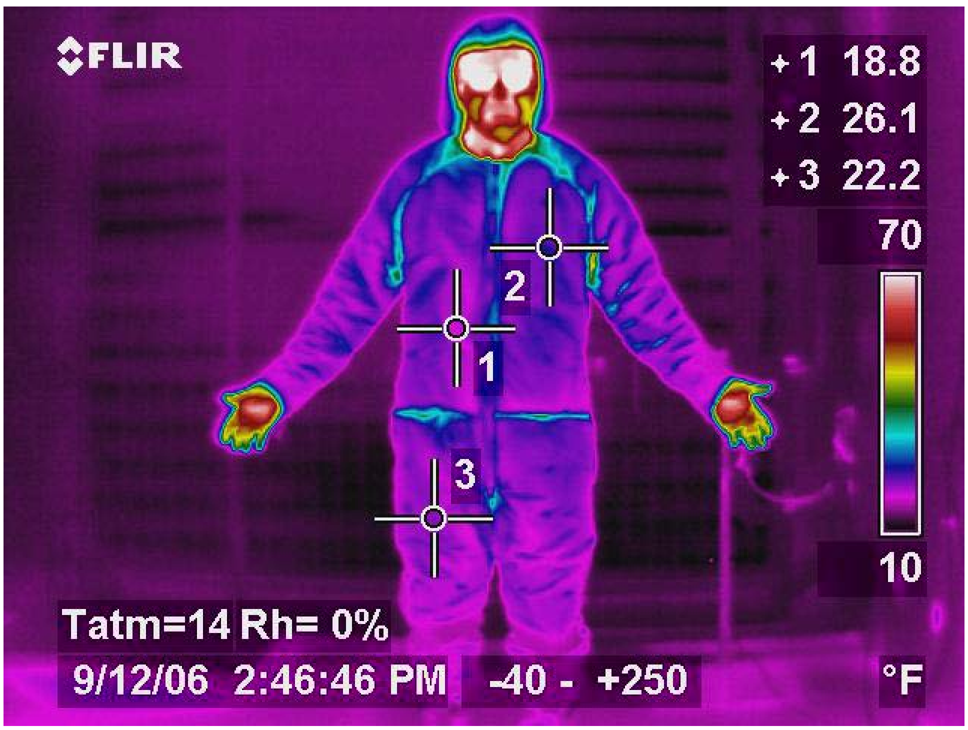

Figure 4. Frontal view of prototype aerogel garment. Typical surface temperatures 18-26°F.

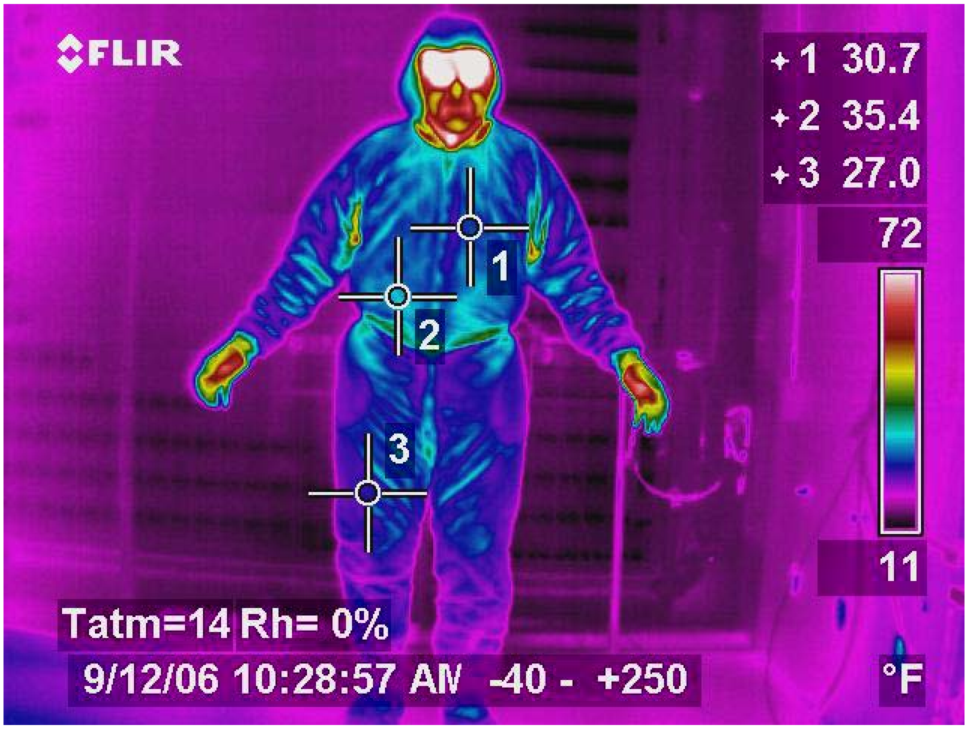

Figure 5. Frontal view of 400-weight Thinsulate garment. Typical surface temperatures 27-35°F.

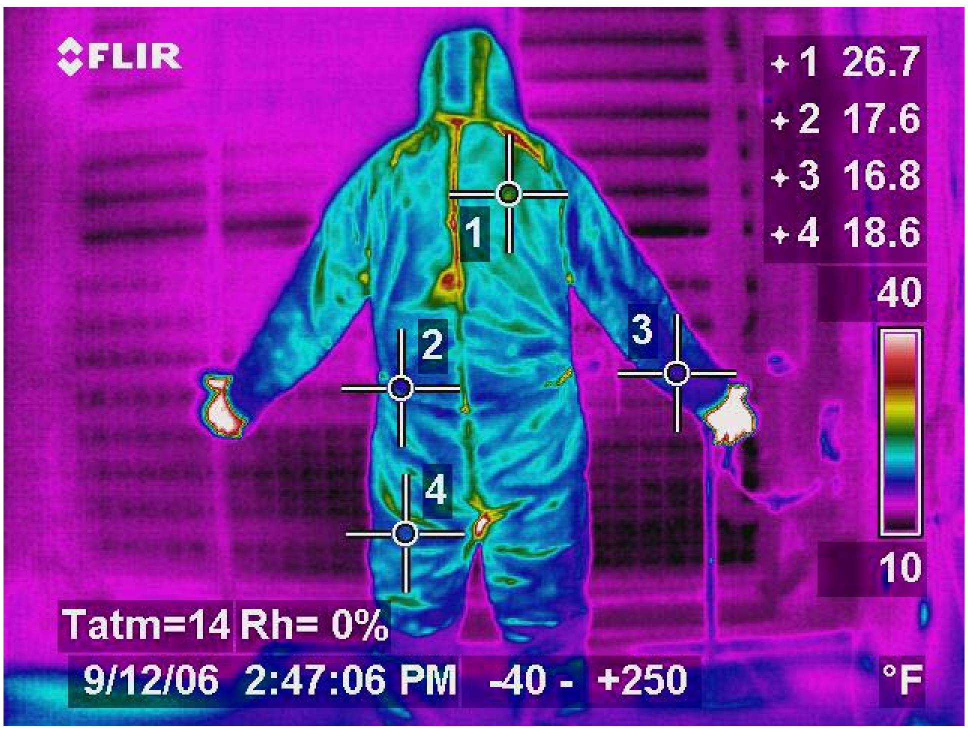

Figure 6. Back view of aerogel garment. Typical surface temperatures 17-27°F.

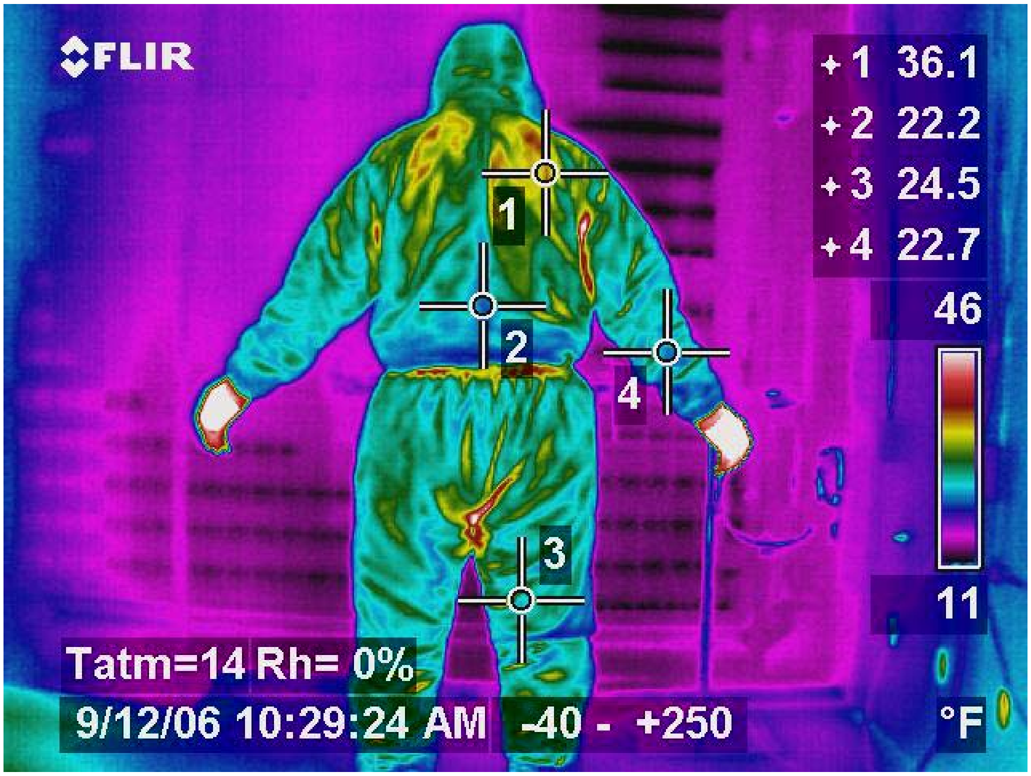

Figure 7. Back view of 400-weight Thinsulate garment (surface temperature range 22-36°F).

Discussion

Aerogel-infiltrated fabrics have been shown to provide superior thermal protection in comparison with commercially-available micro-fibrous polypropylene batts.

- Laboratory testing has shown specific insulation values for aerogel batt materials to approach 12 clo[2] per inch when uncompressed and in excess of 14 clo per inch when compressed. In comparison, 400-weight Thinsulate, a standard for cold weather clothing, has a specific insulation value of approximately 5 clo per inch which changes insignificantly when compressed.
- Prototype aerogel garments have been characterized to provide a thermal improvement of 76% when compared to a 400-weight Thinsulate ensemble during submerged thermal manikin testing (2.22 clo for the aerogel garment versus 1.26 clo for 400-weight Thinsulate). The aerogel garment had approximately the same thickness and weighed approximately 0.2 kg more than the Thinsulate garment.
- Infrared thermal imaging confirmed lower heat loss from the aerogel garment during surface exposures to cold air environments.
- Thermal conductivity testing indicates that this superior thermal performance is minimally impacted by repeated flexure and compression, or when subjected to complete water immersion.

Additionally, the thermal performance of composite aerogel garments has been shown to be minimally affected by either machine- or hand-laundering. Laundering was done using either a weak bleach solution or a non-ioning detergent. Air drying gave the best results in this investigation, as substantial shrinkage of encapsulated aerogel panels was observed during machine drying.

[2] 1 clo is equivalent insulation of a business suit when worn in a comfortable air environment

Acknowledgments

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Underwater Paleontology: Recovery of a Prehistoric Whale Mandible Offshore Georgia

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Abstract

During the fall of 2006, scientific divers from University of Georgia, Athens (UGA) and the National Oceanic and Atmospheric Administration (NOAA) were conducting a reconnaissance dive at JY reef approximately 20 nautical miles offshore Georgia. During this dive, a large subfossil bone was discovered partially embedded in the reef. On subsequent dives, loose sand was removed from around the bone and a small section was recovered. This bone fragment was carbon dated to approximately 36,000 years before present. However, since the bone was determined to be much larger than originally thought; not readily recoverable; and would require extensive excavation, a bottom disturbing permit was required. After approximately one year of discussions with multiple state and federal agencies, the United States Army Corps of Engineers issued a permit for excavation. Excavation began in the summer of 2008 and involved cutting through fossilized shell beds before reaching softer, but hard packed silt. Divers worked diligently with hammers, chisels and knives to cut away the overburden and carefully remove the sediment immediately around the bone. After numerous dives, the bone was recovered in sections totaling approximately 1.5 m in length. The bone has been visually identified as a North Atlantic Gray whale mandible. Ongoing work including visual study and DNA extraction is being conducted to verify the species. A joint UGA and Emory University team is currently working to professionally restore the bone and prepare it for display.

Keywords: baleen whale, gray whale, marine paleontology, prehistoric, scientific diving

Introduction

Researchers from The University of Georgia, Athens (UGA) and National Oceanic and Atmospheric Administration (NOAA) have been studying the surficial geology, invertebrate and vertebrate paleontology and the effects of erosion at Gray's Reef National Marine Sanctuary (GRNMS) and nearby JY reef for several years. GRNMS is located approximately 36 km east of Sapelo Island, Georgia and is home to a vibrant live-bottom community (Figure 1). Unlike tropical carbonate reefs, Gray's Reef is composed of dolomitic sandstone outcrops with upward relief of 2 to 3 m (Hunt, 1974). This geologic structure has been determined to be approximately 2 to 3 million years before present (ybp) (Huddleston, 1988). Considerable attention was brought to Gray's Reef during the 1960s and 1970s as the extent of the live-bottom habitat was documented. It was the realization that Gray's Reef was such a unique marine environment that it was designated as one of NOAA's national marine sanctuaries in 1981. Since then, NOAA has been charged with protecting Gray's Reef from exploitation and abuse.

JY reef is located approximately 18 km north of GRNMS and is also a very active live-bottom community (Figure 1). Unlike the reef structure at GRNMS, JY reef is actually an ancient shell bed mostly comprised of large, coldwater scallops (*Placopectin magellianicus)* that once thrived offshore Georgia between 32,000 and 40,000 ybp (Garrison *et al*, 2008). Structurally, the shell bed at JY reef is considerably less stable than the outcrops at GRNMS. The shell bed is lightly cemented from the seafloor down to approximately 0.3 to 0.5 m after which it is more readily eroded. Bottom currents sweeping along the reef have undercut the softer layers of the shell bed leaving the harder cemented shell bed as exposed ledges. It is not uncommon to find sections of ledges that have broken and fallen to the seafloor.

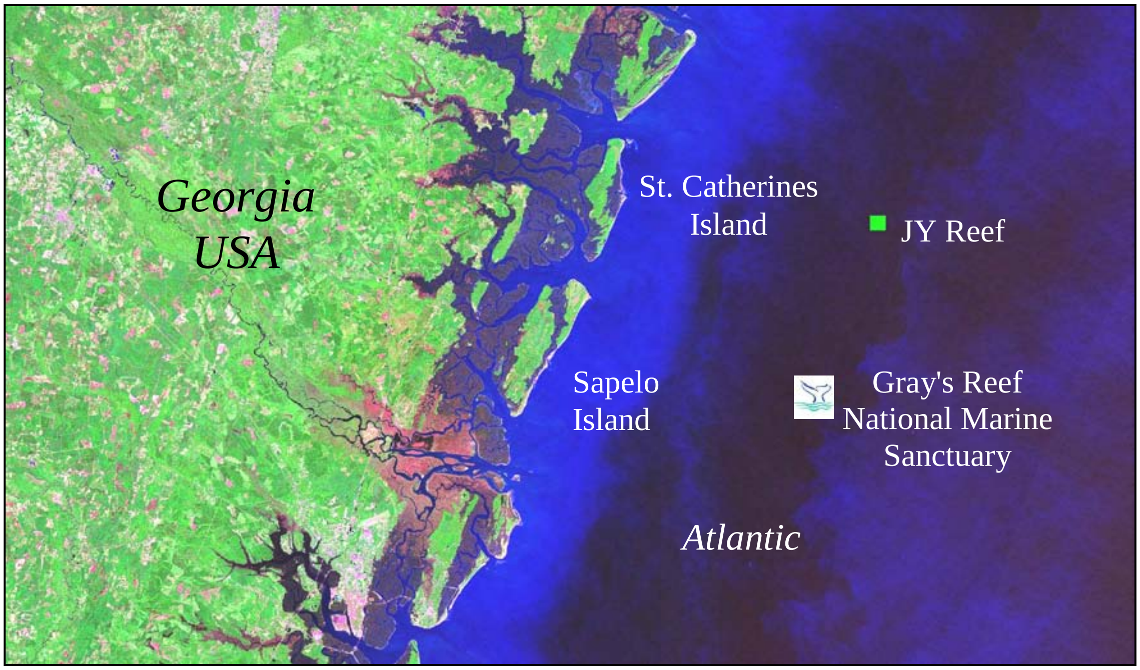

Figure 1. Study area offshore Georgia, USA.

The Discovery

As a result of the erosional process, objects long buried in the reef are slowly being exposed. Over the years, small bone fragments have been recovered from JY reef, but most were not identifiable. One discovery that has been identified was a rostrum of a bottlenose dolphin (*Tursiops truncatus*). Some larger bone fragments and whale vertebrae have also been recovered from the JY reef area, but still were not readily identifiable. It was not until August 2006, that a large subfossil bone was discovered partially protruding from under a ledge at JY reef. Loose sand was swept from the bone and revealed a long, slightly curving bone mostly embedded in the compacted silt and shell. The bone appeared to continue into the reef structure, but no definite concept of the actual length could be determined. In order to evaluate the find, light excavation was performed to determine the approximate size of the bone and possible identification. As a result of this process, it was determined that the bone did extend solidly into the reef bed. Also, due to the cross-sectional view of the now partially exposed bone, it was suspected that the bone was that of a baleen whale such as the Right whale, known to frequent the reef's waters. During inspection of the bone, a small fragment was recovered and was sent to the Center for Applied Isotope Studies (CAIS) at UGA to be dated by accelerator mass spectrometry (AMS). This bone fragment was determined to be approximately 36,000 ybp. This date fit well with the dates already determined for the shell bed and also documented that the bone had been buried relatively quickly after the whale's death.

Permit and Excavation

Since it was determined that the bone would need extensive excavation into the reef bed for recovery, a permit would be required before work could continue. Multiple federal and state agencies were contacted in regard to permits. It was determined that due to the age of the bone and its state of mineralization; it no longer fell under the National Marine Fisheries (NOAA) jurisdiction. Also, the bone was too far offshore to fall under the Georgia Department of Natural Resources jurisdiction. Finally, after much debate, it was determined that the United States Army Corps of Engineers (USACE) would be the permitting agency so a permit was granted for bottom disturbing activities. By the time a permit was in hand, most of the 2007 diving season had passed so very little excavation could be accomplished. It was also determined that it would be better for the bone to remain buried during the winter months to prevent marine growth from attaching to the exposed bone and to avoid potential deterioration due to storms. The site was marked by a 1 m metal rod and the bone was recovered by loose sand.

Starting in June 2008, serious efforts were directed towards excavating the bone. Once again, divers from UGA, NOAA, Georgia Institute of Technology (GT), and Georgia Southern University (GSU) descended upon the bone site. Due to the small excavation site only two divers could effectively work without interfering with one another. However, sufficient divers were on hand to work the excavation in teams. When one dive team returned to the surface, the next team would descend to the excavation site. The digging tools were left on the bottom until the last dive of the day when they would be brought to the surface and rinsed with fresh water. Nitrox 36% gas and dive computers were used for all dives which provided added safety and shorter surface intervals. Each dive team was able to achieve 3 dives in a day for a total of 12 person-dives. A typical dive only lasted approximately 30 minutes due to heavier than normal air consumption while digging. Also, NOAA regulations required that divers leave the bottom with 1000 pounds per square inch (psi) pressure remaining in their scuba tank and that each diver return to the surface vessel with 500 psi.

The first objective towards excavation was to remove part of the overhanging ledge covering the bone (Figure 2). This was accomplished by utilizing a hand-held slide hammer equipped with a spade chisel. The slide hammer allowed divers to remove large sized sections (~30 cm diameter) of the reef at a time. Since much of the overhanging reef had live growth attached, the removed sections were carefully placed on the seafloor below the ledge next to a large reef ledge that had broken away years before. Divers continued to cut the ledge back to an existing hole near the ledge foundation. Approximately 40 dives spread out over many days were required to cut the ledge back to the foundation allowing the divers to access the buried bone. Next, the shell bed foundation had to be cut back in an area estimated where the bone would extend. This was accomplished by an assortment of hand tools including hammers, chisels, knives and small picks. Due to the cemented nature of the shell bed, the reef surface down to approximately 0.5 m required the hammer and chisel. Work was relatively slow at this point with pieces no bigger than ~5 cm diameter being removed at a time. With depth, the digging became easier and the small hand pick was carefully utilized. Once the excavation reached a level just above where the top of the bone was estimated to start, digging was limited to knives and chisels primarily used as scrapers. The divers were careful to scrape the compacted silt and shell along the side of the bone and to stop frequently to allow water clarity to improve and to inspect their progress. As the bone became exposed, it was noticed that it unexpectedly curved westward requiring more excavation of the hard reef foundation. Once the overburden for the newly projected bone position had been removed, the divers were able to carefully remove the compacted silt and shell along the length of the bone without disturbing it. In all, a total of 124 dives were logged by nine divers to accomplish the complete excavation.

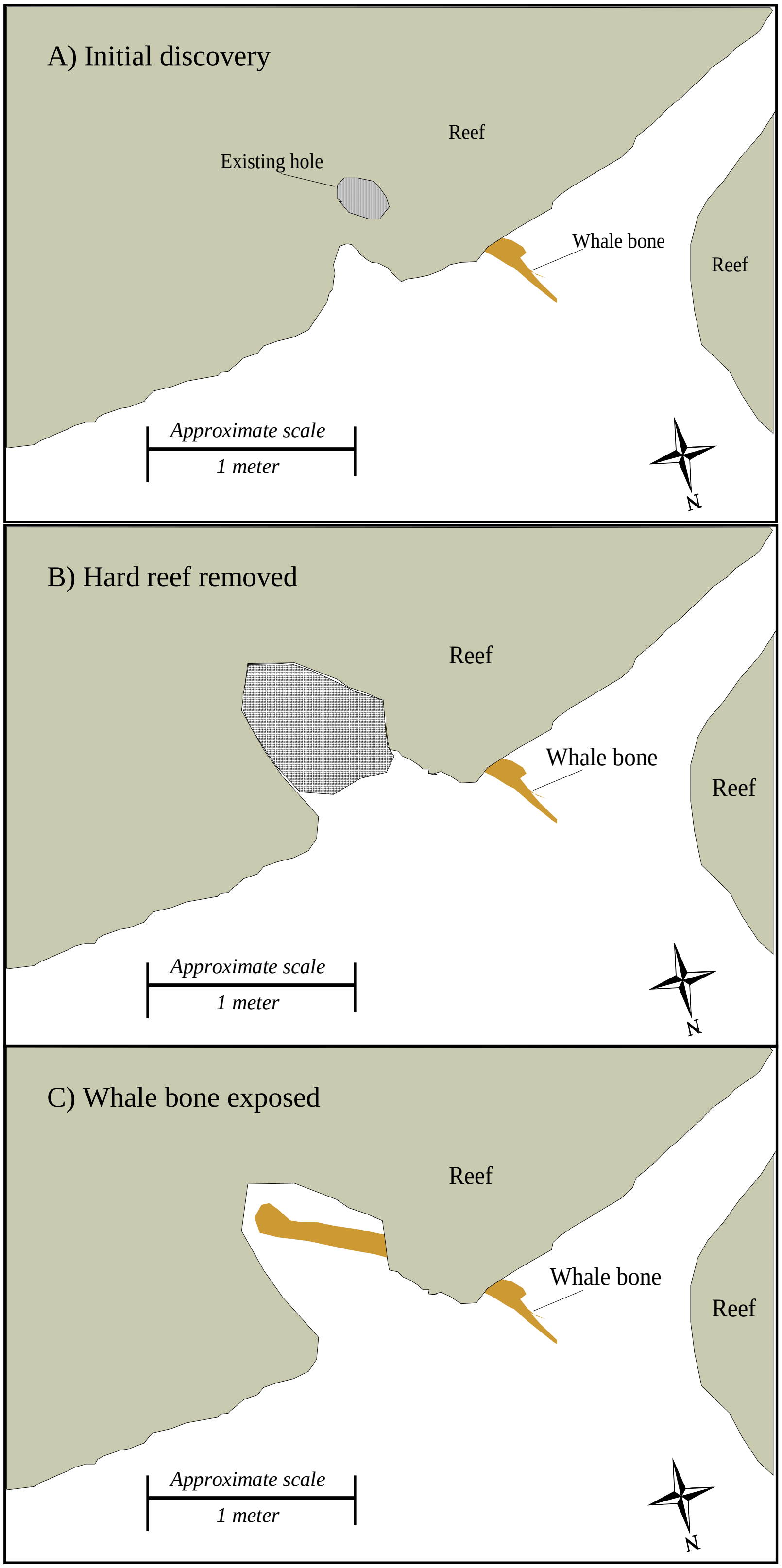

Figure 2. Excavation site showing a) initial discovery, b) hard reef removed and c) whale bone exposed.

Whale Bone Recovery, Assembly, and Identification

Once the entire bone was exposed, the original intent was to slide a board under the bone, secure it and bring it up intact. However, upon close inspection of the bone, it was determined that it had vertical fractures that divided it into roughly thirds. Between the fractures and low visibility when the bottom sediments were disturbed, the decision was made to bring the bone up in sections. It was anticipated that bringing the bone up in sections would insure the least amount of potential damage to the bone. Prior to removal, high-definition video was collected of the bone *in situ* to document its position on the seafloor and for reference upon reassembly. After filming the whale bone, each section was carefully removed and placed in a mesh bag. A line was attached to the bag and a float was inflated to send the line to the surface. Personnel on the NOAA vessel were standing by to retrieve the float and haul in the bone sections. After several dives, the entire bone was now onboard the NOAA vessel. The bone fragments were carefully packed in wood crates for transport back to Athens.

As soon as the whale bone arrived in Athens, the fragments were placed in fresh water to dissolve the chloride salt crystals from inside the bone. The fragments were soaked for approximately two months with the water periodically replaced before being removed and laid out to air dry. Once dried, the bone fragments were assembled (Figure 3). Since the bone had been well preserved and held in place by the surrounding sediment, most of the pieces had a very good fit. The recovered bone measured 1.5 m in length and weighed approximately 22 kg. It was clear that the bone was that of a baleen whale mandible, but further investigation would be required to determine the species. Pictures were taken of the mandible and sent out to cetacean experts for review.

Figure 3. Whale bone dry-fitted for identification.

The consensus was that this was a Gray whale mandible (*Eschrichtius robustus)*, extinct from the Atlantic Ocean since the seventeenth century (Mead and Mitchell, 1984). It was very fortunate that the articulating end or condyle of the mandible had been recovered. That along with the distinctive curve of the mandible was essential for a positive identification. Unlike other whales, the Gray whale feeds in shallow, very productive benthic ecosystems (Nerini, 1984). It has a unique mandible adapted to perturbating bottom sediments and then filtering the benthic organisms (Berta *et al*, 2006). Once identified as a Gray whale, the mandible was added to the Georgia Museum of Natural History collection (27372) and also listed on the Cetacean Distributional Database (STR15264).

The Gray whale has the unusual distinction of first being characterized by fossil remains in Europe (Bryant, 1995). Researchers had discovered the subfossil bones, but a living specimen was no longer found off the European coast. It was not until researchers reviewed whaler's logs that written descriptions of the Gray whale were identified. These logs described the Scrag whale which closely fit the Gray whale (Dudley, 1725). In the logs, the whalers commented that the Scrag or Gray whale was a coastal whale that had high quality oil which made it a highly prized catch (Mead and Mitchell, 1984). Also, since the Gray whale was found along the coast, shore whaling practices were employed (Sayers, 1984). This practice allowed smaller vessels from shore to catch the whales and haul them back to shore for processing.

Very few Gray whale remains have been discovered along the North American eastern coast. This discovery marks the first Gray whale remains to be discovered offshore Georgia. Previously discovered Gray whale remains ranged from New York to Florida with the oldest coming from the Chesapeake Bay, Virginia at approximately 10,000 ybp (Mead and Mitchell, 1984). Since the Georgia Gray whale mandible was dated at approximately 36,000 ybp, it is now the oldest recorded specimen found along the United States eastern coast. Older Gray whale specimens have been found in Europe, Japan, and the North American west coast dating as old as the Pliocene age (Barnes and McLeod, 1984; Hiroto *et al.*, 2006). It is anticipated that continued exploration at the discovery site will yield more Gray whale remains. Future plans call for a systematic sweep of the JY reef area looking sand-ward away from the reef outcrop. It is thought that much of the remains has most likely been eroded from the shell bed and may be scattered in the sand away from the outcrop. Limited exploratory excavation will also be attempted to determine if further remains lie beneath the shell bed.

Research in progress includes the extraction of DNA from the mandible. Samples from the mandible have been sent to McMasters University in Canada to extract DNA. Once extracted, the DNA will be sequenced with known Gray whale DNA to provide positive identification. UGA and Emory University's Carlos Museum in Atlanta, Georgia have agreed on a joint understanding that allows the museum to use the mandible as a teaching tool. In the process, the bone will undergo professional conservation and assembly by the museum's staff and student interns. The final outcome will be a quality museum piece ready for display. Upon completion, a suitable display location will be selected that will allow high visibility for this unique discovery.

Acknowledgments

The authors wish to thank GRNMS-NOAA for the use of the Research Vessel Joe Ferguson and the NOAA divers Chad Meckley and Todd Recicar. Thanks also go out to Jim Demmers (GT) for the video documentation; Kenan Matterson (GSU) for diver support; Lindsey Thomas and Jessica Cook Hale (UGA); Jim Mead (Smithsonian Institute) for providing identification support; and Alex Cherkinsky (UGA) for dating the whale bone.

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AAUS 2009 Symposium Program - Atlanta, GA

<u>March 13th</u>

0800 - 0810 Opening Comments

0810 - 0900 (Invited Plenary) Scientific Diving and the Law: an Evolving Relationship
Dennis Nixon
College of the Environment and Life Sciences, University of Rhode Island, Kingston, RI

0900 - 0925 Commercial Diver Exposure Scenario for the Portland Harbor Risk Assessment
Sean Sheldrake, Dana Davoli, Michael Poulsen, Robert Pedersen, Bruce Duncan
USEPA, Region 10, Environmental Cleanup Office, Seattle, WA

0925 - 0950 Submerged Cultural Resource Discoveries in Albania: Surveys of Ancient Shipwreck Sites in the Ionian Sea
Derek Smith
Hawai'i Institute of Marine Biology, 46-007 Lilipuna Rd, Kane'ohe, HI

0950 - 1015 Break

1015 - 1040 The Minerals Management Service's Seafloor Monitoring Program
David Ball
Minerals Management Service, 1201 Elmwood Park Blvd, New Orleans, LA

1040 - 1105 Underwater Acoustic Ecology
Phillip S. Lobel
Boston University, Biology Dept., 5 Cummington St, Boston, MA

1105 - 1130 Convenient Fish Acoustic Data Collection in the Digital Age
Kathryn E. Kovitvongsa, Phillip S. Lobel
Boston University, Biology Dept., Boston, MA

1130 - 1155 Use of Technical Diving to Study Deep Reef Environments in Puerto Rico
Clark Sherman, Milton Carlo, Richard Appeldoorn, Michael Nemeth, Hector Ruíz, Ivonne Bejarano
Department of Marine Sciences, University of Puerto Rico-Mayagüez, Mayagüez, PR

1155 - 1300 Lunch

1300 - 1325 NOAA's Office of National Marine Sanctuaries and the American Academy of Underwater Sciences: A Look to the Past and the Road Ahead
Mitchell Tartt, Greg McFall
Office of National Marine Sanctuaries

1325 - 1355 The 2008 Battle of the Atlantic U-Boat Survey: Archaeological Recording in the Graveyard of the Atlantic
Joseph C. Hoyt
Office of National Marine Sanctuaries

1355 - 1415 Habitat-Mediated Signal Reception by a Passive Acoustic Receiver Array as Determined by Scuba Transects: Implications for the Design of Fish Movement Studies
James Lindholm[1], Ashley Knight[1], Jeremiah Brantner[1], Les Kaufman[2], Steven Miller[3]
[1] Institute for Applied Marine Ecology, California State University Monterey Bay
[2] Boston University
[3] University of North Carolina at Wilmington

1415 - 1435 From Torrid Seas to Icebound Lakes: Shipwreck Investigations within NOAA's National Marine Sanctuaries
Tane Casserly
Office of National Marine Sanctuaries

1435 - 1505 Flower Garden Banks National Marine Sanctuary and Texas A&M University at Galveston - A Case Study: Building a Research and Learning Partnership
Kevin Buch[1], Emma Hickerson[2]
[1] Texas A&M University Galveston; [2] Office of National Marine Sanctuaries

1505 - 1530 Break

1530 - 1555 Exceptional Areas, Significant Challenges, a Perfect Opportunity: The National Marine Sanctuary University Partnership Program
Bradley Barr, Robert Pavia
Office of National Marine Sanctuaries

1555 - 1620 The 2009 ONMS Science Needs Assessment: A To Do List for Marine Conservation
Mitchell Tartt
Office of National Marine Sanctuaries

1620 - 1645 The Etiology of Spinal Cord Decompression Sickness: A Literature Review
Dawn N. Kernagis
Center for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Center, Durham, NC

1645 - 1710 The Haldane Effect
Michael A. Lang[1], Alf O. Brubakk[2]
[1] Smithsonian Institution, Office of the Under Secretary for Science, PO Box 37012 - MRC 009, Washington, DC
[2] Norwegian University of Science and Technology, Department of Circulation and Medical Imaging, 7491 Trondheim, Norway

March 14th

0800-0805 Opening Comments

0805 - 0830 Community Science for Marine Resource Management: Building a Best Practices Toolkit for Sustainable Fisheries Research

Richard B. Carey[1], Richard V. Ducey[1], Carolyn Winter[2], Miriam Kelty[1], Sally Hornor[1], Bruce Macphail[2]
[1] Magothy River Association Scientific Dive Team, Severna Park, MD
[2] World Bank, Washington, DC

0830 - 0845 Assessing Seasonal Variation in Benthic Macroinvertebrate Biodiversity with a Focus on Polychaete Biomass on Protected Oyster Reefs in the Magothy River

Elizabeth J. Ducey
Department of Biology, St. Mary's College of Maryland, St. Mary's City, MD

0845 - 0910 Exploring the 'Marine Twilight Zone' in the Gulf of Eilat, Red Sea, Israel

Oded Ben-Shaprut
Interuniversity Institute for Marine Sciences in Eilat
POB. 469 Eilat 88103 Israel

0910 - 0940 FPGA-Based Fish Detection Using Haar Classifiers

Bridget Benson, Junguk Cho, Deborah Goshorn, Ryan Kastner
Computer Science and Engineering, University of California San Diego

0940 - 1005 The Science of the National Association for Cave Diving (NACD): Water Quality, Hydrogeology, Biology, and Psychology

Donald (Skip) F. Kendrick
National Association for Cave Diving (NACD) and Department of Psychology, Middle Tennessee State University, Murfreesboro, TN

1005 - 1040 Break

1040 - 1105 Assessing the Health of Coral Reefs: Relative Dominances of Benthic Indicator Groups and Top-Down/Bottom-Up Tipping Points

Mark M. Littler, Diane S. Littler
Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC

1105 - 1120 Methodologies for Benthic Invertebrate and Shellfish Population Assessments in Sheffield Harbor, Norwalk, Connecticut

Ryan D. Patrylak, Robert B. Whitlatch
Department of Marine Sciences, University of Connecticut, Groton, CT

1120 - 1145 Collaborative Diving for Science: A Report on the Diving Equipment, Techniques and Collaborative Approach Used to Conduct Subtidal Shellfish Surveys in Coos Bay, Oregon

Vallorie Hodges[1], Caren E. Braby[2], Alix M. Laferriere[2]
[1] Oregon Coast Aquarium, Newport OR
[2] Shellfish and Estuarine Assessment (SEACOR), Oregon Department of Fish and Wildlife, Coos Bay, OR

1145 - 1300 Lunch

1300 - 1330 Oxygen and Hydrogen Isotopes Suggest Two Sources for Little Salt Spring

Noelle J. Van Ee, Rick Riera-Gomez
University of Miami, Miami, FL

1330 - 1400 Time Series Observations of Species Composition and Behavioral Interactions of Fish at an Ocean Observatory off the Coast of Georgia

Amy E. Paquette[1], Peter J. Auster[2], Michael D. Arendt[3]
[1] University of Connecticut, Department of Marine Sciences
[2] University of Connecticut, Department of Marine Sciences
[3] Marine Resources Research Institute South Carolina Department of Natural Resources

1400 - 1430 Tourist Charge Capacities for Recreational SCUBA Diving in Marine Protected Areas and Establishment of Interpretative Underwater Paths

Vicente Munoz-Fernandez, Alejandro Ramirez-Cordero, Eduardo Rios-Jara
Laboratorio de Ecosistemas Marinos y Acuicultura, Departamento de Ecología. Centro Universitario de Ciencias Biológico Agropecuarias (CUCBA). Universidad de Guadalajara Apartado Postal 52-114, Zapopan, Jal. 45110, México

1430 - 1500 Break

1500 - 1525 Algal Garden Cultivation and Guarding Behavior of Dusky Damselfish on Coral Rubble and Intact Reef in Dry Tortugas National Park

Valentina Di Santo, Christopher M. Pomory, Wayne A. Bennett
Department of Biology, University of West Florida, Pensacola, FL

1525 - 1550 Population Analysis of an Introduced Coral Species, *Tubastraea coccinea*, in Florida

Tonya L. Shearer
Georgia Institute of Technology, School of Biology, Atlanta, GA

1550 - 1620 Design and Evaluation of Cold Water Diving Garments Using Super-Insulating Aerogel Fabrics

M. Lew Nuckols
Mechanical Engineering and Materials Science Department, Duke University, Durham, NC

1620 - 1645 Underwater Paleontology: Recovery of a Prehistoric Whale Mandible Offshore Georgia

Scott E. Noakes, Erv G. Garrison, Greg B. McFall

1645 - 1700 AAUS Photo Collage

Derek M. Smith

1700 - 1700 Closing Comments