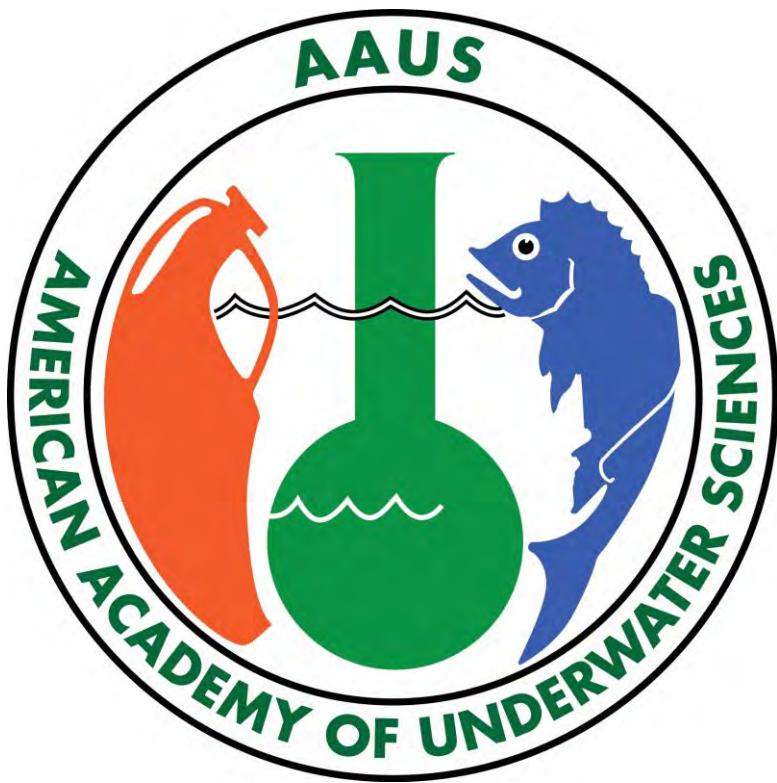


**Diving For Science 2012  
Proceedings of the  
American Academy of Underwater Sciences  
31<sup>st</sup> Scientific Symposium**



**Diana L. Steller, Lisa Kerr Lobel  
Editors**

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The American Academy of Underwater Sciences (AAUS) was formed in 1977 and incorporated in the State of California in 1983 as a 501c6 non-profit corporation. Visit: [www.aaus.org](http://www.aaus.org).

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.

## Acknowledgements

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## Aquatic Research Opportunities with the National Park Service

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### Abstract

The United States National Park Service (NPS) protects and preserves unparalleled natural aquatic resource diversity. Ecosystems range from marine coral reefs, freshwater lakes and estuaries, to cave system aquifers; the NPS's unique resources are unmatched. The National Park Service Dive program consists of thirty programs that span the United States and its outlying territories. Each program is governed by the National Park Diving Control board under the authority of the Law Enforcement, Security, and Emergency Services department of the National Park Service. The National Park Mission Statement outlines "...*The Park Service cooperates with partners to extend the benefits of natural and cultural resource conservation....*". In an effort to conserve and protect these areas the NPS encourages natural and cultural research within the parks. The National Park Service and The American Academy of Underwater Sciences are working to establish a formal relationship to bring the academic and diving capabilities shared by the two organizations together to provide researchers opportunities and to investigate topics that promote natural and cultural resource conservation. This paper explains the scope of the National Park Service Dive program, a description of individual park capabilities, opportunities available for research within the parks, and the benefits of developing partnerships with individual parks.

Keywords: American Samoa, diving research projects, National Park Service

### Introduction

Perhaps the best-kept secret of our National Parks is the underwater realm, including millions of acres of submerged lands, only a fraction of which have been explored by divers. From the geysers on the bottom of Yellowstone Lake to the coral reefs of American Samoa, the National Parks have much to offer aquatic scientific researchers.

The National Park Service (NPS), which is a division within the US Department of Interior (DOI), is comprised of 397 units, including National Parks, Recreation Areas, Monuments and other designations (hereafter referred collectively as parks). To manage and protect these resources, the NPS depends on reliable and current scientific data to assist in management decisions.

Knowledge of the state of resources is vital to achieving the NPS mission; "*The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*".

Within the National Park Service, thirty units have an active dive program (Figure 5 and Table 4). In striving to achieve its goals, the National Park Service encourages collaborative partnerships with academic and private researchers to enhance public awareness and to provide continued monitoring and protection of America's natural and cultural resources.

### **Background**

The National Park Service was the first civilian federal agency to formally adopt scuba diving as a management tool. By 1960, NPS had divers trained and using "modern" SCUBA to manage and monitor resources within the NPS protected areas. In 1963, NPS had developed a formal diving policy. Initially NPS diving was a job responsibility of Law Enforcement Rangers to aid in the protection of submerged park resources and a tool for body recovery due to park visitor accidents. Perhaps the biggest change in the role of the NPS dive program since its conception in 1960 is that diving has become a scientific, interpretive and facility management tool. Currently NPS divers recover drowning victims, conduct biological and archeological surveys, create interpretive and educational products, and monitor the condition of historical shipwrecks sunk on submerged park lands. The NPS dive policy was originally based, for a short period, on a US Navy model, but by the mid-1960's NPS divers had adopted the Scripps model. This model later served as a "genesis" for the diving policies of a large number of academic and public services agencies. The American Academy of Underwater Science (AAUS) is essentially a modified Scripps policy (Lenihan, nd). Scripps Institute of Oceanography Dive Safety Officer Jim Stewart worked with early NPS divers like Jack Morehead and Jim Randall to standardize new NPS protocols and provide training to the first of NPS "diving" rangers.

NPS dive program capabilities have evolved with new management issues, advances in dive technologies, and environmental issues. NPS divers have participated in projects using not only open circuit scuba but mixed gas diving, cave diving, deep wreck diving, closed circuit rebreather diving and surface supplied diving. Due to the vast scope of missions for the NPS diver, they are afforded a less restrictive approach in accomplishing our goals than other civilian government agencies. This is all done with the highest attention being paid to diver safety. In over 50 years of organizational diving NPS has never had a diver fatality.

### **NPS Dive Structure**

The National Park Service covers 4,502,644 acres of oceans, lakes and reservoirs. Addressing issues in various areas of the system can differ completely in topic and/or approach, but in many cases there is an overlap or similarities in diving operations and safety issues which necessitates a singular system approach evaluated and managed through a hierarchy structure

### **Documentation Authority:**

The DOI authorizes the use of diving in the work place at divisional levels through the *Department of Interior Manual 465 Ch. 27 "Safety and Health Standards, Procedures and Guidelines"* (1997). The National Park Service placed *Director's Order #4* (1999) which permitted diving within NPS, guided by *Reference Manual #4- Diving Management (RM-4)* (2000). RM-4 requires and dictates the administration of all dive operations through the NPS National Dive Control Board.

### **Organizational Structure:**

#### **National Dive Control Board (NDCB)**

The NDCB is comprised of the NPS Dive Safety Officer, five Regional Dive Officers (RDO's), Deputy Chief of Law Enforcement and Emergency Services, and a representative from risk management, cultural and natural resources. Responsibilities of the NDCB include recommending changes in NPS diving policy, providing annual review of Regional Dive Programs, developing/maintaining liaison with other agencies/groups, adjudicating appeals from divers, parks or

regions, approving NPS dive instructors, securing funding for service-wide training and conducting dive program reviews as needed. The NDCB grants management oversight to each individual region to the Regional Dive Officers.

#### Branch Chief, Emergency Services

The Branch Chief, Emergency Services (WASO) provides leadership and direction to the NPS NDCB in the development of the program's Directors Order and Reference Manual. The branch chief secures funding for service-wide training and equipment while also maintaining an advocacy in the Washington Directorate.

#### Regional Dive Officer (RDO)

Due to the large coverage of the National Park Service, dive program management has been divided into five diving regions; Intermountain, Midwest, Northeast, Pacific West and Southeast. Each region has a Regional Dive Officer appointed by the NPS Regional Director to manage all dive operations within their region. This individual plans, directs, develops, coordinates, and advises on all phases of the Regional Diving Program. In doing so, the RDO serves as a technical advisor to the Associate Regional Director for Park Operations, or their designee. It is required that each RDO possess a nationally recognized Instructor or Dive Master credential. A contact list of Regional Dive Officers is found in Table 1.

Table 1. Regional Dive Officer List

Region	Regional Dive Officer	Email	Phone
Intermountain	Brett Seymour	Brett_Seymour@nps.gov	303-969-2993
Southeast	Shelby Moneysmith	Shelby_Moneysmith@nps.gov	305-230-1144
Pacific West	Dave Kushner	Dave_Kushner@nps.gov	805-658-5773
Northeast	Michael Croll	Michael_Croll@nps.gov	570-426-2470
Midwest	Steve Martin	Steve_A_Martin@nps.gov	906-487-7175

#### Dive Safety Officer (DSO)

The DSO is an active NPS diver administered by the Branch Chief, Emergency Services and supervised by the Submerged Resources Center Program Manager. This individual plans and manages a professional, comprehensive, and complex dive safety and training program. Under the direction of the NDCB, the DSO plans and implements multiple aspects of the dive safety program. It is required that the DSO possesses a nationally recognized instructor credential.

#### Park Dive Officer (PDO)

In Parks/Units having diving programs, the Park Superintendent/Program Manager shall be responsible for its management. The Superintendent/Program Manager shall appoint a PDO to fulfill Park/Unit obligations in keeping diving records, dive planning, dive operations management, training, etc. Experience and leadership ability should play an important part in the selection of the PDO. The PDO will perform as the area's subject matter expert on diving matters pertaining to overall park management and goals.

#### ***NPS Dive Statistics***

Over the past decade, with heightened public concerns of global climate change, NPS has increased its dive efforts to better investigate this phenomenon. The world's aquatic environments play a critical role in and are dramatically affected by climate change. NPS divers, along with outside researchers, have spent more time underwater to better investigate these changes. Along with more natural

resource research being done in America's National Parks; divers are spending many more submerged hours studying America's cultural resources. Rebreathers, mixed gases and remotely operated vehicles provide researchers with various tools to investigate cultural and natural resources that have been unreachable in the recent past. A review of the NPS dive statistics over the past seven years illustrates that more dives are conducted each year and more divers are participating in the NPS dive programs (Table 2)

Over the past seven years the NPS dive program has increased its number of divers by 56%, its number of dives by 75% and its total dive hours by 40% (Table 2) (Figures 1,2,3). The National Oceanographic and Atmospheric Administration (NOAA) is largely considered to be the biggest and most active civilian federal dive program; this provides a good measuring tool to compare against NPS dive numbers. Over the past seven years the NOAA dive program has remained largely stable while the NPS dive program is a growing program. As NPS recognizes the need for aquatic research we see that more of our resources and budgets are being directed to the aquatic environments of our national parks.

Table 2. NPS/NOAA Yearly Statistics.

<b>2011</b>		<b>2010</b>			
	<u>NPS</u>	<u>NOAA</u>		<u>NPS</u>	<u>NOAA</u>
Number of divers	204	423	Number of divers	209	466
Number of dives	10516	13859	Number of dives	10464	13987
Number of dive hours	5177	8168	Number of dive hours	5289	9099
<b>2009</b>		<b>2008</b>			
	<u>NPS</u>	<u>NOAA</u>		<u>NPS</u>	<u>NOAA</u>
Number of divers	171	486	Number of divers	153	508
Number of dives	7803	13430	Number of dives	9146	14630
Number of dive hours	6674	8149	Number of dive hours	5887	8765
<b>2007</b>		<b>2006</b>			
	<u>NPS</u>	<u>NOAA</u>		<u>NPS</u>	<u>NOAA</u>
Number of divers	150*	457	Number of divers	149	516
Number of dives	7000*	14906	Number of dives	6766	16910
Number of dive hours	5000*	8954	Number of dive hours	4079	10424
<b>2005</b>					
	<u>NPS</u>	<u>NOAA</u>			
Number of divers	131	476			
Number of dives	6008	13232			
Number of dive hours	3705	7419			

\*number(s) extrapolated due to data loss

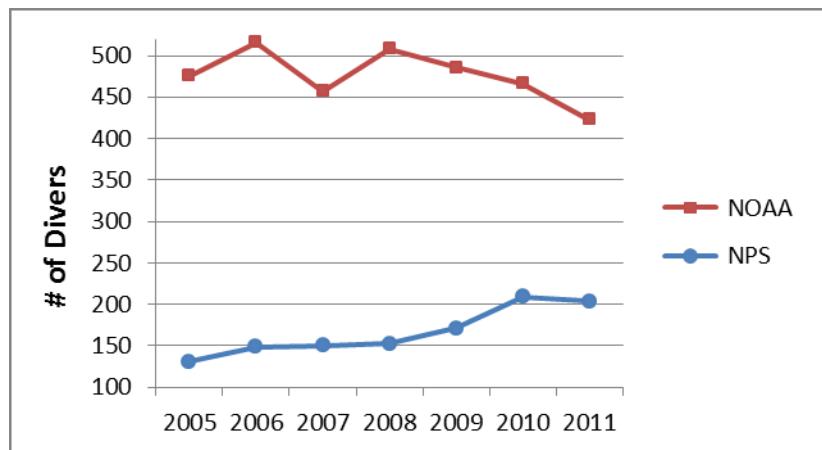


Figure 1. Number of Divers by Year.

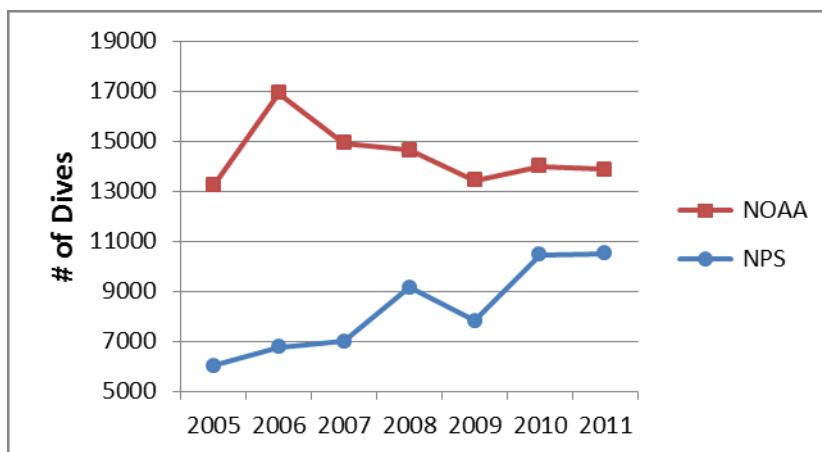


Figure 2. Number of Dives by Year.

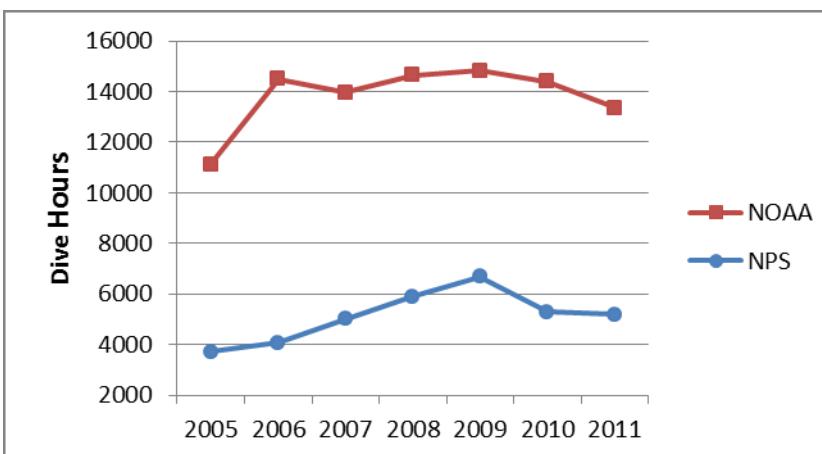


Figure 3. Dive Hours by Year.

A review of dive 2011 statistics shows that a majority (70%) of NPS diving is for the purposes of natural and cultural resource management. The next greatest obligation is training and proficiency (Figure 4).

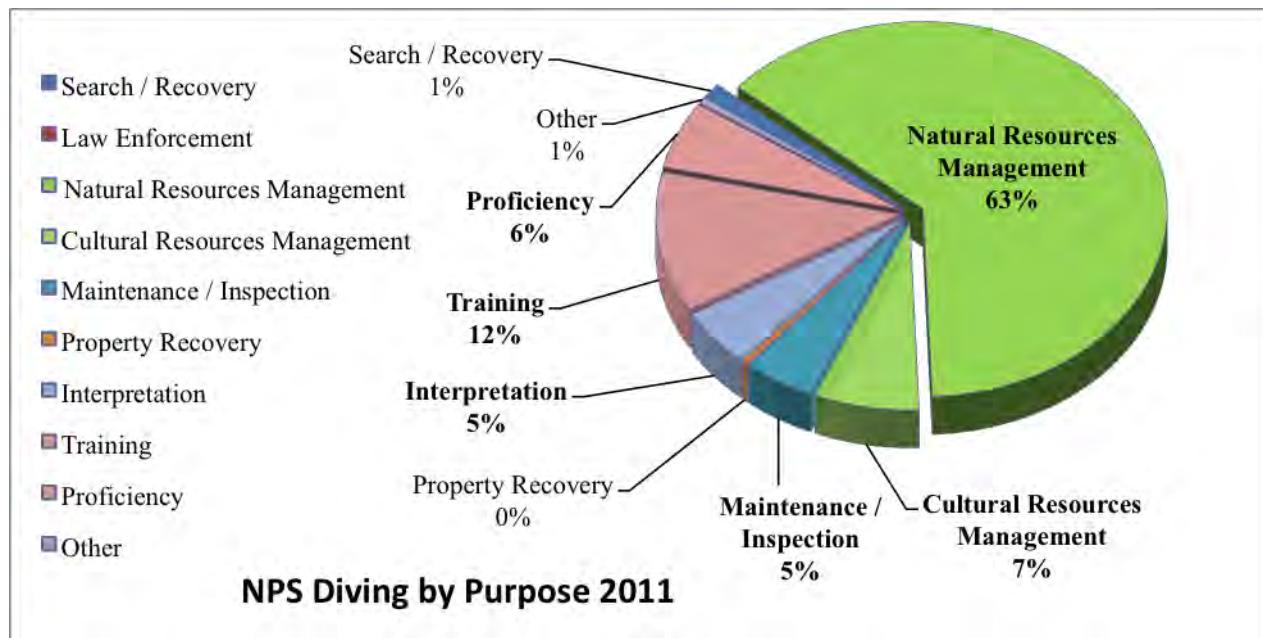


Figure 4. Summary of NPS dive purposes by percentage.

#### ***Research Application and Usage of National Parks***

A *Scientific Research and Collecting Permit* is required for most scientific activities pertaining to natural resources or social science studies in National Park System areas that involve fieldwork, specimen collection, and/or have the potential to disturb resources or visitors. Each NPS unit requires researchers to submit an “application and usage” request. These requests are reviewed on an individual basis. Upon approval, each park will govern the extent of research permitted within its boundaries. Items often addressed include; the period of time research is permitted, limitation regarding investigation and final dissemination of research results to the federal government.

The National Park Service’s Research Permit and Reporting System (RPRS) will provide the following services for interested parties seeking permission to conduct a natural resource or social science study in a unit of the national park system. RPRS allows researchers to review NPS scientific permit requirements and application procedures. RPRS provides potential researchers with the following:

- Ability to review permit conditions before beginning the permit application process
- Ability to review accomplishments of previous research conducted in a park before planning a new study
- Ability to review the types of research specific parks are especially interested in attracting
- Ability to complete and submit an application for a scientific research and collecting permit

Most parks have a Research Coordinator who can be consulted for more information. To access the NPS Research Permit and Reporting System and learn more about the NPS scientific permit application process, go to <http://science.nature.nps.gov/research>.

#### **NPS Resource Availability**

The NPS contains thirty diving units. Within these units, the diving operations span a wide spectrum of skills and specialties. Each unit, within an active program, independently supports and regulates diving within their boundaries. For authorization and use of resources with NPS support, each unit must be contacted independently or through their applicable PDO and/or RDO.

Geographic location coupled with resource diversity necessitates that each dive operation operates their own unique dive program within the guidance of the national dive program. Each dive unit has particular tools and procedures used to manage their diving needs (i.e. resource management, cultural preservation, facility management and law enforcement). To obtain the most accurate available resources available to an outside researcher, interested parties should contact specific Park Managers and/or Park Dive Officers. Figure 5 and Table 3 show specific locations of diving units within the National Park Service. A brief description of each of these units is also provided. Along with a description, applicable information such as dive capabilities, support operations, current research, desired research and contact information are also provided.

**Amistad National Recreation (AMIS)** is located on the US and Mexico border near Del Rio, Texas and is between San Antonio and Big Bend National Park. The park is 150 miles west of San Antonio

For possible projects at AMIS please contact:

Regina Klien, Park Dive Officer - [regina\\_klien@nps.gov](mailto:regina_klien@nps.gov) (830) 775-7492 x2213

Special use permits: (830) 775-7492 ext. 200

**Bighorn Canyon National Recreation Area (BICA)** is located in north-central Wyoming, and south-central Montana. The aquatic resources are typical of those in freshwater reservoir systems associated with lakes formed by man-made dam structures. The Yellowtail Dam was constructed for flood control and electrical power generation on the Big Horn and Shoshone rivers.

BICA supports a man-made resource of two reservoirs separated by the Yellowtail Dam. Currently, BICA conducts minimal cultural and resource investigations. Both Wyoming and Montana state fish and wildlife agencies have conducted fish research and population studies using surface visual counts from netting and shocking techniques.

The majority of diving in the dive program consists of maintaining anchor systems, docks, navigation buoys, and performing visitor services for lake facilities. The program could provide air fills for bottles and a support crew for diver assistance if special funding were obtained.

Some issues which BICA warrants further studies include:

- Determining locations of spawning / rearing sites for freshwater fish species below the dam
- Habitat changes and effects of flushing flows in the river below the dam
- Monitoring for aquatic invasive species
- Monitoring and or mapping of underwater dam construction conditions

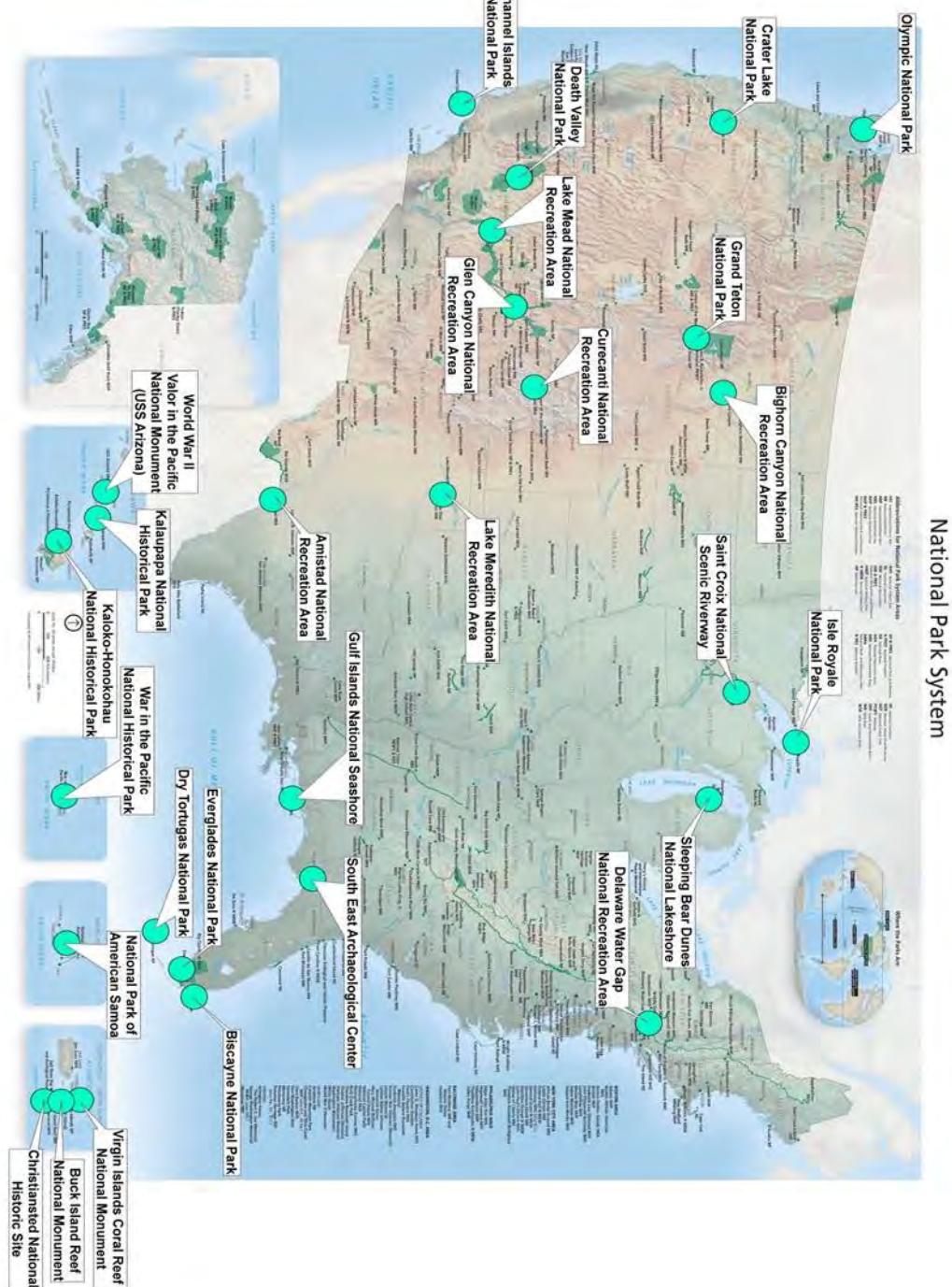


Figure 5. NPS Dive Unit Locations.

Table 3. NPS Dive Unit Locations.

Intermountain Region	Pacific West Region	Southeast Region	Northeast Region
Amistad National Recreation Area	Del Rio, TX	Biscayne National Park	Bushkill, PA
Bighorn Canyon National Recreation Area	Fort Smith, MT	Buck Island Reef National Monument	Saint Croix Fall, WI
Curecanti National Recreation Area	Gunnison CO	Dry Tortugas National Park	
Glen Canyon National Recreation Area	Glen Canyon, AZ	Everglades National Park	
Grand Teton National Park	Moose, WY	Gulf Islands National Seashore	
Lake Meredith National Recreation Area	Enrich, TX	South East Archaeological Center	
		South Florida/Caribbean Network	
		Virgin Islands National Park	
		St. John, VI	

Intermountain Region	Pacific West Region	Southeast Region	Northeast Region
Amistad National Recreation Area	Del Rio, TX	Biscayne National Park	Bushkill, PA
Bighorn Canyon National Recreation Area	Fort Smith, MT	Buck Island Reef National Monument	Saint Croix Fall, WI
Curecanti National Recreation Area	Gunnison CO	Dry Tortugas National Park	
Glen Canyon National Recreation Area	Glen Canyon, AZ	Everglades National Park	
Grand Teton National Park	Moose, WY	Gulf Islands National Seashore	
Lake Meredith National Recreation Area	Enrich, TX	South East Archaeological Center	
		South Florida/Caribbean Network	
		Virgin Islands National Park	
		St. John, VI	

Water clarity above stream from the Yellowtail Dam makes underwater visibility poor and limits the effectiveness of underwater research. Water clarity below the Yellowtail Dam is good for freshwater conditions; however, water temperatures are usually within the range of 35 – 50° F.

For possible projects at BICA please contact:

Keith Biermann, Park Dive Officer - [Keith\\_Biermann@nps.gov](mailto:Keith_Biermann@nps.gov) (406) 666-2412

Ms. Cassity Bromley, Natural and Cultural Programs [Cassity\\_Bromley@nps.gov](mailto:Cassity_Bromley@nps.gov) (307) 548-5416

Park Offices: (406) 666-2412

**Curecanti National Recreation Area (CURE)** is located in Western Colorado outside the town of Gunnison. It is comprised of three man-made reservoirs including the largest in Colorado, Blue Mesa Reservoir, with 96 miles of shoreline. Blue Mesa, Morrow Point and Crystal reservoirs are collectively called the Wayne N. Aspinall Storage Unit, and were created primarily to provide water storage to the Upper Colorado River Basin states of Colorado, Wyoming, New Mexico and Utah.

Human occupation of the Curecanti area dates back at least 10,000 years. Fossils, primarily dinosaur bones, from the Jurassic Morrison formation are also found at CURE. These are a couple of resources that could make CURE a place of interest to outside researchers

Currently, CURE dive team's main purpose is public safety. Starting summer of 2012, the dive team is going to assist the Resource Management Division in completing invasive mussel surveys. The team is going to conduct underwater searches for invasive mussels.

Some issues which CURE warrants further studies include:

- Topographical underwater survey to explore/locate possible ancestral rock shelters
- Submerged survey for fossil deposits—including human habitation and primarily dinosaur bones, from the Jurassic period

It should be noted that the diving environment at Blue Mesa Reservoir can be challenging, although rewarding, even with the best conditions. High altitude conditions exist as full pool elevation is 7,519 feet. The reservoir is typically ice covered from January through April and water temperatures remain cold year round (ranging from 66° in the summer to 34° F in the winter). Visibility at Curecanti NRA is always limited, ranging from 0 – 15 foot. Generally, visibility will be in the 3-5 foot. range.

For possible projects at CURE please contact:

Melissa Post, Park Dive Officer - [melissa\\_post@nps.gov](mailto:melissa_post@nps.gov) (970) 641-2337 x246

Park Offices: (970) 641-2337

**Glen Canyon National Recreation Area (GLCA)** straddles the Arizona and Utah borders and surrounds Lake Powell the second largest man-made lake in the country. With over 1900 miles of shoreline and depths in excess of 500 foot Lake Powell presents many underwater opportunities.

The area around and within GLCA contains multiple ancient ruins and artifacts. Many of these sites have been inundated by the waters of Lake Powell. These sites were inventoried pre-inundation but no research or inspections have been made since. Most of the sites are mapped and can be located with a reasonable amount of effort.

The Underwater Recovery Unit (URU) at Glen Canyon maintains twelve divers and a remotely operated vehicle (rov) capable of diving to 1100'. The URU has two vessels assigned to them a 46 foot landing craft and a 28 foot. tender both equipped with cranes and other necessary equipment. The

Unit can also draw from the park's fleet any number or type of vessel needed for any particular assignment.

The unit's primary duties are maintenance of docks and marinas, and the search and recovery of drowning victims. Recent scientific efforts undertaken by the Underwater Recovery Unit (URU) include the determination of the source of the water to Montezuma's Well in Central Arizona, where divers lowered sampling devices into the crevice that feeds the well and removed samples from deep in the crevice, and the completion of the ten year study of Crater Lake National Park where the URU's ROV was used to collect samples in over 38 transects of Crater Lake from depth ranging from 100 - 800 ft. deep. Currently the URU is involved in monitoring the lake facilities for aquatic invasive species and removing waste and debris from the lake bottom in the Marina areas.

Scientific projects that could benefit the park:

- Recovery of a sandstone slab that contains dinosaur footprints left while the creature was sitting down; these tracks are on a soft sandstone slab that can be lost if the slab is mishandled
- Survey and document the effects of the reservoir on ancient structures
- Monitoring of invasive species within the reservoir

For possible projects at GLCA please contact:

Patrick Horning, Park Dive Officer - [pat\\_horning@nps.gov](mailto:pat_horning@nps.gov) (928) 608-6514  
Park Offices: (928) 608-6404

**Grand Teton National Park (GRTE)** located in northwestern Wyoming, Grand Teton National Park protects spectacular mountain scenery and a diverse collection of wildlife.

For possible projects at GRTE please contact:

Rick Guerrieri, Park Dive Officer - [rick\\_guerrieri@nps.gov](mailto:rick_guerrieri@nps.gov) (307) 739-3619  
Park Offices: (307) 739-3300

**Lake Meredith National Recreation Area (LAMR)** is located in Fritch, TX which lies on the high plains of the Texas Panhandle. The lake itself was created by Sanford Dam on the Canadian River. The 50,000-acre national recreation area includes a 10,000-acre reservoir.

LAMR currently supports no research activity. LAMR dive team is established for Law Enforcement Protection.

For possible projects at LAMR please contact:

Paul Jones, Park Dive Officer - [paul\\_jones@nps.gov](mailto:paul_jones@nps.gov) (806) 865-3874 x37  
Park Offices: (806) 857-3151

**Channel Islands National Park (CHIS)** is located in Ventura, California. CHIS includes the islands of San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara. The islands' isolation has left them relatively undeveloped. The significance of Channel Islands National Park stems from the islands' remote, isolated position at the confluence of two major ocean currents, a region of persistent oceanic upwelling, and the border of two tectonic plates. The park contains examples of two biogeographical provinces in the ocean, the Oregonian and the Californian, and a dynamic transition zone between them. Cool, nutrient-rich oceanic waters rise into abundant sunlight and mix with warm coastal waters, accelerating photosynthesis and growth rates of myriad forms of sea life from

microscopic plankton to blue whales. CHIS ecosystems encompass kelp forest, soft bottom and eel grass communities.

Facility and logistical support of research divers is based on availability and funding. With proper notification a 60 ft. dive boat and all the diving necessities may be available.

CHIS staff is actively involved in kelp forest monitoring and submerged cultural resource surveys.

For possible projects at CHIS please contact:

David Kushner, Park Dive Officer - [\(david\\_kushner@nps.gov\)](mailto:david_kushner@nps.gov) (805) 658-5773  
Park Offices: (805) 658-5730

**Crater Lake National Park (CRLA)** is located in southern Oregon. The lake is 1,943 ft. deep at its deepest point which makes it the deepest lake in the United States, the second deepest in North America and the ninth deepest in the world.

For possible projects at CRLA please contact:

Mark Buktenica, Park Dive Officer - [\(mark\\_buktenica@nps.gov\)](mailto:mark_buktenica@nps.gov) (541) 594-3077  
Park Offices: (541) 594-3100

**Death Valley National (DEVA)** is located east of the Sierra Nevada in the arid Great Basin of the United States. The only diving is a very limited access to Devil's Hole pupfish (*Cyprinodon diabolis*), the last known surviving fish species of what is thought to have been a large ecosystem that lived in Lake Manly, which dried up at the end of the last ice age leaving the present day Death Valley in California.

For possible projects please at DEVA contact:

Bailey Gaines, Park Dive Officer - [\(bailey\\_gaines@nps.gov\)](mailto:bailey_gaines@nps.gov)  
Park Offices: (760) 786-3200

**Kalaupapa National Historical Park (KALA)** is located on the Island of Molokai, Hawaii. Kalaupapa cannot be reached by automobile. No roads lead to the park because of the surrounding ocean and steep cliffs. The park can be reached by air from Oahu, Maui and Ho'olehua, Moloka'i located topside. Flights to Kalaupapa Airport (LUP) can be arranged through Pacific Wings, Moloka'i Air Shuttle and Paragon Air.

Some of the natural and cultural resources in the park include rugged lava boulder habitat with coral reef communities, the highest fish biomass levels found in the Pacific parks, and submerged cultural resources such as the wreck of a 1936 freighter found in 12ft of water.

KALA dive program capabilities include an onsite air compressor with 20 tanks and enough weights to support 4 divers. KALA also have a 19ft and 22ft Boston Whaler with 3 full-time marine staff to support diving projects.

Projects being conducted in the park include monitoring of the benthic communities, fish assemblages, and water quality characteristics/nutrient studies for the cesspool upgrade, examining near-shore oceanographic characteristics, surveys in support of the harbor improvement project, and supporting outside research projects such as the UH-Hilo herbivore study.

Research projects that would benefit KALA include:

- Current studies to document the flow regime around the park

- Examining movement patterns of large, apex predators

For possible projects at KALA please contact:

Eric Brown, Park Dive Officer - [eric\\_brown@nps.gov](mailto:eric_brown@nps.gov) (808) 567-6802, x1502  
Park Offices: (808) 567-6802

**Lake Mead National Recreation Area (LAME)** is located in southeastern Nevada and northwestern Arizona.

For possible projects at LAME please contact:

Marc Burt, Park Dive Officer - [marc\\_burt@nps.gov](mailto:marc_burt@nps.gov) (928) 767-3401  
Park Offices: (702) 293-8990

**National Park of American Samoa (NPSA)** is located in the South Pacific Ocean about 2,298 miles southwest of Honolulu and 2,220 miles northeast of New Zealand. NPSA is really 'three parks' on three separate islands--Ta'u, Ofu, and Tutuila.

NPSA contains the greatest coral reef biodiversity in the National Park System, with over 250 coral species, 1,100 species of marine fishes and local populations of hawksbill and green sea turtles. The Samoan archipelago is a calving ground to the less studied populations of Southern Humpback and Sperm whales. Unique to Ofu Island is an atypical coral population that has developed a natural protection against temperature gradient stresses. This unique population is being investigated to help understand how coral populations may be resistant to global warming (Smith et al., 2008; Oliver and Palumbi, 2010).

The NPSA dive team's primary responsibilities involve inventory and monitoring of marine resources. The dive team maintains six vessels including one 30ft, one 25ft, two 14ft and one 10ft vessel. The staff maintains three air compressors and one Nitrox membrane compressor, thirty scuba cylinders, two DPV's and multiple sets of "loaner gear". With advance notice and NPS approval staff divers can support research projects with mixed gas and rebreather diving.

Currently staff research includes a Humphead wrasse (*Cheilinus undulatus*) tracking project and water quality sampling project. Recent outside research has been conducted on ocean acidification, coral bleaching, coral tumor monitoring, the effects of waste water run off on coral populations and marine sponge distribution.

Research projects that would benefit NPSA are:

- Ocean currents and larval transport mechanisms
- Archipelago fish population dynamics
- Life history of reef fishes

For possible projects please contact:

Jim Nimz, Park Dive Officer - [jim\\_nimz@nps.gov](mailto:jim_nimz@nps.gov) (684) 633-7082 ext. 43  
Sean Eagan, Cultural & Natural Resources - [sean\\_eagan@nps.gov](mailto:sean_eagan@nps.gov) (684) 633-7082 Ext. 40  
Tim Clark, Marine Resources - [tim\\_clark@nps.gov](mailto:tim_clark@nps.gov) (684) 633-7082 ext. 41

**Olympic National Park (OLYM)** is located in Washington State on the Olympic Peninsula. The park can be divided into four basic regions: the Pacific coastline, alpine areas, the west side temperate rainforest and the forests of the drier east side. The coastal portion of the park is a rugged, sandy beach along with a strip of adjacent forest. It is 73 miles long but just a few miles wide, with native communities at the mouths of two rivers. The beach has unbroken stretches of wilderness ranging from 10 to 20 miles. While some beaches are primarily sand, others are covered with heavy rock and very large boulders. The Elwha Ecosystem Restoration Project is the second largest ecosystem restoration project in the history of the National Park Service after the Everglades restoration. The primary purpose of this project is to restore anadromous stocks of Pacific Salmon and Steelhead to the Elwha River.

For possible projects at OLYM please contact:

Mark O'Neill, Park Dive Officer – [\(mark\\_o'neill@nps.gov\)](mailto:mark_o'neill@nps.gov) (360) 374-5460  
Park Offices: (360) 565-3130

**WWII Valor in the Pacific (USAR)** is a United States National Monument honoring several aspects of American engagement in World War II. It encompasses 9 sites in 3 states totaling 6,310 acres (2,550 ha).

Hawaii: USS Arizona Memorial and Visitor Center, USS Utah Memorial, USS Oklahoma Memorial, Six Chief Petty Officer Bungalows on Ford Island, Mooring Quays F6, F7, and F8, which formed part of Battleship Row

Alaska: Battlefield remnants on Attu Island, Japanese occupation site on Kiska Island, Crash site of a B-24D Liberator bomber on Atka Island.

California: Tule Lake Segregation Center. Due to these sites being considered national monuments honoring deceased Americans, diving is very restricted and permitting to do any cultural and/or natural research is very limited. Permitting often requires extensive investigation and applications.

For possible projects at USAR please contact:

Scott Pawlowski, Park Dive Officer - [\(scott\\_pawlowski@nps.gov\)](mailto:scott_pawlowski@nps.gov) (808) 423-7300 x7300  
Park Offices: (808) 423-7300

**War in the Pacific National Historical Park (WAPA)**, WAPA is comprised of multiple protected areas on the islands of Guam and Saipan. Guam is located in the western Pacific Ocean. It is one of five US territories with an established civilian government. WAPA's divers provide continual monitoring of surrounding coral reefs and fish populations.

For possible projects at WAPA please contact:

Justin Mills, Park Dive Officer – [\(justin\\_s\\_mills@nps.gov\)](mailto:justin_s_mills@nps.gov), (671) 477-7278 x1012  
Park Offices: (671) 477-7278

**Biscayne National Park (BISC)** is located in southern Florida, due east of Homestead. The park preserves Biscayne Bay, one of the top scuba diving areas in the United States. The park covers 172,971 acres. Ninety-five percent of which is water. In addition, the shore of the bay is the location of an extensive mangrove forest. Biscayne National Park is the largest Marine Park in the National Park System. Biscayne National Park is noted for many features, including the blue waters of the bay itself, extensive coral reefs, fish and other marine animals, many different varieties of sea birds, subtropical vegetation, and trails on the islands and the mainland. This park, only 30 miles from downtown Miami, contains the longest undeveloped shoreline on Florida's east coast. There is great

need to develop population dynamics models and conduct fishery-independent surveys for these resources.

For possible projects at BISC please contact:

Shelby Moneysmith, Park Dive Officer – [Shelby\\_moneysmith@nps.gov](mailto:Shelby_moneysmith@nps.gov) (305) 230-1144 x3009  
Park Offices: (305) 230-1144

**Buck Island Reef National Monument (BUIS)** is a small, uninhabited, 176 acre (712,000 m<sup>2</sup>) island about 1.5 miles (2.4 km) north of the northeast coast of Saint Croix, U.S. Virgin Islands. Buck Island Reef National Monument was established by Presidential proclamation in 1961, and expanded in 2001, in order to preserve "one of the finest marine gardens in the Caribbean Sea." The park is now one of only a few fully marine protected areas in the National Park System. The 176-acre island and surrounding coral reef ecosystem support a large variety of native flora and fauna, including several endangered and threatened species such as hawksbill turtles and brown pelicans. The Elkhorn coral barrier reef that surrounds two-thirds of the island has extraordinary coral formations, deep grottos, abundant reef fishes, sea fans and gorgonians.

For possible projects at BUIS please contact:

Ian Lundgren, Park Dive Officer – [ian\\_lundgren@nps.gov](mailto:ian_lundgren@nps.gov) (340) 773-1460 x236  
Park Offices: (340) 773-1460

**Dry Tortugas National Park (DRTO)** Almost 70 miles west of Key West lies a cluster of seven islands, composed of coral reefs and sand, called the Dry Tortugas. Along with the surrounding shoals and waters, they make up Dry Tortugas National Park. The park is accessible only by seaplane or boat. Ferries leave from Key West. Monitoring for the coral reef fish assessment project, which includes game species, is conducted every two years in collaboration with an interagency Florida Keys reef fish assessment project. The goal of the coral monitoring and assessment project is to evaluate the ecological status of the common and rare reef coral communities in the park through annual monitoring. Dry Tortugas National Park offers unique opportunities for research and scholarship. Modern scientific research in the Tortugas dates back to the late nineteenth century. Geographic isolation and a long history of resource protection continue to provide opportunities to study tropical marine ecosystems in the park.

For possible projects at DRTO please contact:

Clay Douglas, Park Dive Officer – [clay\\_douglas@nps.gov](mailto:clay_douglas@nps.gov) (303) 215-4767  
Park Offices: (305) 242-7700

**Everglades National Park (EVER)** was first created to protect a fragile ecosystem. The Everglades are a network of wetlands and forests fed by a river flowing .25 miles per day out of Lake Okeechobee, southwest into Florida Bay. Everglades National Park is home to 36 threatened or protected species including the Florida panther, the American crocodile, and the West Indian manatee and 300 species of fresh and saltwater fish. Freshwater sloughs are perhaps the most common ecosystem associated with Everglades National Park. These drainage channels are characterized by low-lying areas covered in fresh water, flowing at an almost imperceptible rate of 100 feet per day. The largest body of water within the park is Florida Bay, which extends from the mangrove swamps of the mainland's southern tip to the Florida Keys. Over 800 square miles of marine ecosystem lies in the park range. Coral, sponges, and seagrasses serve as shelter and food for crustaceans and mollusks, which in turn are the primary food source for larger marine animals. Sharks, stingrays, and barracudas also live in this ecosystem, as do larger species of fish that attract sport fishing.

For possible projects at EVER please contact:

Clay Douglas, Park Dive Officer – [clay\\_douglas@nps.gov](mailto:clay_douglas@nps.gov) (303) 215-4767

Park Offices: (305) 242-7700

**Gulf Islands National Seashore (GUIS)** is a wild 150-mile stretch of barrier islands and coastal mainland in Mississippi and Florida. The warm waters of the Gulf of Mexico nourish 11 separate units that include bayou, salt marsh, live oak and southern magnolia forest, and snow-white beaches.

For possible projects at GUIS please contact:

Matthew Johnson, Park Dive Officer – [matthew\\_w.johnson@nps.gov](mailto:matthew_w.johnson@nps.gov) (228) 230-4139

Park Offices: (850) 934-2600

**Virgin Islands National Park (VIIS)** comprises about 58% (14 square miles) of St. John Island, with 5050 acres to adjacent marine parks. St. John is one of the U.S. Virgin Islands located 990 miles SSW of Miami in the Lesser Antilles, Caribbean Sea. It is an unincorporated territory of the United States. Natural/cultural resources which would interest outside aquatic researchers include coral reefs, seagrass, algal plain and mangrove habitat, coral reef fishes, invasive lionfish, historical shipwrecks, near shore and nearly submerged burials of enslaved people, as well as protection of Acroporid (Elkhorn and staghorn) corals (ESA Threatened species).

VIIS is a small and taxed program with myriad duties. Minimal vessel support and minor logistical support may be possible with sufficient lead time.

Recently outside researchers have been studying benthic habitat and characterization, comparative study of fisheries between territorial and park protected waters, ongoing monitoring of Elkhorn coral populations, reef damage mitigation efforts, long term coral reef monitoring, effects and control of invasive lionfish populations, protection and preservation of historical shipwrecks and protection of near shore and nearly submerged burials of enslaved people.

Some issues which VIIS warrants further studies include;

- Determine the impacts of local stressors: anchor damage, runoff from development of park “inholdings”, contaminants from upland watersheds, and release of sewage may increase the vulnerability of corals to bleaching and disease
- Determine effects of contaminants and poor water quality on park resources
- Determine the status of threatened coral species and use the NOAA *Acropora* Recovery Plan as a guide for further actions to help promote recovery of these species
- Determine links/connections among the NPS units in the Virgin Islands, and their links to upstream and downstream Marine Protected Areas
- Investigation of Hurricane Hole mangrove ecosystems: determine if the high coral and sponge diversity in H. Hole is unique in the Caribbean and therefore greater protection is warranted
- Support research on corals (particularly framework-building reef corals) that survived the massive bleaching in 2005 and subsequent disease outbreak (determine genotypes and genotypic diversity on park reefs)
- Further investigate lionfish control measures and impacts

For possible projects at VIIS please contact:

Thomas Kelley, Park Dive Officer – [Thomas\\_kelley@nps.gov](mailto:Thomas_kelley@nps.gov) (340) 693-8950 ext 225..  
Rafe Boulon Chief RM (340) 693-8950 ext 224,  
Jeff Miller, Fisheries Biologist (340) 693-8950 ext 227,  
Ken Wild, Cultural RM/Archeologist (340) 693-8950 ext 223,  
Park Offices: (340) 776 6201

**Delaware Water Gap National Recreation (DEWA)** is an area preserves almost 70,000 acres (28,000 ha) of land along the Delaware River's New Jersey and Pennsylvania shores, stretching from the Delaware Water Gap northward almost to the New York state line. Middle Delaware National Scenic River is a designated 40-mile section of the river entirely within the recreation area.

For possible projects at DEWA please contact:  
Mike Croll, Park Dive Officer – [michael\\_croll@nps.gov](mailto:michael_croll@nps.gov) (570) 426-2470  
Park Offices: (570) 588-2435

**Saint Croix National Scenic Riverway** is a federally protected system of river ways located in eastern Minnesota and northwestern Wisconsin. It protects 252 miles of river, including the St. Croix River (on the Wisconsin/Minnesota border), and the Namekagon River (in Wisconsin), as well as adjacent land along the rivers.

For possible projects please contact:  
Byron Karns, Park Dive Officer – [byron\\_karns@nps.gov](mailto:byron_karns@nps.gov) (715) 483-2281  
Park Offices: (715) 483-3284

**Isle Royale National Park (ISRO)** is located In Lake Superior about 20 miles west of the NE tip of Minnesota, headquartered out of Houghton, MI. ISRO consists of the main Island, about 450 surrounding islands, and Lake Superior waters and bottom lands extending 4.5 miles out from the park land areas. The Lake Superior waters and bottom lands total about 438,000 acres, ranging from the shoreline to several hundred feet deep. The main Island is about 45 miles long by 9 miles wide at the widest point, and includes several inland lakes which have been cut off from Lake Superior waters for about 5000 years.

Natural/cultural resources consist of shipwrecks, the possible remnants of past use by Native Americans, underwater sites associated with historical, cultural, and archaeological land sites. Fresh water mussels at Isle Royale occur at densities not seen since pre-settlement. Inland lakes include endemic species that have been isolated for about 5000 years. Isle Royale has aquatic invasive species concerns.

Logistical capabilities of the park include boats, air/NITROX compressor, support staff, and logistical support might be made available based on availability and whether the research meets park needs and priorities. The compressor on-island is capable of mixing nitrox.

Most of the scientific diving being done in the park on a regular basis consists of assessment and monitoring of shipwrecks representing 70 years of Lake Superior maritime history. In 1999 the NPS partnered with USGS to survey our inland lakes for freshwater mussels. (USGS divers were amazed at the density of freshwater mussels, and also found sponges larger than previously encountered). Currently the park is working with Great Lakes Shipwreck Preservation Society on a study to assess the bottom of a bay for remnants of Native American occupation and use.

ISRO has an interest in the gathering of research data pertaining to:

- Baseline for studies of atmospheric deposition
- Biogeochemical controls on mercury cycling
- Studies of food web theory
- Study of climate change impacts on biogeochemistry

For possible projects at ISRO please contact:

Steve Martin, Park Dive Officer - [steve\\_a\\_martin@nps.gov](mailto:steve_a_martin@nps.gov) (906) 487-7175

Natural Resources Chief, Paul Brown - [paul\\_brown@nps.gov](mailto:paul_brown@nps.gov) (906) 487-7154

Cultural Resources Program Manager, Seth DePasqual - [seth\\_c\\_depasqual@nps.gov](mailto:seth_c_depasqual@nps.gov) (906) 487-7146

**Sleeping Bear Dunes National Lakeshore (SLBE)** is located in northern lower Michigan, near Traverse City, MI. The park encompasses 10 inland lakes, two rivers and has over 30 miles of Lake Michigan Shoreline in addition to the two Manitou Islands.

SLBE works in collaboration with University of Wisconsin-Milwaukee/NPS directed research on aquatic invasive species such as zebra mussel and round gobies, proliferation of *Cladophora* algae, as well as monitoring the underwater scientific equipment.

Facilities are available for housing and support of diving operations in the park. With advanced notice SLBE has a large 42ft landing vessel that is an excellent support craft during the research dives and the shipwreck dives in Lake Michigan.

Diving activities are normally accomplished between the months of May and November.

For possible projects at SLBE please contact:

Chris Johnson, Park Dive Officer - [chris\\_b\\_johnson@nps.gov](mailto:chris_b_johnson@nps.gov) (231) 334-3756

Mike Duwe, Chief of Natural Resources - [Michael\\_duwe@nps.gov](mailto:Michael_duwe@nps.gov) (231) 236-5135

Laura Quackenbush, Cultural Resources - [Laura\\_Quackenbush@nps.gov](mailto:Laura_Quackenbush@nps.gov) (231) 236-5134

**Submerged Resources Center (SRC)** Working with park staff and other agencies, the SRC's mission is to inventory and evaluate submerged resources throughout the national park system. Projects the SRC has been involved in include work on USS Arizona, the shipwrecks of Isle Royale National Park, mapping the shipwrecks of Dry Tortugas National Park, and many others.

For possible projects please contact:

Brett Seymour, SRC Dive Officer – [brett\\_seymour@nps.gov](mailto:brett_seymour@nps.gov) (303) 969-2993

## Discussion

With an increasing awareness of climate change and public concern of submerged cultural resource, the National Park Service dive program has been increasing in budget and commitment to assist outside researchers. The National Park Service encourages scientific resource investigation into our countries protected resources. Many of these resources have been protected from human encroachment and facilitate a near baseline experimental platform from which changing environments can be evaluated. The natural and cultural resources belong to the people of the United States and should be used for the benefit of our citizens. The knowledge achieved through resource investigation

can benefit our entire US population. We at the National Park Service encourage researchers to contact their local parks or parks of interest and pursue research to improve the knowledge and facilitate the conservation of resources for future generations.

### Acknowledgments

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## Alcohol and Diving

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### Abstract

Alcohol is a known hazard for its impairment of physical and cognitive performance. While its use is generally accepted as incompatible with diving activity, written policies vary substantially among institutions. In this study we examined the available policies for eleven organizations in the US and abroad. Manuals available online were used, while for large organizations (e.g. NOAA) they were solicited directly. Where no written standards exist, it is possible that policy makers rationalize the issue as being adequately self-regulated or too difficult to regulate. These positions are untenable since the available literature implicates alcohol as a contributing factor in numerous diving incidents. The written policies we reviewed were found reflect one or more of the following elements: evaluation of diver history with alcohol, specific proscription and punitive actions, monitoring requirements and, less commonly, preventative and educational initiatives. We recommend that best practices for the scientific diving community should include specific direction on each of these elements, in addition to reinforcing a culture to separate alcohol from diving activities.

Keywords: alcohol, alcohol consumption policy, diving

### Introduction

#### *History of Study*

Alcohol is known to impair judgment and physical performance. Problematically, the slow rate of metabolism and elimination in humans, on the order of  $9.0 \text{ g} \cdot \text{h}^{-1}$  ( $0.3 \text{ oz} \cdot \text{h}^{-1}$ ) of pure alcohol, depending on size, can produce prolonged effects. Alcohol consumption has long been at least tacitly discouraged in conjunction with diving activity. Alcohol acts as a central nervous system depressant, slowing response time and compromising performance in complex situations, such as many emergent events. Alcohol may also play a role in diving situations by potentiating narcosis (Jones et al., 1979; Fowler et al., 1986; Hobbs, 2008). Increases have been reported in nystagmus-induced disorientation (Hamilton et al., 1989) as well as motor and general vision impairment (Howland and Hingson, 1988). Alcohol has also been found to alter the diving reflex, specifically inhibiting nominal heart rate decreases and altering autonomic nervous system response (Wittmers et al., 1987). Pilot research has suggested that individuals who respond strongly to alcohol may also be more susceptible to narcosis (Monteiro et al., 1996). It is unclear how to interpret a study of commercial, saturation divers in which regular consumers of alcohol were found to have more normal electroencephalograms than their non-drinking counterparts (Todnem et al., 1991).

The influence of alcohol on decompression safety is complicated and incompletely understood. Certainly, impaired decision-making and/or inattentiveness could increase the risk or slow proper

response through the masking of symptoms. A pattern of drinking that produces a relative dehydration could also theoretically increase the risk of decompression sickness (DCS), although the magnitude of this hazard remains unclear. Pattern of alcohol use has not been shown to be associated with DCS risk in limited retrospective self-reported data (Dowse et al., 2002, Hagberg and Ormhagen, 2003; Trevett et al., 2003). Even more controversial is an animal study that reported a therapeutic benefit of ethanol treatment post-dive (Zhang et al., 1989). In this case, rabbits were exposed to a pathological decompression from 6 ATA to 1 ATA. The untreated group suffered 50% mortality within 15-35 minutes of surfacing. The experimental group receiving 25% ethanol intravenously upon surfacing had no mortality. An unconfirmed report by the same authors claimed a similar benefit in human divers (Zhang et al., 1991). An attempt to validate these effects through a controlled chamber study of humans found no impact of post-dive alcohol ingestion on bubble formation (Eckenhoff and Olstad, 1991).

While the possible biochemical interaction between alcohol and decompression stress warrants further investigation, such work must be approached carefully. The line of investigation of Zhang et al. (1989) certainly drew rapid and critical comment (Eckenhoff, 1989). Most importantly, any research on biochemical effects should not detract from the primary concerns of impaired decision-making and diminished physical performance that can undoubtedly create great overall risk to the compromised diver.

#### ***Need for an alcohol policy for diving***

Given the known negative effects of alcohol, there is cause for concern on the part of the dive supervisor if a diver has been drinking. Based on recreational dive community surveys, alcohol is often consumed within temporal proximity to diving activity (Dowse et al., 2002; Trevett et al., 2003). While the impact on diving operations is typically unknown, studies in other fields of physical activity have identified problems. One recreation-based study found that alcohol was a factor in various sports injuries (Schmitt and Gerner, 2001). The mortality rate in general of alcoholics is between 2.5 and 8-fold greater than non-drinker baseline risks (Smith and Kraus, 1988). Alcohol is often a factor in recreational near-drowning incidents. There is a dearth of alcohol-related data collected post-incident in the occupational setting (Smith and Kraus, 1988).

Some governmental organizations have experienced fatalities in diving programs which have prompted examination of alcohol policies. Examples include National Oceanic and Atmospheric Administration (NOAA) following an incident in the Dry Tortugas (NOAA, 2008) and the US Coast Guard following an incident on the *m/v Healy* in Alaska (USCG, 2007).

#### ***Range of Possible Policy Positions***

Diving program requirements must cover a range of exigencies. For alcohol and diving, there are a range of issues that can be considered, including:

1. history of alcohol use/abuse (related or unrelated to diving) as a predictor of future problems;
2. impairment window, timing over which consumption of alcohol could affect the diver or dive operations;
3. monitoring procedures to identify signs of alcohol use by personnel; and
4. strategies to develop a culture that limits alcohol use.

## **Methods**

The published safety manuals for organizations with scientific diving programs were reviewed from September to December 2011 for the presence or absence of alcohol-related policies specifically

pertaining to diving activity. This review was conducted in an opportunistic fashion for organizations recognized as setting industry standards, such as the American Academy of Underwater Sciences (AAUS, 2011) and the Association of Diving Contractors International (ADCI, 2011), those with large diving programs such as NOAA, and those discovered through professional contacts to have written policies. Four primary areas were evaluated:

1. diver history inquiry (e.g., written responses to a medical questionnaire);
2. dive policy with respect to impairment discovered on the dive platform;
3. random testing requirements; and
4. preventative measures.

If alcohol policies were conjoined with other drug-related policies both are presented.

## Results

The organizations for which written policies were reviewed are listed in Table 1.

Table 1. Survey of Dive Program Policy

Organization	Alcohol consumption query on medical questionnaire	Written policy addressing worksite impairment	Written policy for random testing	Preventative Standards
EPA	X			
NOAA	X	X	X	X
AAUS	X			
CRA-DFG	X			X
ADCI	X	X	X	
USN				
U Queensland				X
Reef Check Aust				X
U West Aust	X			X
DOI	X		X	
USCG	X			

EPA - US Environmental Protection Agency; NOAA - US National Oceanic and Atmospheric Administration; AAUS - American Academy of Underwater Sciences; CRA-DFG - California Resources Agency and Department of Fish and Game; ADCI - Association of Diving Contractors International; USN - US Navy; U Queensland - University of Queensland; Reef Check Aust - Reef Check Australia; U West Aust - University of Western Australia; DOI - US Department of the Interior (including National Park Service [NPS], US Geological Survey [USGS], and US Fish and Wildlife [USFW]); and USCG - US Coast Guard. All manuals and publication dates are cited in the reference section of this paper.

### ***Existing Dive Policies on Alcohol Consumption***

AAUS has long been recognized as the primary standard setting organization for scientific diving in the US. AAUS standards include some medical questionnaire coverage on alcohol consumption patterns, but do not address other items such as onsite screening, testing, or preventative standards (AAUS, 2011):

Conditions Which May Disqualify Candidates from Diving (adapted from Bove, 1998)  
" Substance abuse, including alcohol."

Appendix 3

Diving Medical History Form  
(To Be Completed By Applicant-Diver)

"5. Substance abuse, including alcohol.      Yes      No"

AAUS members have the option of adopting the standard text or replacing text detailing different institutional standards. It is noted that many AAUS organizational members surveyed adopted the standard AAUS text noted above. AAUS organizational member standards were not included in this paper unless their approach differed from the AAUS 2011 standards. It is noted that the presentation of the "substance abuse" question on the AAUS medical questionnaire leaves an individual diver to qualitatively assess the normalcy of their personal alcohol consumption rate. It is highly unlikely that this qualitative self-report would produce consistent results in identifying potential problems.

The NOAA dive program is the largest civilian diving organization within the US federal government, and includes both scientific and working dives. NOAA's scientific diving training and certification standards requirements directive introduced a program of random drug and alcohol testing (NOAA, 2011a). This was the most comprehensive program encountered amongst the diving organizations surveyed. For NOAA working divers, the NOAA Working Diving Standards and Safety Manual (NOAA, 2011b) required drug and alcohol testing as well:

"D. A verified positive drug test for any employees for which diving is not included in their position descriptions will result in denial of initial diving certification or, if already certified to dive, termination of NOAA diving privileges.

E. Specific information on the drug testing program is outlined in the US Department of Commerce (DOC) Drug-Free Workplace Plan and the DOC Drug and Alcohol-Free Workplace Testing Guide; both can be downloaded at [hr.commerce.gov](http://hr.commerce.gov)."

The NOAA Working Diving Standards and Safety Manual (NOAA, 2011b) also includes prohibitions to avoid dive site impairment:

3.6.2 Temporary Suspension.

"8) Reporting to the dive station mentally or physically impaired due to alcohol or other substance abuse;"

5.2.6 Fitness to Dive.

"C. Divers exhibiting any effects of alcohol or substance abuse shall not be permitted to dive and will have their diving certification temporarily suspended or permanently revoked from diving pending review by the NDCSB."

Beyond consequence-related policy, NOAA (2011b) has policy to prevent impairment on the project site:

5.2.6 Fitness to Dive.

"B. Divers should refrain from alcohol consumption for a minimum of 12 hours prior to diving..."

US Federal agencies, including NOAA, EPA (EPA, 2010) and Geological Survey (USGS, 2008), require divers to complete a medical history on a yearly basis. The approach is semi-quantitative, reducing the respondent's need to make a judgment regarding abuse (NOAA, 2012):

"Drink alcoholic beverages (how much) \_\_\_\_\_ Yes/No"

Numerous organizations question divers on alcohol consumption when medicals are performed, at a frequency of two to five years for USGS (2011), USFW (2011a;b) and others.

California Resources Agency and Department of Fish and Game (CRA-DFG, 2005) employs a similar approach to NOAA with respect to a preventative standard:

2.33 Diving Under the Influence of Drugs or Intoxicants

"Alcoholic beverages will not be consumed eight hours before any dive."

The University of Queensland provides prescriptive rules, guidelines and explanation (University of Queensland, 2010):

8.27 Alcohol

"Alcohol should not be consumed within 12 hours prior to diving, and must not be taken until after any diving for the day is over. At all times, especially when diving over multiple days, alcohol should only be consumed in moderation, if at all. Alcohol consumption will increase a diver's susceptibility to decompression illness, enhance the effects of inert gas narcosis, and increase a diver's rate of heat loss in cold water."

Reef Check Australia (RCA, 2010) and the University of Western Australia (UWA, 2010) both prohibit alcohol ingestion 12 hours prior to diving. The University of Western Australia safety manual incorporated the following recommendations (UWA, 2010):

"The dive tables and computers are to be used even more conservatively if the diver is subject to conditions which increase the possibility of decompression illness (i.e., dehydration, alcohol consumption, age, excessive fat tissue, injury, tiredness or strenuous exercise before, during or immediately after a dive)."

The US Navy diving manual (USN, 2008) includes the following explanatory text regarding alcohol:

3-10.4.4 Prevention of Hyperthermia

"... Adequate predive hydration is essential. Alcohol or caffeine beverages should be avoided since they can produce dehydration."

11-5.1 General Precautions for Ice and Cold Water Operations

"... Dives should be well rested, have a meal high in carbohydrates and proteins, and should not consume alcohol. Alcohol dilates the blood vessels in the skin, thus increasing heat loss."

ADCI is recognized as the standards setting organization in the US for commercial diving. ADCI did not have any alcohol-related policy specifics within their consensus standard, instead noting that member organizations shall have a policy with respect to alcohol and drugs (ADCI, 2011):

### 2.3.6 Disqualifying Conditions

"A person having any of the following conditions, as determined by a physician's examination, shall be disqualified from engaging in diving or other hyperbaric activities.... Chronic alcoholism, drug abuse or history of psychosis."

### 5.3 Drug and Alcohol Screening

- "- A pre-employment drug screening program shall be in place.
- A routine, random and 'for cause' drug screening program shall be in place."

All US Department of Interior (DOI) divers (USGS, National Park Service, etc.) likewise have a random testing policy:

"(2) Take a drug test administered in accordance with 370 DM 792.9 and 792.10 for which a negative drug test is received prior to appointment. Once employed, the diver will be subject to the DOI's random drug testing program." (personal communication, M. Blouin, USGS, 2012).

## Discussion

We reviewed written policies on alcohol and diving from 11 standards-setting diving organizations. Specific policies may not be a priority for organizations conducting the majority of their dive operations on a "dry" (alcohol-free) vessel at sea for weeks at a time, such as the EPA, NOAA and the military. The state of enforced abstinence applies fully to diving activity. Similarly, organizations such as the military may have an umbrella "no alcohol policy" that encompass all on duty activities. Only organizations with specific written diving-targeted prevention policies are discussed here. The effects of unwritten policies or expectations for alcohol consumption were not evaluated. These could range from verbally conveyed "everyone stops drinking when the divemaster does" or informal drink limits or rates of drinking.

Alcohol impairment may be obvious or less so depending on the presentation of the individual and the level of training that the dive site supervisor possesses, making a dive site standard difficult to reliably enforce. A dive partner or supervisor may not be able to discern subtle alcohol impacts in a diver until performance is substantially impaired. Further complicating this issue, rough sea states can obscure a supervisor's ability to evaluate a diver's gait or ability to discriminate between alcoholic impairment and motion sensitivity. Dive supervisors may also be reluctant to take a diver aside for a field neurological exam to look specifically for indicators of inebriation, such as signs of nystagmus, even though such tests take minutes for a practiced administrator and would not be expected to unreasonably delay dive operations (NHTSA, 2011). The odor of alcohol or ketoacidosis indicating incomplete metabolism of alcohol could be missed in a scent-rich or well-ventilated environment. Cultural norms and chain of command issues may make it uncomfortable for a dive supervisor or partner to ask or challenge responses to questions regarding drinking prior to diving raised in a pre-dive briefing.

With respect to medical questionnaires, it is unclear whether the majority of divers in any program have an understanding of what "history of abuse" actually constitutes. Does this refer only to individuals with a medical diagnosis? To those that have undergone treatment? The annual questionnaires of NOAA and EPA, for example, notably avoid this confusion by simply asking the diver how much they consume on a regular basis, then leaving it to the medical professional to interpret. This contrasts the AAUS questionnaire that asks individuals to characterize their

consumption as to whether it constitutes abuse. One might argue that wording the question with "abuse" might encourage a "no" selection whether or not this is accurate.

Liability and risk management are often issues when discussing the ability of a dive organization to meet an industry standard, or when falling short of an industry standard. Part of a good risk management campaign is a significant effort at education of dive professionals and divers (Nimb, 2004). Educational policies with respect to the risks of alcohol and diving were not evidenced in the written dive safety policy of any of the 11 organizations surveyed. Though it can be surmised that what is contained in a diving organization's written policy would be conveyed in an initial training and ongoing education settings, this is among other important issues that could be formalized into a training program. Lastly, given the highly variable nature of alcohol policies among the organizations surveyed worldwide, ostensibly being on the less stringent end of the continuum of written policy and lack of any formal educational process may imply a higher risk of liability, should an accident occur.

The regulation of diver off-duty hours can present substantial difficulties, especially in land-based, non-military operations. This is problematic since it is not uncommon that diving accidents are reported with alcohol being ingested within hours of diving (NOAA 2001; Vann et al., 2006; Pollock et al., 2007; 2008). This runs counter to the call for 12 hours of abstinence that was the most common of any time restriction. No written policy attempted to quantify an acceptable amount of alcohol consumption. The most effective strategy to affect off-hour activities is the establishment of cultural norms decrying alcohol ingestion during the span of diving activities. Prohibition based on example and peer expectation is likely to be important to convey expectations to divers for "unpaid" hours. This should be supported by clearly documented policies.

### ***Recommendations***

Key elements of the written alcohol policies identified in this review included: rules regarding pre- and post-dive consumption, random testing, questions regarding history of drinking, and a written policy on impairment evident at the dive site. Clearly, a "no alcohol" consumption policy aboard research vessels or within working units obviates the need for more detailed policies, however, such inclusive restriction is difficult to enforce for land-based operations which encompass "off-duty" diver time. Clear and specific policies are required to ensure appropriate practice in less controlled circumstances. The obvious missing element in the alcohol policies reviewed was diver education. An awareness of both obvious and less obvious hazards of alcohol and the prolonged window of impairment should be included in initial training and reinforced through operational culture. Reinforcing positive cultural norms may effectively establish expectations regarding alcohol that can encourage peer support of proper behavior.

Written alcohol policies should include the following:

#### **Alcohol consumption prohibitions**

- 1) Pre-dive to avoid systemic effects
- 2) Post-dive to avoid symptom masking

#### **Monitoring practices**

- 1) Periodic assessment of alcohol use patterns  
(for example, at hiring and/or volunteer screening, as part of an annual review with medical/health questionnaire and/or following alcohol-related incident)  
Note: questions should be in quantitative versus qualitative form to allow medical professionals to assess the meaning of the data
- 2) Random testing

#### **Intervention options**

- 1) Counseling

- (including response to monitoring concerns and mandated and voluntary access)
- 2) Punitive actions for violations in prohibition and/or refusal to participate in random testing program
  - (for example, loss of diving privileges, employment suspension and/or termination)
- 3) Restoration of status following punitive action
  - (return to diving requirements such as counseling or treatment programs)

#### **Education**

- 1) Initial diver training (working and scientific) should include discussion of alcohol effects, institutional rules including prohibitions, incident reporting and penalties for violation
- 2) Dive supervisor training should include the topic provided for initial diver training, plus specifics on evaluating divers, incident reporting, and strategies to promote a culture to minimize alcohol-related incidents
- 3) Training updates should include regular reminders to staff (for example, pre-dive briefings, staff memoranda and meetings)

*Disclaimer: This paper is an illustration of steps that diving control boards might take to minimize the risk of injury related to alcohol consumption and is not the official view of the USEPA diving safety board. Mention of any specific brand or model instrument, material, or protocol does not constitute endorsement by the USEPA.*

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## Investigation of Scuba Diving Accidents

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### Abstract

The investigation of scuba diving accident fatalities is not handled in a consistent manner in the USA. Most diving accidents are investigated by law enforcement to rule out criminal activity. Diving accidents that take place within the scientific diving community are usually also investigated by the sponsoring agency's diving safety board. A proper investigation of a diving accident requires a thorough examination of the equipment, interviews with persons who were on the scene, and a reconstruction of the time frame of the events that transpired.

This paper is based upon the book, *Investigating Recreational and Commercial Diving Accidents*, by Steven M. Barsky and Tom Neuman, M.D. (Barsky, S. and Neuman, T. 2003). The book is the result of the two authors' experience dealing with the investigation of diving accidents as well as their work as expert witnesses in diving accident cases. The field investigation of diving accidents is discussed, including the techniques, interview methods, photographic and video documentation, and creation of an accurate chronology. The elements of a complete report are also included. Although scientific diving accidents are not addressed in the title of the book, due to the low number of accidents that occur, the subject is addressed in the book and will be discussed in this paper.

Keywords: scuba accident investigation, scuba diving fatality, underwater forensics

### Introduction

Scuba diving accidents are dramatic events that are always the subject of intense speculation whenever they occur. In the sport diving realm, the number of fatal diving accidents that occur in most recent years hovers around 100 accidents per year, based upon fatality statistics from the Divers Alert Network (DAN) (Pollock, 2008). The number of scientific diving accidents is small, likely due to the more extensive training that scientific divers receive, their annual medical screening, the structured system in which they dive, and the fact that there are simply fewer individuals who participate in scientific diving than recreational diving. In DAN's Project Dive Exploration study in 2006, out of 937 divers who collected data on their dive profiles, only 5 were identified as scientific divers (Pollock, 2008).

In 2005, with 90 organizational AAUS members reporting the diving of 3,984 divers, they completed a total of 124,722 dives with only five pressure related diving accidents, including decompression illness, sinus/ear barotraumas, lung over-expansion accidents, etc. (Dardeau & McDonald, 2007). This is a relatively high number of dives per person (31 dives/person) per year, compared to the sport diving realm where an estimated "core group" of 840,000 "active" divers makes 8 or more dives a year, out of an estimated population of 2,866,000 divers (SGMA, 2012). Scientific diving statistics are far more complete than recreational diving statistics, where it is unknown exactly how many divers there are participating in the sport, or how many dives they actually make annually. The SGMA defines a scuba diver as a person who participates in the sport once a year (SGMA, 2012).

The annual number of scientific diving accidents is very low, usually one or none a year. For example, in 2007 there was only one incident (Nixon, 2010) and the same holds true for 2008 (Roy, 2008) as well as 2009 (Nixon, 2010).



Figure 1. There are approximately 100 recreational diving fatalities each year in the U.S., but commonly only one or no scientific diving fatalities in any given year. (© S. Barsky. All rights reserved.)

When a fatal diving accident does occur, there will always be a police investigation, as well as an investigation by the U.S. Coast Guard, if the incident took place in offshore waters. If the dive took place as part of instruction or an organized dive, the insurance company who provides the diving officer's liability insurance will also investigate the incident. For a dive that took place under the auspices of an AAUS affiliated organization, the dive control board will usually conduct its own inquiry. Investigators working for different organizations will always have differences in the way they approach their inquiry.

## Methods

The proper investigation of a diving accident requires an experienced investigator who has the skills required to determine what took place in an atmosphere that will be fraught with emotion. The skills required to perform this type of work are somewhat like those needed by a scientist who is conducting an experiment, or those of the investigative journalist, but they go beyond that.

In most academic settings, the task of investigating a diving accident that took place under the organization's auspices will probably fall to the Diving Safety Officer (DSO) unless they were directly involved in the incident.

### ***Skill Set for Diving Accident investigators***

To be an effective diving accident investigator, a person must possess the following skills and characteristics:

- **Extensive knowledge of diving equipment, underwater environment, and diving procedures**

Diving accident investigators must be familiar with both current and older diving equipment. It is impossible to know how to operate every type of gear on the market, but investigators must have sufficient knowledge to identify common gear and know where to get information on unfamiliar equipment.

- **Excellent interpersonal skills**

Conducting a diving accident investigation primarily involves the ability to effectively interact with people who have been traumatized by the events they have witnessed. The individuals who were directly involved in the accident will have to live with the consequences for the rest of their lives. During an interview, you will be asking the individual whom you are working with to relive the accident, which is usually a very disturbing event for most people.

- **Ability to think logically**

A good diving accident investigator is able to sort out those items that were important to the chain of events from those issues that were unimportant. Investigators need to be able to explain the “why” of how a particular event took place.

- **Video/photographic skills**

Almost all investigations will require photographic (and/or video) records of the diver’s equipment. The ability to produce properly exposed, sharp, detailed photographs requires more than just owning the equipment. The investigator must also be able to use the equipment properly to obtain the best results.

- **Ability to think on one’s feet**

During the course of a dive accident investigation, it’s not uncommon to discover new information that may not have been previously known. When new information becomes available, it may shift the focus of the investigation and take the investigator in a new direction.

- **Tenacity**

A good diving accident investigator is tenacious. They follow up on every piece of information to ensure that there is nothing that might be relevant to the case that is overlooked.

- **Discretion**

Divers are naturally curious whenever there is a diving accident and will want to discuss these events with other divers whether in person, or on the Internet. They will often speculate or pass judgment about the actions of the people involved, the dive operation, and the equipment. The prudent dive accident investigator will avoid commenting or discussing the incident with anyone who does not have a direct “need-to-know” about what took place.

- **Organizational skills**

To be a good diving accident investigator, you must be highly organized and capable of keeping track of all of the different elements of an investigation. Organization will help the investigator to see the links between different aspects of the incident.

- **Writing Ability**

The end product of any investigation is normally a written report on the incident. An investigator’s report should include strictly the facts of what took place – no speculation, no assignment of blame. In many cases, you will never know all of the facts of the case, so any conclusions on the investigator’s part may be pure conjecture that could have serious legal repercussions in the event of litigation.

### ***Equipment***

An investigator will normally need to take a number of items with him for any investigation conducted in the field. These items may include, but are not limited to, the following:

- **Digital Camera**

The camera should be capable of shooting both video and stills at high resolution and in low light. Adequate recording media must also be on hand. Cables or other accessories required to transfer images to a computer for back-up and use in the investigator's report are essential.

- **Checklist**

Developing a checklist of questions and gear to inspect will make any field investigation more efficient and complete.

- **Laptop Computer**

Required for doing Internet research on people, weather conditions, historical tidal flows, etc.

- **Fiberglass Measuring Tape**

A fiberglass tape is essential for taking dimensions on dive boats and at dive sites.

- **Magnifying Glass**

A magnifying glass is invaluable for reading the very small serial numbers often stamped into diving equipment.

- **Chalk**

Chalk can be rubbed into the engraved serial numbers, particularly in black plastic pieces of diving equipment. This will make it much easier to read serial numbers as well as to photograph them.

- **Handheld GPS**

A handheld GPS is vital for determining the precise location of dive sites and geographic features of sites.

- **Oxygen Analyzer**

When nitrox or other gas mixtures are used, an analyzer will be needed to determine the exact gas mixture remaining in the cylinder.

- **Air Sampling Kit**

An air sample may be drawn from any compressed gas cylinders that were used by the victim to check for any contaminants that may be present in the breathing gas. A qualified independent laboratory should analyze the sample. Air sample kits are available from a number of third party laboratories.



Figure 2. A typical air sample kit. (© S. Barsky. All rights reserved.)

Particular care must be taken if air samples are drawn from a cylinder with low air pressure. If low cylinder pressure is known or suspected, it's best to leave gas analysis to law enforcement or insurance investigators, unless these individuals are not conversant with the need to conduct such analysis, or the proper methods for sampling.

### ***Conducting an Investigation***

Conducting the field investigation of a diving accident requires good planning on the part of the investigator, especially if the location where the accident took place is particularly remote. In this situation, it is crucial to ensure that the investigator has taken all of the equipment he will need with him to perform his job. Even if the accident is a local event, the investigator needs to have the correct gear on hand each time he steps out of the office.

Interview questions for each witness should be prepared in advance, based upon any preliminary questions you have about the incident. In interviewing a witness to the accident, the good investigator will maintain a neutral attitude. The fastest way to make a witness uncooperative is to be critical of that individual.

Only one person should be interviewed at a time to avoid "contaminating" a witness with the recollections (which may be incorrect) of others. Realize in advance that there may be discrepancies between individuals in the way they recall the event, depending on their level of involvement as well as their physical proximity to the injured or deceased person at the time of the accident. Unless the investigator is working for law enforcement or an insurance company, it's generally considered best not to record any witness interviews unless the investigator has been specifically direct to do so by their employer.

One of the elements that will help improve the clarity of a report will be the inclusion of charts of the dive site. If the accident involved a vessel, blueprints of the vessel will be extremely helpful.

The cooperation of other agencies that may have responded to the accident will be very helpful, particularly if you are able to get copies of their field reports. These may or may not be available from the police, fire department, park rangers, lifeguards, coroner, or U.S. Coast Guard. If an investigation is conducted outside of the U.S., the assistance of a local interpreter can be priceless in non-English speaking locales.

If the investigation involves the use of closed-circuit apparatus, or surface-supplied gear, with which the investigator is not familiar, the assistance of a qualified diving instructor or other expert in that particular equipment is considered essential. There are few, if any, individuals who have a working knowledge of every type of diving equipment available on the market today.

No disassembly or testing of equipment should ever be done by an investigator working on behalf of an academic institution. Since most diving accidents ultimately result in litigation, the investigator could be accused of spoliation of evidence should they accidentally change or damage the equipment. *Dive gear should only be inspected and photographed, but not tested.*

Keep in mind that defective diving equipment is truly rare, especially equipment produced by a reputable manufacturer. If the equipment is implicated in the accident, it is most likely that it has either been improperly maintained or modified.

Investigators need to collect as much background information on any individual involved in a diving accident as possible, including dive training records, dive logs, and gear maintenance records. Access to medical exam forms is usually limited by HIPPA regulations.

### ***Elements of a Dive Accident Report***

The elements that should be contained in a report include a table of contents, a summary of the incident, a timeline detailing when specific events occurred, individual narratives, a report on the inspection of the dive gear, photographs, charts or drawings of the site, and an index.

Investigators must report only the facts of the case clearly in their report.

## **Discussion**

Dive accident investigation is an unpleasant task, but necessary to identify deficiencies in equipment, training, and procedures. Performing an investigation takes an emotional toll on both the people who were involved in the accident as well as the investigator. The best investigators are those who can combine compassion with critical insights and technical knowledge. While we will never achieve the goal of zero diving accidents, because humans make mistakes, we can reduce the number of diving fatalities through better training, improved procedures, and respect for the risks inherent in diving.

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## Not All are Created Equal: Operational Variability in 49 Models of Diving Computer

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### Abstract

Diving computers marketed in Europe must comply with European Standard EN 13319:2000. Some EU occupational divers employ diving computers to calculate and manage decompression schedules; they have also been used as depth and temperature measurement tools. This on-going study is evaluating and validating the performance of diving computers in relation to realistic operational requirements. Depth measurement and recording from 49 models of diving computer were analysed at pressures of 203 to 608 kPa; temperature measurement was assessed over ranges relevant for polar, temperate and tropical environments. Decompression isopleths for single square-wave profiles were constructed and compared with tables; occurring unit faults were recorded. Depth conversions, temperature measurements and decompression schedules varied markedly between different models of diving computer; units may not conform fully to EN 13319:2000. A total of 49 “faults” of varying seriousness were recorded over a total of 2009 operational hours. Occupational divers need to risk-manage the use of some computers for decompression management and be aware of the potential for battery or unit failure. The accuracy levels of depth and temperature recordings made by diving computers may not be acceptable for some scientific and forensic studies.

Keywords: depth, decompression, diving computers, EN 13319:2000, temperature

### Introduction

Diving computers marketed in Europe must comply with European Standard EN 13319:2000. However, the standard only details the measurement and recording of time and pressure. Some EU occupational divers employ diving computers to calculate and manage decompression schedules; they have also been used as depth and temperature measurement tools. This on-going study is evaluating and validating the performance of diving computers in relation to realistic operational requirements of various diving industry sectors.

### Methods

Forty-nine models of diving computer with download capability were purchased from independent suppliers. The rates and methods of recording and display, and claimed accuracies for each unit were reviewed. Depth measurement and recording were analysed at “depths” equivalent to pressures of 203 to 608 kPa; temperature measurement was assessed over ranges relevant for polar, temperate and tropical environments. Decompression isopleths for single square-wave profiles to maximum depths of 50msw and staged decompressions to maxima of 30 minutes were constructed and compared with tables; occurring unit faults were recorded.

## Results

Data frequency (1-180sec), resolution (0.1-0.5m), recording method (max, min, average, final point) and storage varied greatly between models (Azzopardi and Sayer, 2010). Pressure measurements to displayed depth conversions were markedly inaccurate for some computers (though nearly all read deep); displayed temperatures were highly unreliable. There was wide inter-model variability in permitted bottom times per depth/time profile but, in general, computer-generated values tended to be more conservative than tables at depths shallower than 30m, but less at 30-50m. Battery replacement occurred once every 49h of operation (n=41), a major fault once every 251h (n=8; one was terminal).

### Depth

Diving computers only measure pressure; depth is estimated. EN 13319:2000 only details the levels of accuracy of the pressure and time measurements that diving computers make. Although many computers have freshwater or seawater mode settings, these will be generic values for the two modes and so all computed conversions to “depth” must make some assumption of water density. Very few of the computers gave accurate estimates of depth across the range tested (10-50m); nearly all gave depth estimates that were deeper than the assumed pressure measurement (Figure 1). In some cases, the variance appeared to be relatively standard for certain models and makes of computer, possibly suggesting that the offset was a deliberate design criterion. Pressure is used for decompression calculations; geometric depth may only be relevant for scientific measurement, forensic examinations of dive computers and/or for divers using standard decompression tables.

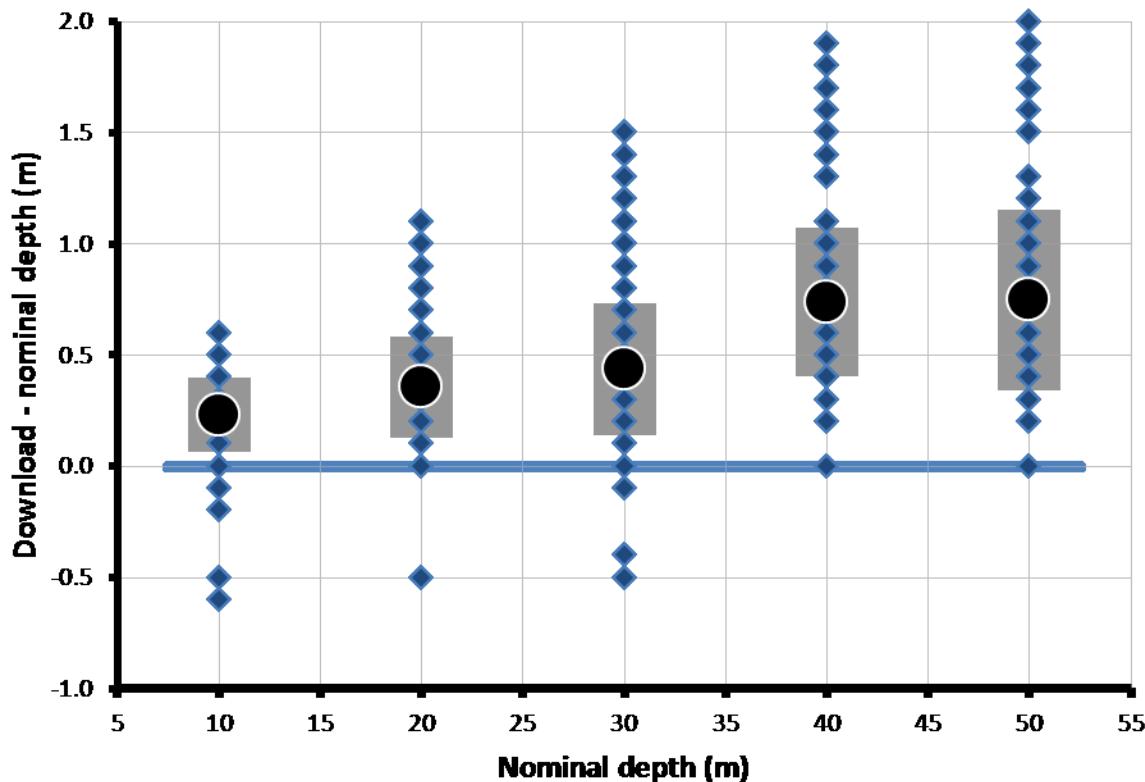


Figure 1. Variance between nominal and downloaded depths in seawater from 46 models of diving computer showing range ♦ and mean •  $\pm$  SD (■; n=276 in each case).

### **Temperature**

EN 13319:2000 does not outline how diving computers must record or display water temperature. Apart from some form of temperature measurement being required to compensate the method for recording pressure, the downloaded or displayed temperatures that a diver can access may be of low priority in the overall design of a diving computer. Direct comparisons of performance were compromised by the marked variation in the methods for displaying and/or downloading temperature information (Azzopardi and Sayer, *in press*). Temperature “measurement” ranged by +4.6/-7.0°C, +1.1/-4.6°C and +3.7/-11.9°C against nominal representative polar, temperate and tropical temperature regimes, respectively (Figure 2). Diving computers are not designed nor intended to be reliable or accurate temperature measurement devices and their use for scientific study should be avoided.

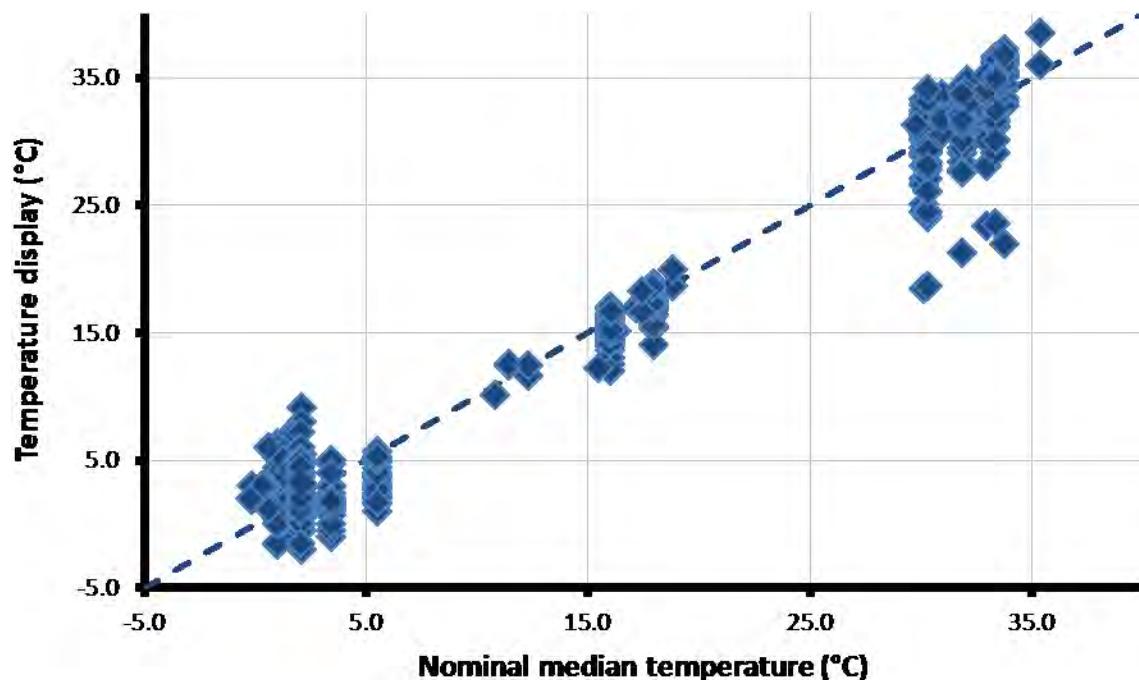


Figure 2. Downloaded temperature records from 47 models of diving computer subjected to temperatures representative of polar (0-5°C), temperate (12-17°C) and tropical (28-33°C) regions (n=800)

### **Decompression**

Any information on decompression obligations displayed by diving computers is explicitly excluded from the scope of EN 13319:2000. Many computers employ established algorithms to manage decompression but the technical literature can state that the algorithms are “modified”. The modification is probably a compromise driven by the size and power limitations of the computer (Sieber et al., 2011). In general, for a single square-wave dive, diving computers were more conservative than tables shallower than 30m but less conservative in the 30-50m depth range. Permitted no-stop bottom times ranged between models of diving computer by 23, 15, 8, 5 and 9 minutes at 15, 20, 30, 40 and 50m, respectively (Figure 3). Considerable variation was also recorded at the five depths investigated between the bottom times needed to generate a range of decompression limits.

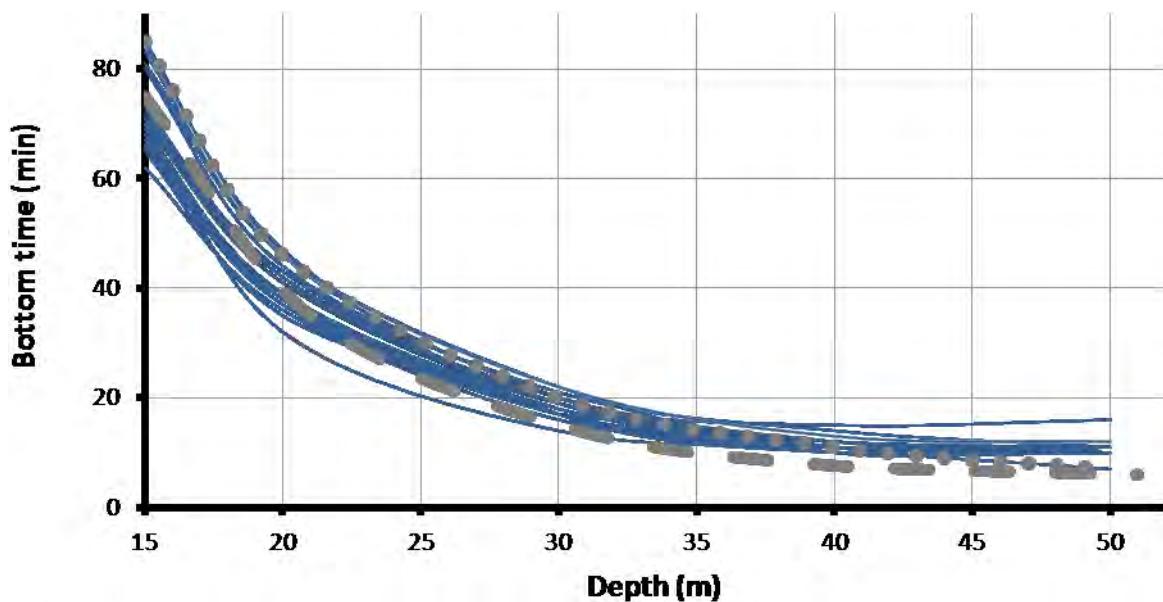


Figure 3. No-stop decompression isopleths for 40 models of diving computer tested over a depth range of 15–50m; compared against DCIEM (---) and "RNPL"(···) tables

## Discussion

Care should be taken when interpreting downloaded computer data for uses such as scientific measurement or forensic examination; units may not conform fully to EN 13319:2000. Occupational divers need to risk-manage the use of some computers that generate longer bottom times at some depths and for some decompression schedules and be aware of the potential for battery or unit failure. Battery “life” is invariably estimated by diving computer algorithms and not measured directly.

## Acknowledgments

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## Estimating Geoduck Harvest Rate and Show Factors in Southeast Alaska

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### Abstract

In Southeast Alaska, guideline harvest levels for commercial harvest of geoduck clams are calculated as the product of estimated biomass and a fixed annual 2% harvest rate. Prior to applying the harvest rate, biomass estimates are inflated by 20% to account for geoducks that were not counted during dive surveys. Use of the inflation factor, termed “show factor”, is intended to produce a more accurate estimate of biomass, by acknowledging that some geoduck siphons remain hidden beneath substrate at the time of survey. The current show factor was calculated with limited data. The current harvest rate was established as a compromise between those rates used for geoduck fisheries in British Columbia and Washington State. This report outlines the background, study plan and data collection methods for this age composition and show factor project. The analysis phase of the project, which has not been completed, will use these recently produced results to estimate parameters used to calculate harvest rate and show factors that are explicitly intended for Southeast Alaska geoduck populations. Additionally, show factors will be calculated for several sites, including geoduck beds with and without evidence of sea otter predation to determine if geoduck shows are influenced by sea otters.

Key words: age composition, dive survey, geoduck, harvest, show factor, Southeast Alaska

### Introduction

#### ***Management and harvest rate history***

The geoduck fishery management plan for Southeast Alaska was adopted by the Alaska Board of Fisheries in 2000 and was developed by the department in cooperation with the Southeast Alaska Regional Dive Fisheries Association (SARDFA) Geoduck Committee. The core elements of the plan include establishment of guideline harvest limits based on biomass estimates, survey frequency requirements, a limit reference point (i.e. threshold) of 30% of original estimated biomass, and an annual harvest rate of 2% in all fishery areas. The harvest rate was established as an intermediate level between those used in Washington State and British Columbia fisheries, where age-based equilibrium models were used to estimate harvest rate (Breen, 1992; Bradbury and Tagart, 2000; Bradbury et al., 2000; Hoffman et al., 2000). More recently, in British Columbia an age-structured projection model has been used to determine harvest rates (Zhang and Hand, 2007). The annual harvest rate in British Columbia varies from 0.75 – 2 % of the virgin biomass per year, and in Washington the annual harvest rate is 2.7 % of the total estimated biomass.

The geoduck management plan also requires a self-imposed tax on SARDFA members for all geoduck landings. The revenue is used in part to test for water quality and paralytic shellfish poisoning, both of which are mandatory prior to geoduck harvest and sales. The tax also helps fund geoduck stock assessment surveys and management and is the primary source of funding for this study.

### ***Stock Assessment, biomass, and show factor***

Stock assessment surveys for geoducks in Southeast Alaska began in 1994 and methods have evolved since that time. Prior to 2006, biomass was estimated based on the mean count of geoducks per meter of shoreline and the mean weight (called shoreline-based model). Starting in 2006, there was a shift from the shoreline-based model to an area-based model, which relies on estimates of geoduck density and measurements of bed area, along with mean weight, to produce estimates of biomass. One effect of switching to the area-based approach was reduced variability surrounding biomass estimates. Since the lower-bound biomass estimate of the 90% confidence interval is used to calculate guideline harvest levels (GHLs), the new model approach led to a corresponding increase in GHLs in most surveyed areas. Although this has been an improvement to the method of estimating biomass and setting GHLs, the show factor value has remained unchanged and studies in Southeast Alaska have been limited. Show factor is defined as the ratio of geoduck siphons visible during a single observation of any defined area to the true abundance of harvestable geoducks in that area (Bradbury et al., 2000). Since visibility of geoduck siphons may be influenced considerably by survey site conditions at the time of survey, the show factor may greatly impact estimates of biomass. For this reason, it is important to use show factor values that are as accurate as possible when estimating biomass and setting GHLs.

Extensive research has been conducted on geoduck show factors in British Columbia and Washington State over many years. British Columbia uses a show factor of 90% (Campbell et al., 2004) and Washington found mean show factors to be 73% (Bradbury et al., 2000). Study of show factors in Southeast Alaska has been limited to very few sites, and may not be fully representative of areas, habitat types, and conditions encountered during geoduck surveys. Results of these studies indicate that about 83% of geoducks are counted by divers (Pritchett et al., 1999). Currently, biomass estimates are adjusted upward by using a show factor of 80%. Although this value is within the range of values estimated in British Columbia and Washington, the appropriateness is unknown due to the sparse data upon which it is based. For an example of how show factors have been applied in Southeast Alaska, see Rumble and Siddon (2011).

Southeast commercial geoduck harvesters believe that the show factor of geoduck clams is affected by the presence of sea otters. Sea otter populations have exploded in Southeast Alaska since their reintroduction in 1965. Predation by sea otters has negatively affected the region's dive fisheries, including geoducks, by reducing standing stock biomass and in turn, GHLs. To determine if geoduck show factor is affected by the presence of sea otters, we conducted show plot studies in fishery areas known to have sea otter predation and areas that do not have sea otter predation.

### ***Goals and objectives***

The goals of the study were twofold: 1) produce an appropriate Southeast Alaska-specific harvest rate for geoducks, and 2) produce a show factor, or show factors, that are valid for use in a wide range of scenarios (areas, habitats, ocean conditions, sea otter presence or not) encountered during dive surveys of geoducks.

Objectives for estimating the harvest rate for Southeast Alaska were:

- 1) Determine the age structure of various populations by collecting and aging approximately 200 randomly chosen geoduck shells from at least four different geoduck fishery areas in Southeast Alaska (Figure 1).
- 2) Determine size distribution (weight and length) and estimate growth rates for each fishery area.
- 3) Calculate growth rate for each fishery area.
- 4) Calculate the natural mortality rate for each fishery area.

Objectives for estimating show factor(s) were:

- 1) Count geoduck siphons and then verify by digging all geoducks within ten 10m<sup>2</sup> (10-meter by 1-meter) show plots from each of at least two different geoduck fishery areas in Southeast Alaska where sea otter predation is evident.
- 2) Count geoduck siphons and then verify by digging all geoducks within ten 10m<sup>2</sup> (10-meter by 1-meter) show plots from each of at least two different geoduck fishery areas in Southeast Alaska where there is no sea otter presence.

## Methods

Some of the goals and objectives were accomplished for the harvest rate and show factor studies in conjunction with each other. Combining these two projects reduced the amount of geoducks that were removed from each of the fishery areas. Within each fishery area, about 200 geoducks were sampled for the harvest rate study, and show factor studies were conducted in the following four fishery areas in summer 2012 (see Figure 1):

- 1) Cone Island North (District 3) - sea otter affected
- 2) East San Fernando (District 3) - sea otter affected
- 3) Vallenar Bay (District 1) - not sea otter affected
- 4) Nakat Inlet (District 1) - not sea otter affected

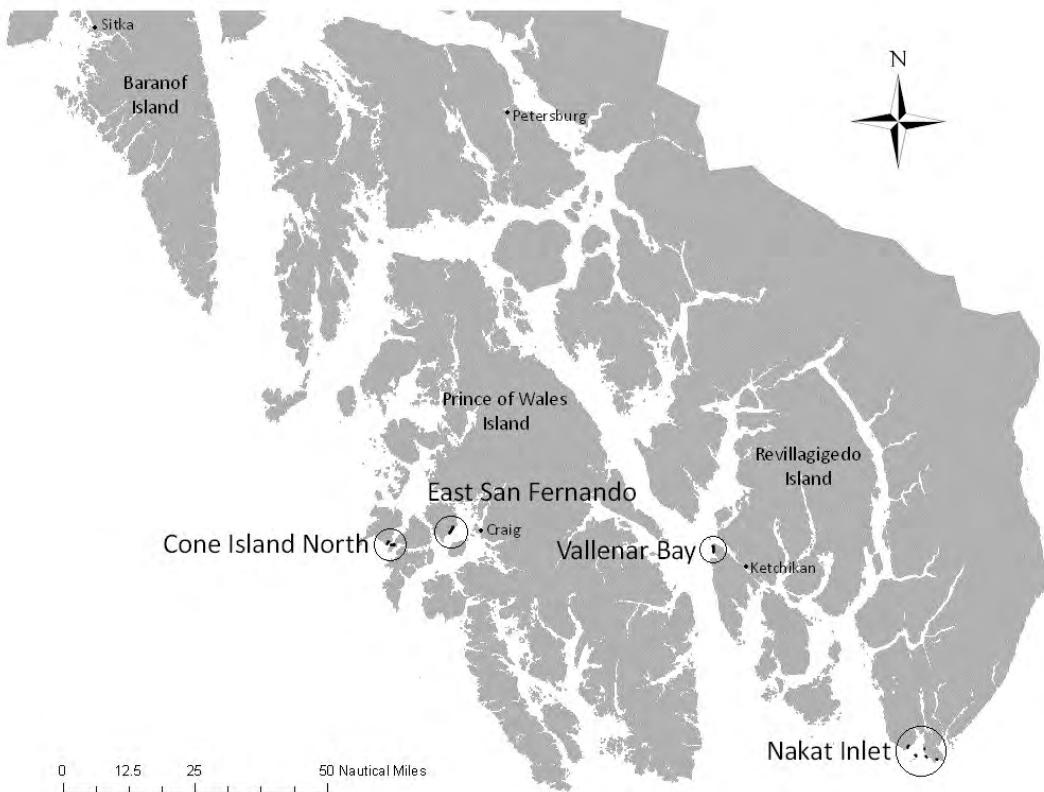


Figure 1. Four Southeast Alaska fishery areas (circled) that are age composition and show plot research sites.

Transects and geoduck counting, attempted dredging, and geoduck collection was completed for each of the four fishery areas. The laboratory sample processing, estimates of growth rate and mortality, and estimates of show factor for the four fishery areas will be completed in before the summer of 2013.

In each of the fishery areas, 10 transects were surveyed. These transects were pre-determined and spaced out evenly across the geoduck beds. Transect coordinates were loaded into the GPS units of each of the two skiffs that were used for diving.

In order to produce the most valid show factor (number of geoducks counted/total geoducks present), show plot transects in this study closely mimicked transects conducted during stock assessment surveys. Two divers swam as a team along each transect, each diver holding a 1-meter rod (a 2.1cm diameter white PVC tube) in a horizontal position perpendicular to the transect path. Diver 1 carried a 10m line with attached weight, and a compass mounted on the transect rod to maintain the predetermined compass bearing. Diver 2 carried a writing slate with a data form attached to the rod. As soon as geoduck clams were found, Diver 1 dropped the weight and both divers swam and counted geoduck clams under their respective rods until the line was taut. Diver 1 used hand signals to relay geoduck counts to Diver 2 for recording. Then Diver 1 pulled the line and weight to the next starting position and began next 10-meter segment.

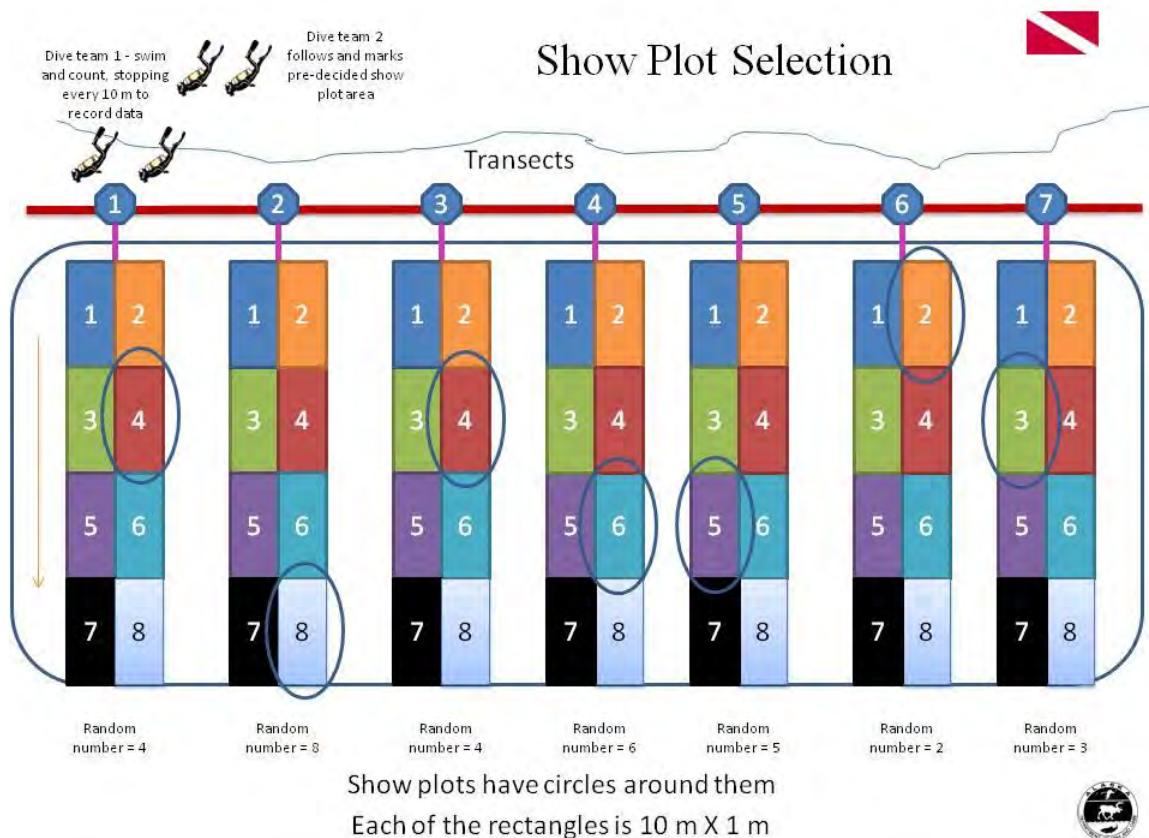


Figure 2. Show plot selection diagram.

As the divers surveyed the transect, one 10-meter segment had been randomly selected (pre-determined) as the show plot site by a second dive team swimming behind the first dive team (for example see Figure 2). To reduce chance of bias, Dive Team 1 was informed of the show plot selection only after estimates within the segment had been completed. Immediately after Dive Team 2 identified the show plot, the four corners were marked by Dive Team 2 with flagging, and then the entire perimeter was marked with line with the help of both dive teams.

Each show plot was marked with a buoy to the ocean surface so that it could be found for future geoduck marking and dredging. After the show plot boundaries were marked, divers placed flags in the substrate next to each geoduck siphon observed within the show plot area. Divers returned to the sample site after at least 18 hours to flag geoducks that they had not flagged before in the defined show plot. After all visible geoduck siphons were flagged, the total number of flags in the show plot were counted and recorded. The flags, show plot lines, and anchors were then removed.

### ***Geoduck sample removal***

Attempted geoduck removal from show plot areas by commercial geoduck harvest divers, contracted by SARDFA, was not successful. The contracted divers were responsible for operation of harvest/sampling equipment, removing substrate to expose geoducks, and freeing geoducks from the substrate. The equipment setup of the dredge did not work as originally planned. The removal of the substrate was slow and the sides of the show plot area caved in, producing inadequate results. ADF&G dive teams conducted dives separate from contract divers (separate dive partners, equipment, and surface support), but were in close proximity and observed and recorded the sampling process with video and still photos. The purpose of ADF&G divers diving near the show plots was to ensure that show plot line boundaries remain intact, to make sure that digging stayed within boundaries, and to help collect and transport the geoducks. Sampled geoducks were bagged and brought to the surface where they were counted, weighed, processed to remove the meat, and the shells were cleaned and tagged with an identification number.

### ***Laboratory sample processing***

Geoduck valves were processed at the Alaska Department of Fish and Game Age Determination Unit (ADU). The ADU processed the left valve (shell) for aging (with few exceptions). Processing included measurement of valve length (mm), height (mm), and weight (g). To determine ages, subsamples from each valve were obtained using a thin-section technique similar to that found in Hagen and Jaenicke 1997 (see Neves and Moyer 1988 for a comparison of techniques). For each specimen, a rough cut section centered around the umbo was cut out of the valve hinge using a tile saw. Three serial sections were cut using a thin-section saw. The first cut was positioned as close to the center of the umbo as possible and subsequent cuts were made into the hinge plate. The sections were mounted to a glass petrographic slide with clear mounting resin. Slides were placed in a slide holder and the sections were thinned using a mechanical grinding wheel and then polished. Aging of these specimens has not been completed. Ages will be estimated by counting annuli viewed using reflected light and a stereomicroscope, and the specimen age recorded.

### ***Estimates of growth rate and natural mortality***

Sampled geoducks will be used to assess growth and natural mortality for the region or by individual area where appropriate; currently, no data exist for these life history parameters in Southeast Alaska. Growth will be compared among areas using the Ludvig von Bertalanffy model:

$$W_{(t)} = W_{\infty} [1 - e^{-k(t-t_0)}]^{\beta}$$

where  $W(t)$  is the weight at age  $t$ ,  $W_\infty$  the maximum weight, and  $k$  and  $\beta$  are growth parameters (Quinn and Deriso, 1998). Growth parameters will be estimated and compared among areas using nonlinear least squares methods.

Estimates of natural mortality rate will be calculated using catch curve analyses (Seber, 1982; Quinn and Deriso, 1998) in a similar manner done with geoducks in British Columbia (Bradbury and Tagart 2000) by examining age frequency data. Generally, a regression of the frequency of geoducks ( $\ln$ -transformed) as a function of age will be performed on a truncated dataset where both young and old ages will be removed. Although estimates of natural mortality rate for each area are desired, sampling constraints will likely require pooling age frequency data among areas.

### ***Estimates of Show Factor***

Show factor experiments have been conducted but not analyzed and estimated. To estimate the ability of divers to accurately count geoducks during normal survey procedures we will compare the percentage difference between total geoducks and the survey count (i.e., show factor) in the 10m<sup>2</sup> show plots. Total geoducks will be estimated by either the total number of flags placed or the total number extracted by the commercial divers within the show plots. Variation in show factors will be compared among areas using a nested one-way ANOVA with areas nested within the otter treatment (presence/absence). However, due the low sample size ( $n=2$ ) for the otter treatment and the confounding affect of spatial proximity, the analysis may be simplified into a one-way ANOVA with the main treatment being area (rather than otter presence). In addition, covariates of substrate type, water temperature, and a subjective estimate of how easy geoducks are to see (showing) will be examined. All data will be transformed appropriately to meet assumptions of ANOVA.

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## Effects of Substrate Rugosity on Subtidal Algal Recruitment

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### Abstract

This study examined the effects of substrate rugosity and season on subtidal algal recruitment. Resin molds were made from silicone casts of two common rock types found in Carmel Bay, California; the Carmelo Formation sandstone and Santa Lucia granodiorite. Due to the different formation processes of these rock types, the surfaces exhibit different rugosities on a micron to centimeter scale that had the potential to affect algal propagule settlement and recruitment. Recruitment onto two substrate types was observed over a 13-month field period for the following four groups: red algae, *Ulva* spp., coralline algae and kelp species. 2-Factor ANOVA results identified seasonal differences in the *Ulva* spp. ( $p \leq 0.001$ ), coralline algae ( $p \leq 0.001$ ) and kelp species ( $p = 0.022$ ) categories, but not for red algae ( $p = 0.188$ ). The red algal grouping was the broadest category, encompassing species that likely recruit at different times throughout the year and thus may be why seasonal effects were not seen. Effects of substrate were detected in the kelp species category ( $p = 0.023$ ). This result may be due to life history traits exhibited by these algal species. Results from this study show that macroalgal species that require propagules to settle in close proximity for successful recruitment (i.e., kelp species) may be more affected by substrate rugosity.

Keywords: coralline algae, kelp, macroalgal settlement, *Ulva*, recruitment, red algae, rugosity

### Introduction

Effects of substrate microtopography or rugosity, influencing macroalgal recruitment, have been observed in previous studies. The non-motile propagules of the brown alga species *Sargassum muticum* were observed settling into depressions of the substrate (Norton and Fetter, 1981) and an optimal range of rugosity was observed, where settlement decreased above or below the ideal range. Experiments have shown that kelp sporophytes or recruits occur more often on frosted glass slides than smooth glass slides (Reed et al., 1997) suggesting that the roughness of the frosted glass slide facilitated fertilization possibly by increasing zoospore densities or zoospore aggregation.

The size and shape of the peaks and depressions that make up substrate rugosity have the potential to affect macroalgal propagules differently and therefore affect recruitment. Depressions in the substrate may protect particles such as macroalgal propagules from detachment caused by turbulent eddies created by waves and other hydrodynamic processes (Denny, 1988). Over rugose surfaces, it has been shown that water flow will slide over the peaks and not reach into the depressions (Nowell and Church, 1979). Substrate rugosity also protects organisms from higher water velocities by creating a break within the laminar flow (Denny, 1988; Denny and Shibata, 1989); these reduced velocities may also enhance propagule attachment and settlement (Eckman, 1983).

Two rock types found in Central California were used to compare macroalgal recruitment onto different substrates. The rock types used were the Carmelo Formation sandstone, composed of uniform sized sand particles creating a consistent rugosity with small peaks and depressions and the Santa Lucia granodiorite, composed of a variety of mineral crystals with various sized peaks and

depressions. A year-long, field-based study was conducted to test the effect of these different substrate rugosities on macroalgal recruitment and to determine if the effects changed with season as environmental factors varied.

## Materials and Methods

Naturally occurring, subtidally weathered samples of the Carmelo Formation sandstone and Santa Lucia granodiorite were collected from Stillwater Cove, CA. These samples were cast using OOMOO® Silicone Rubber. From these casts, resin molds ( $24.6\text{ cm}^2$ ) were made to mimic the substrate rugosity and to act as settlement plates in the field (Figure 1; Risk, 1973; Harlin et al., 1977; Johnson, 1994; methods from Muth, 2012).



Figure 1. Field settlement plates, paired molds of each substrate rugosity type on each plate.

Fifteen pairs of the molds were placed randomly along a 12 m lead line located in inner Stillwater Cove. Stillwater Cove is located at the north end of Carmel Bay ( $36^{\circ}33'56.79''\text{N}$ ,  $121^{\circ}56'35.88''\text{W}$ ). The plates remained in the field for 4 months, keeping field exposure time for the plates constant between seasons. After 4 months, the plates were removed and brought back to the lab to quantify macroscopic recruitment of four algal categories: red algal species, *Ulva* spp., coralline algal spp., and kelp spp. The numbers of individual recruits per mold were counted for each category except coralline algal spp., which was estimated using percent cover, as individuals are hard to distinguish. Every 3 months, 15 new plates were placed in the field to detect any seasonal changes. Plates that had no recruitment on both molds were not analyzed due to recruitment failure. Model I, 2-factor ANOVA was used to test the effects of season, substrate and the interaction of substrate and season on recruitment. A Fisher's LSD post hoc test was used to detect any seasonal variation of recruitment for each algal category.

## Results

A total of 56 plates were analyzed for macroscopic algal recruitment. Of those 56 plates, 36 had red algal species recruitment, 38 plates had *Ulva* spp. recruitment, 50 plates had coralline algal recruitment, and 21 plates had kelp recruitment. Results from the 2-way ANOVA for the red algal species category showed no significant difference in recruitment between season ( $F_{3,70} = 1.64$ ,  $p = 0.188$ ), however a Fisher's LSD post hoc test did show a significant difference between fall and winter ( $p = 0.045$ ; Figure 2). Substrate ( $F_{1,70} = 1.24$ ,  $p = 0.269$ ), and the interaction of season and substrate ( $F_{3,70} = 1.19$ ,  $p = 0.318$ ) were not significant.

For the *Ulva* spp. category, season was significant ( $F_{3,70}=8.587$ ,  $p<0.001$ ), and this difference was due to all seasons differing from summer (fall and summer  $p < 0.001$ , winter and summer  $p < 0.001$ , spring and summer  $p = 0.003$ ; Figure 2). Substrate ( $F_{1,70} = 0.078$ ,  $p = 0.780$ ) and the interaction of season and substrate ( $F_{3,70} = 0.811$ ,  $p = 0.492$ ) were not significant.

Seasonal differences were also detected in the coralline algae category ( $F_{3,92} = 102.615$ ,  $p < 0.001$ ) with each season differing significantly from each other (fall and winter  $p < 0.001$ , fall and spring  $p = 0.006$ , fall and summer  $p < 0.001$ , winter and spring  $p < 0.001$ , winter and summer  $p < 0.001$ , spring and summer  $p = 0.004$ ; Figure 2). Substrate ( $F_{1,92} = 0.044$ ,  $p = 0.834$ ) and the interaction of season and substrate ( $F_{3,92} = 0.479$ ,  $p = 0.698$ ) were not significant.

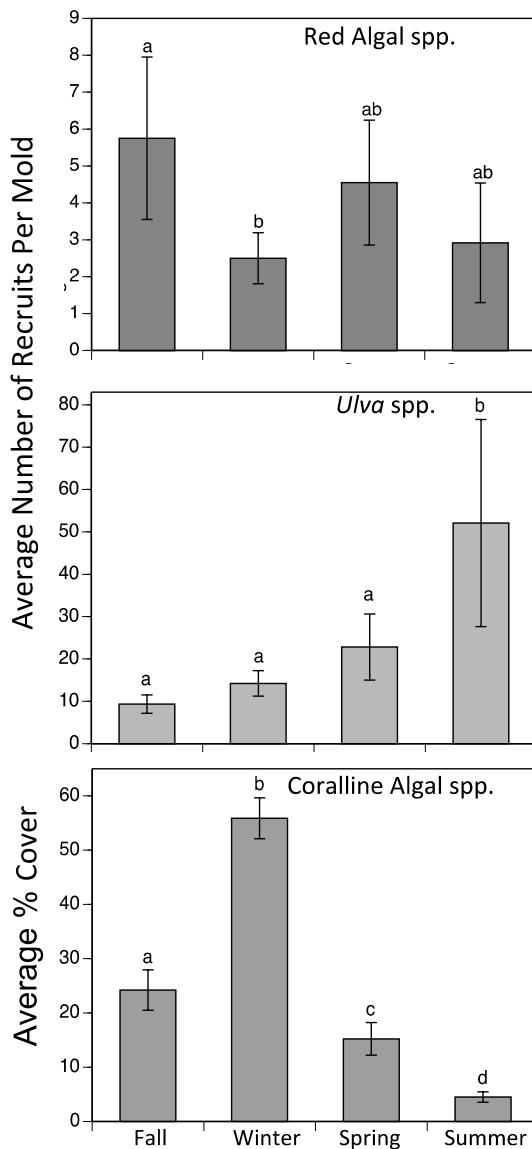


Figure 2. Average recruitment for each season for the algal categories: red algal spp., *Ulva* spp., and coralline algae. Letters represent seasons that significantly differ.

Seasonal differences were detected in the kelp spp. category ( $F_{3,34} = 3.648$ ,  $p = 0.022$ ) with significant differences between winter and summer with spring (winter and spring  $p = 0.008$ , summer and spring  $p = 0.005$ ). Kelp spp. was the only category to show a significant difference in recruitment between substrate types ( $F_{3,34} = 5.658$ ,  $p = 0.023$ ), but the interaction between season and substrate were not significant ( $F_{3,34} = 1.64$ ,  $p = 0.132$ ; Figure 3; taken from Muth, in press).

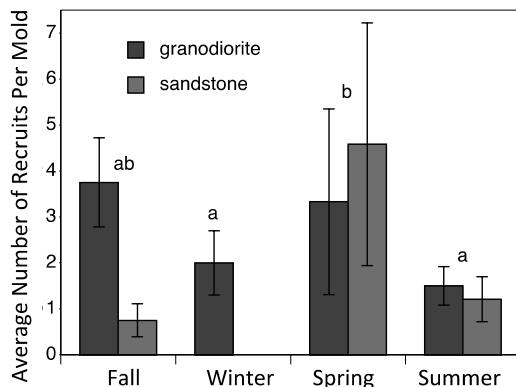


Figure 3. Average recruitment for each season and between substrate types for the kelp species algal category. Letters represent seasons that significantly differ.

## Discussion

Effects of micro-rugosity on macroalgal recruitment have been explored in multiple studies (Christie, 1968; Risk, 1973; Harlin and Lindbergh, 1977; Norton and Fetter, 1981; Amsler et al., 1992; Johnson, 1994). In many cases, the rugose surfaces used were manufactured and do not occur in nature (Harlin and Lindbergh, 1977; Norton and Fetter, 1981). This study used naturally occurring rock types to test the effects of substrate rugosity on macroalgal recruitment. Kelp was the only algal category observed in this study to show differential recruitment onto the two substrates and more kelp was seen to recruit to the granodiorite molds than the sandstone molds. Other studies using artificial substrate (Risk, 1973; Harlin et al., 1977) have observed recruitment differences onto surfaces with different rugosities in other macroalgal categories (list them), but rugosity effects were only detected for kelp recruitment in this study. This may be due to the different life histories that algal species exhibit. Kelp species release zoospores into the water column and each zoospore must settle and mature into either a male or female gametophyte. Once the gametophytes are mature, the male fertilizes the female gametophyte and a sporophyte or recruit is produced. Proximity of male and female gametophytes is essential for recruitment to occur in kelp species (Reed et al., 1991). In contrast, in other algal species such as in *Ulva* spp., fertilization occurs in the water column and the propagule that settles on the substrate is a zygote or recruit. Red algal species have very complex life histories, but again, fertilization occurs before propagules settle onto the substrate. The two rugosities compared in my study may not have differed enough to see a difference in settlement in these other macroalgal species. The effects of substrate rugosity did not change with season for any of the four algal categories, meaning that changing environmental conditions, such as water motion did not change recruitment between the two substrates. Results from this study show that macroalgal species that require propagules to settle in close proximity for successful recruitment (i.e., kelp species) may be more affected by substrate rugosity.

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## The Antarctic Benthos: Temperature, Oxygen, and Body Size

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### Abstract

Many Antarctic marine invertebrates exhibit ‘polar gigantism’. Using nudibranch egg masses, we tested the hypothesis that polar gigantism is facilitated by cold-mediated low metabolic oxygen demands and high rates of diffusive oxygen delivery. Working from McMurdo Station, we collected nudibranch egg masses on SCUBA. We measured internal oxygen levels in masses in the field and made morphological measurements, comparing Antarctic to temperate masses. Egg masses of Antarctic nudibranchs were on average >2X thicker than temperate masses, and contained embryos that were ~35-fold larger and occurred at lower densities. Antarctic masses were less oxygen-limited than temperate masses. Egg masses of Antarctic nudibranchs display gigantism, but also show other structural differences that cause the overall metabolic demand to be unusually low; thus the oxygen-temperature hypothesis cannot fully explain the evolution of large egg masses at the poles.

Keywords: nudibranchs, Antarctica, polar gigantism

### Introduction and methods

Many marine invertebrates from the Southern Ocean have unusually large body sizes, a phenomenon known as “polar gigantism” (Arnaud, 1974; Chapelle & Peck, 1999). There are many ecological, physiological, and biogeographic hypotheses that have been put forward to explain polar gigantism (see Moran & Woods, 2012 for review); currently, the most broadly-accepted hypothesis is that of Chapelle & Peck (1999) who suggested that high oxygen availability in polar oceans permits larger body sizes. The low temperatures in the Southern Ocean (which averages -1.8 degrees C around much of the Antarctic shoreline; Clarke, 2003) also reduce metabolic oxygen demand in ectothermic organisms, which may also contribute to a comparative oxygen surplus in the cold, highly oxygenated waters of Antarctica (Woods, 1999; Pörtner, 2001; Moran & Woods, 2012). However, there have been few experimental or comparative tests of this ‘oxygen-temperature hypothesis’, and little is known about the physiology or morphology of Southern Ocean invertebrates. Likewise, the phylogenetic affiliations of many Antarctic marine invertebrates are poorly known (Arnaud, 1974; Moran and Woods, 2012), making comparisons with temperate or tropical fauna difficult.

In this study, we collected nudibranch egg masses from McMurdo Sound, Antarctica, and compared their physiology and morphology to egg masses of related animals from warmer waters. Nudibranchs are shell-less gastropods that inhabit oceans throughout the world (Thompson, 1976). Nudibranchs place fertilized eggs into protective, benthic gelatinous egg masses from which embryos hatch as swimming larvae or crawling juveniles, depending on species (Strathmann, 1987; Goddard, 2004). These egg masses make excellent systems for modeling oxygen dynamics because they rely entirely on diffusion, they can be readily collected and manipulated, and are amenable to mathematical modeling (e.g. Strathmann & Strathmann, 1995; Cohen & Strathmann, 1996; Moran & Woods, 2007; Woods & Moran, 2008a, 2008). The oxygen-temperature hypothesis predicts that because Antarctic

masses have comparatively higher oxygen availability, polar nudibranchs may evolve larger mass sizes than temperate species if selection favors larger size. Many temperate genera of nudibranchs have Antarctic members (Wägele 1991; Valdés et al. 2011), making it possible to test the oxygen-temperature hypothesis in a controlled phylogenetic context.

#### **Collection and physiological measurements**

Antarctic nudibranchs and their egg masses were collected at between 30 and 130 ft depths at several sites around McMurdo Sound, Antarctica, over two field seasons (2006-2007 and 2007-2008), and temperate nudibranchs were collected from similar depths at several sites near the Friday Harbor Laboratories, Puget Sound, Washington. On collection dives, divers visually searched benthic substrate for the inconspicuous egg masses using lights and magnifying mask see-unders (Prescription Dive Masks, La Mesa, CA). Masses were collected intact and placed into a hard-sided open collecting jar with a snap-down lid. At the end of dives, the water-filled containers were handed up through the dive hole, immediately placed in a cooler with ice, transported back to the laboratory, and placed in mesh-sided boxes in flowing seawater at appropriate environmental temperatures. If species identity could not be established using morphology, masses were placed in a phylogenetic context using COI mRNA and 18S (Shields et al., submitted). Oxygen measurements were taken on masses in the field and in the laboratory, at different temperatures and under different flow regimes, as described in Moran & Woods (2010) (Figure 1), and respiratory rates of embryos were measured as described in Moran & Woods (2007).

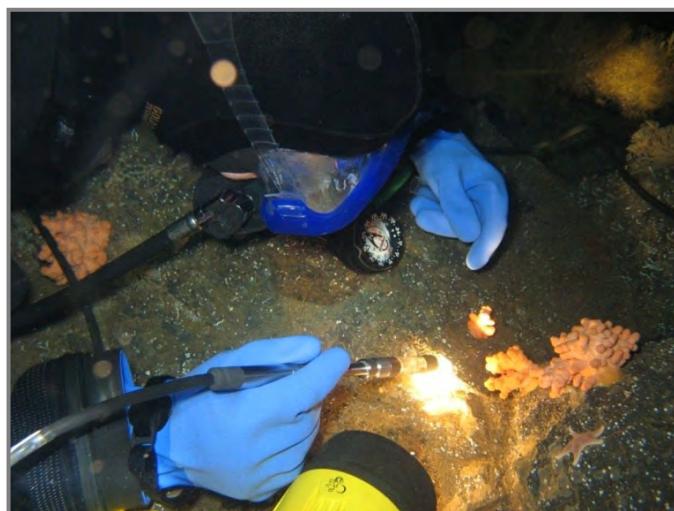


Figure 1. Diver measures internal oxygen concentrations in Antarctic nudibranch egg masses. Photo by B. Miller.

#### **Photography and morphometrics**

Masses were photographed in a black-bottomed chilled shallow aquarium and photographed with a Nikon digital SLR camera on a camera stand. For fine morphometric measurements or very small or sectioned masses, masses were placed in chilled black-bottomed watch glasses and photographed under an Olympus BXT compound microscope with an attached Nikon Coolpix digital camera. Images were calibrated with a stage micrometer and measurements of mass diameter and embryo size were made with Olympus Microsuite image analysis software. For two known congeners, *Tritonia diomedea* and *Tritonia challengeriana*, egg mass diameter and embryo size were measured as described in Woods & Moran (2008b).

## Results and Discussion

We collected > 15 genetically distinct lineages of nudibranchs in McMurdo Sound, two of which were subsequently described as new species (see Valdés et al., 2011). We also collected numerous egg masses of the Antarctic nudibranch *Tritonia challengeriana* for morphological and physiological comparison with its temperate congener, *Tritonia diomedea* (Figure 2), and focused our comparative study on these two species. Egg masses of *T. challengeriana* were 2x larger (in diameter) than masses of *T. diomedea*, an outcome consistent with polar gigantism and with model predictions. However, embryos of the Antarctic species were ~35x larger than embryos of the temperate species and occurred at a much lower density in egg masses. In both temperate and Antarctic masses, embryos towards the center of masses were increasingly oxygen-limited with rising temperatures due largely to temperature-induced increases in metabolic oxygen consumption by embryos (Woods & Moran, 2008b); this effect was less prominent in Antarctic masses, and Antarctic masses do not appear to be oxygen-limited in the field for the majority of development (Moran & Woods, 2010). The low volume-specific metabolic rates of Antarctic embryos, combined with the low density of embryos in Antarctic masses, are likely the factors underlying the consistently high oxygenation of *Tritonia challengeriana* in both the laboratory and field (Figure 3). These results are consistent with the predictions of parameterized oxygen diffusion models (see Woods & Moran, 2008a, 2008b), and suggest that Antarctic masses are “overbuilt” with regards to oxygen transport. Thus, the oxygen-temperature hypothesis cannot fully explain gigantism in polar egg masses.

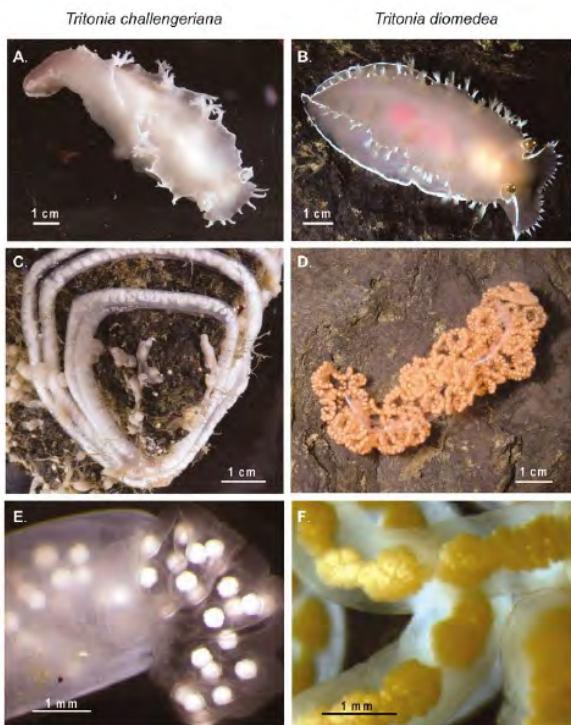


Figure 2. Adults and egg masses of *Tritonia challengeriana* (Antarctic; A,C,E) and *T. diomedea* (temperate; B,D,F). (A,B) Adults. (C,D) Egg masses (macro view). The egg mass of *T. challengeriana* (C) is in situ; the egg mass of *T. diomedea* was removed from its substrate with a razor blade. (E) Cut section of a egg mass of *T. challengeriana* with embryos spilling out of the cut end, showing gelatinous egg string in which embryos are contained. White spheroids are individual embryos at an early cleavage stage. (F) Uncut sections of coiled egg mass of *T. diomedea*, showing embryos (small yellow dots) in egg capsules (clusters of yellow embryos) contained within the mucous sleeve. Reprinted from Woods & Moran 2008b.

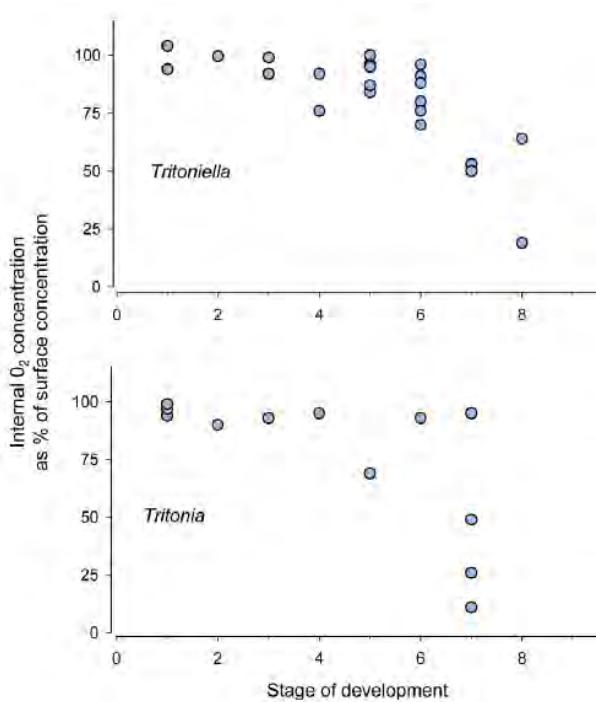


Figure 3. Developmental stage vs. internal O<sub>2</sub>. Relationship between developmental stage (x axis) and internal O<sub>2</sub> concentration (y axis) for masses of two Antarctic nudibranch species, *Tritoniella belli* (top; linear regression,  $R^2 = 0.46$ ;  $p = < 0.001$ ) and *Tritonia challengeriana* (bottom;  $R^2 = 0.39$ ,  $p = 0.018$ ). Reprinted from Moran & Woods, 2010 (no permissions necessary).

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## Genetic Connectivity of Endemic Damselfishes in the Hawaiian Archipelago

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### Abstract

Marine protected areas are employed as management tools to protect marine resources and allow overexploited regions to recover. Connectivity, the degree to which populations are linked through the exchange of individuals, is an important criterion in determining the placement of marine protected areas. This research addresses whether endemic species share similar patterns of connectivity throughout their range. The Hawaiian Archipelago, one of the most isolated archipelagos in the world, is a hotspot for endemic reef fishes, making it an ideal system for this study. Understanding whether endemic species exhibit similar patterns of connectivity is valuable knowledge since the restricted range size of endemics places them at a greater risk of extinction than more broadly distributed species. Molecular genetics techniques were utilized to evaluate levels of genetic connectivity in populations of three damselfish species endemic to the Hawaiian Archipelago (*Abudefduf abdominalis*, *Chromis ovalis*, and *C. verater*). *A. abdominalis* and *C. ovalis* shared significant genetic breaks near the northwestern end of the archipelago and between the Northwestern Hawaiian Islands and the Main Hawaiian Islands. These results support conclusions from previous studies that there are limitations to gene flow between the Main Hawaiian Islands and the Papahānaumokuākea Marine National Monument.

Keywords: connectivity, damselfish, endemism, genetics, marine protected areas

### Introduction

Coral reefs are some of the most biologically diverse ecosystems on the planet, and over half of all coral reef systems are significantly threatened by human activity (Burke et al., 2011). Consequently, networks of marine protected areas are being designated to help protect these ecosystems and to allow overexploited areas to recover. Understanding the ecological processes operating on coral reefs will inform where marine protected areas should be placed in order to maintain biodiversity, and among the important criteria in selecting potential sites for marine protected area is connectivity (Roberts et al., 2003). Connectivity is the degree to which populations are linked through the exchange of individuals. This promotes gene flow between different populations, maintaining genetic homogeneity (lack of genetic structure) across the species' range. This study utilized genetic surveys to evaluate the nature and scale of larval dispersal and connectivity in three species of endemic Hawaiian damselfishes: *Abudefduf abdominalis*, *Chromis ovalis*, and *C. verater*. Because of their isolation, archipelagos have high rates of endemism. Endemic species are restricted to a particular geographic range and represent marine systems that are maintained through the local retention of larvae (Swearer et al., 2002). The Hawaiian Archipelago is a hotspot for endemic reef fishes, making it an ideal system for investigating patterns of connectivity in marine populations (Allen, 2008). The

data from this study provide information on the extent of connectivity between the Main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI) – a subject that has been identified as a research priority for the Papahānaumokuākea Marine National Monument, which encompasses the NWHI.

## Methods

### ***Collection and physiological measurements***

Divers collected specimens of *A. abdominalis*, *C. ovalis*, and *C. verater* from 11 to 15 sampling sites in the NWHI and the MHI. Collections in the NWHI were carried out during National Oceanic and Atmospheric Administration (NOAA) research cruises aboard the NOAA research vessel Hi'ialakai. Specimens were sequenced for the mitochondrial marker cytochrome b, and data were analyzed with ARLEQUIN (Excoffier and Lischer, 2010), software that estimates population structure, molecular diversity, and patterns of connectivity.

## Results

Analyses of Molecular Variance (AMOVAs) elucidated locations of genetic breaks in the archipelago. Number of migrants per generation (Nm) was calculated from FST values, providing an estimate of migration across the genetic breaks. *A. abdominalis* and *C. ovalis* demonstrated multiple significant breaks, while no significant breaks were identified for *C. verater*. For *A. abdominalis*, the most pronounced break occurred between Kauai and Oahu ( $\Phi_{CT} = 0.015$ , Nm = 37). For *C. ovalis*, the most pronounced break occurred between Pearl and Hermes Atoll and Lisianski ( $\Phi_{CT} = 0.016$ , Nm = 64), and this break was significant in *A. abdominalis* as well ( $\Phi_{CT} = 0.010$ , Nm = 1). *A. abdominalis* and *C. ovalis* shared additional significant breaks, and the southernmost of these breaks was located to the east of French Frigate Shoals ( $\Phi_{CT} = 0.010, 0.012$ ; Nm = 11, 89).

## Discussion

The most divergent genetic breaks detected by AMOVAs overlapped with previously identified barriers to dispersal in the Hawaiian Archipelago. Toonen et al. (2011) compared genetic surveys for 27 taxonomically diverse marine species and found four shared genetic breaks between: 1) the Big Island and Maui, 2) Oahu and Kauai, 3) the MHI and the NWHI, and 4) the northwestern end of the chain around Pearl and Hermes Atoll and the rest of the archipelago. In the current study, the most pronounced break for *A. abdominalis* corresponded to break #2 between Oahu and Kauai, while that for *C. ovalis* corresponded to break #4 near Pearl and Hermes Atoll. Additionally, these two species demonstrated a significant break to the east of French Frigate Shoals, lending further support to break #3 between the MHI and the NWHI. Restricted gene flow between the MHI and the NWHI has significant implications for management of the archipelago. Management should not rely on the well-preserved reefs of the NWHI to replenish diminishing populations in the MHI and may need to enact separate management models for each region of the archipelago (Toonen et al., 2011).

Even though concordant barriers to dispersal in the Hawaiian Archipelago have been recognized, the presence and strength of these barriers vary for each species (Toonen et al., 2011). This is evident in the current study, where focusing on endemic damselfishes still produced complex patterns of genetic connectivity. Although *A. abdominalis* and *C. ovalis* shared multiple significant genetic breaks, *C. verater* demonstrated no significant breaks in the archipelago. *Stegastes marginatus* and *Dascyllus albisella* are the only other endemic damselfishes that have been surveyed throughout the chain, and

like *A. abdominalis* and *C. ovalis*, they exhibited significant breaks near Pearl and Hermes Atoll and between the MHI and the NWHI (Ramon et al., 2008). However, as in the current study, the pairwise comparisons revealed different patterns of gene flow among sampling locations for each species. Future work comparing the results for *A. abdominalis*, *C. ovalis*, and *C. verater* to *A. vaigiensis* and *C. vanderbilti*, congeneric species that have broader ranges, will elucidate whether endemic species exhibit patterns of connectivity that differ from those of widespread species.

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## Validation of Dive Computers

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### Abstract

This paper reviews a workshop on the validation of dive computers that was convened by the Baromedical and Environmental Physiology Group of the Norwegian University of Science and Technology on 24 August 2011 in Gdansk, Poland as part of the European Underwater and Baromedical Society annual scientific meeting. The use of dive computers by working (commercial inshore) divers in Norway to determine decompression status is not currently authorized by the legislative body, the Norwegian Labour Inspection Authority. The objectives of the workshop were to devise recommendations for the process of dive computer validation. Dive table and dive computer validation procedures were considered along with their applicability for commercial diving operations. Current European Union validation standards were reviewed, and the lengthy process of validation of the U.S. Navy dive computer explained involving man-dive testing of algorithms using decompression sickness (DCS) as an endpoint. Results from examinations of dive computer algorithms using a test chamber documented a relative conservatism among those dive computers tested. The use of venous gas emboli as an alternative to DCS as measurable endpoint for validation of dive computers was considered. Data were presented on recreational dive computer use and a dive computer management system for scientific divers was outlined. Discussion of presented data resulted in a set of consensus findings and recommendations that were presented to the Norwegian authorities.

Keywords: algorithm, CE marking, DCS endpoint, dive computer, normatives, personal protective equipment, validation

### Introduction

Dive computer evolution has taken place at a rapid rate since the first modern-day, diver-carried electronic dive computer (the ORCA Industries' EDGE) became commercially available in 1983, through to the 2012 VR3 dive computer that is programmable for air, enriched air nitrox, mixed gas, and rebreather use. The emergence of dive computers has raised a number of questions regarding their safety, evaluation procedures and guidelines for use in the scientific and recreational diving communities (Lang and Hamilton, 1989; Wendling and Schmutz, 1995), and for this particular project, the Norwegian commercial diving community. Uncertainty was indicated regarding the dive computer's ability to manage multiple deep repetitive dives, which was reconfirmed when it was noted that little data existed on repetitive diving in general (Lang and Vann, 1992). Incidence data available for dive computers is drawn from recreational divers usually diving within no-stop limits. However, dive computer effectiveness in providing real-time guidance on decompression status and ascent rate monitoring has been established since 1983.

The main problem with algorithms in dive computers is in their disability to 'guarantee' safety to their users, and the legislative bodies who have a duty of care to workers. Lang and Angelini (2009) represented that it would not be unreasonable to state that regardless of the number of algorithm variations incorporated in modern dive computers, they all appear to fall within an acceptable window of effectiveness based on the available databases of pressure-related injuries.

Here lies the predicament: there are millions of recreational and scientific dives performed each year that are successful and without incident. Despite this acceptance, the use of dive computers is prohibited in commercial diving operations. The path to commercial acceptance of dive computers is mostly thwarted by economics, i.e., the manufacturers do not want to put their product through the costly and time consuming process of official validation, while governing bodies will not accept their dive computers for a specific purpose until a pertinent validation process has been documented.

The emphasis of this paper is to review and provide considerations for the validation of dive computers for use by working (commercial inshore) divers, with a particular focus on the profiles for inspection and repair dives done in support of Norway's salmon fisheries. Currently these divers must follow the Norwegian Diving and Treatment Tables (Arntzen et al., 2008). Realistically, dive computers could provide benefits for those divers who do not spend their entire bottom time at a fixed depth. The current diving practice within the salmon pen diving population is some type of multi-level dive, with work as they ascend. With past estimates of at least 35,000 dives per year on fish farms in Norway (Brubakk, 2001), the ability to use dive computers should have a major impact on improving the efficiency of these dives.

## Methods

### *Dive computer validation procedures*

It is important to differentiate between the terms 'validation' and 'verification', both of which are fundamental in evaluating dive computers. 'Verification' determines that a dive computer functions correctly, i.e., it executes its inbuilt algorithm, while 'validation' confirms that the algorithm performs at the accepted level of risk. A number of efforts have taken place to characterize the functionality and effectiveness of dive computers (Lang and Hamilton, 1989; Hamilton, 1995; Wendling and Schmutz, 1995) and dive tables (Schreiner and Hamilton, 1989; Simpson, 2000) and it is implicit that in order to validate a dive computer for use, one must first define its functionality.

The dive computer should allow a diver to perform the chosen dive profile without any adverse effects upon decompression. As it is worn by the diver and therefore exposed to the same depth changes in real time, it should calculate decompression for multi-level pressure exposures and in this way is not tied to the 'square' profiles prescribed by dive tables. It should take into account breathing gas and temperature when calculating decompression and record the time/pressure and gas profiles.

Dive computer validation consists of a number of steps (Hamilton, 2012):

1. Consideration of ergonomics.

Most importantly, the dive computer interface should be clear and provide unambiguous information to the user, particularly if errors occur. It should be intuitive to use and comfortable to wear. It should be rigorously leak tested to avoid malfunction within the battery compartment and circuit board in particular.

2. Model function and algorithms.

Function is dependent on the algorithm that the dive computer uses to calculate the decompression requirements. Therefore, validation may be carried out similarly to that of dive

tables. Schreiner and Hamilton (1989) reviewed the procedures for the validation of decompression tables, the central concept of which also applies to dive computers.

3. Testing dive computer function.

The dive computer should be put through its paces in simulation mode. The results can then be compared carefully to benchmarked reference tables and judgment applied as to acceptability.

4. Field testing.

When testing a dive computer, relatively few or quite a lot of profiles can be used. Judgment at this stage determines how many profiles are required to declare a profile as safe.

What is apparent is that 'judgment' needs to be applied throughout the validation process. Exactly how judgment of what is acceptable is agreed upon is important, because many of these decisions are not simple or obvious. A judgment panel should oversee the validation process, with their principal function determined in the developmental phase. In the later stages, a higher order of control might be beneficial: in the U.S. Navy this is called 'configuration management'. In this way, a broader perspective can be provided, perhaps outlining different goals for the dive computer. If possible, the most beneficial mix of panelists throughout the process will include scientists, business people (if the development is commercial) and independent analysts, in order to focus and authenticate the process. It is imperative that the final distributed product has not been changed from the original, validated version, so the 'configuration management' board should oversee distribution and determine that any changes have been authorized.

The validation process and the integration of judgment principles were outlined by Elliott (1989) at a previous dive table validation workshop and is illustrated by Figure 1.

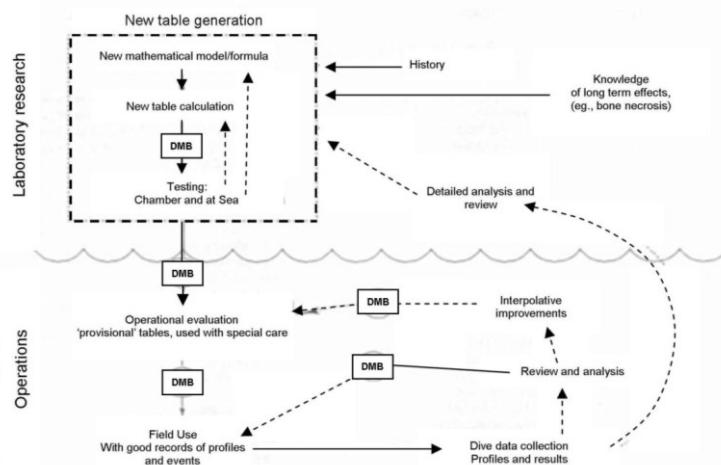


Figure 1. Flow diagram of the decompression table development and validation process by Elliott (1989; reprinted with permission from Schreiner and Hamilton, 1989). The upper part of the diagram is by intent research and subject to "informed consent" procedures. The lower half is operational, and is considered to be within the job description of the divers. Solid arrows show flow of information, dotted arrows show feedback, and those with squares imply some judgmental approval by the Institutional Review Board (IRB) or the "DMB," a competent authority (board or committee) within the organization conducting the dives; it might be called the "Decompression Monitoring Board."

### **Dive computer validation considerations**

Dive computers are standard pieces of equipment in recreational, scientific, and military diving. In less than 30 years, commercially viable electronic dive computers have almost completely eclipsed the teaching and use of decompression tables in recreational dive planning and execution. In scientific diving, guidelines were established that allow researchers to utilize dive computers in their research (Lang and Hamilton, 1989), and dive computers have been specifically developed for military diving operations (Butler and Southerland, 2001; Gault, 2006; 2008). However, in the commercial diving community dive computers have to date not been utilized to the same extent.

For this type of diving, a dive computer poses a number of benefits over tables. Use of a dive computer makes a dive more flexible: it allows dives of unlimited and arbitrary complexity and still provides a decompression solution (W. Gerth, pers. comm.). Multi-level dive calculations can be produced, without the limitations of the “maximum depth for the entire bottom time” rule that accompanies tables. In addition, the decompression calculations are based on the actual depth of the dive, without the need to round to the next deeper depth, and repetitive dives based on the entirety of the decompression model. Most decompression tables use only one compartment in the model to calculate repetitive dive allowances (Huggins, 2012).

However, in order to gain the benefits of dive computer use, the diver gives up some of the safety margins built into decompression tables. The assumption that the entire dive was spent at the maximum depth adds a safety margin to the diver who has performed a multi-level dive. Likewise, entering the table at the next deeper depth and following tested repetitive dive schedules that are based on a single compartment of the underlying decompression model also adds safety (Huggins, 2012). Additionally, there is the potential for dive computer electrical or mechanical failure and user error.

There has been very limited human subject testing of dive computers, meaning that most support for their use has been due to their operational success in the recreational and scientific diving communities. Yet operational safety does not translate to decompression algorithm safety, since most dives performed do not push the algorithms to their limits, according to recreational diving community records (Huggins, 2012). There is a need for a method to evaluate the associated decompression risk of dive computers for commercial diving use. The simplest method of understanding some of the operational benefits that result from dive computer over table use is to simulate dives using dive computer software and then compare the generated profiles to validated, i.e., known outcome, tables. If the results are very similar, then the risk of DCS should be approximately equal.

Studies at the USC Catalina Hyperbaric Chamber ran dive computers against a group of dive profiles that had been tested with human subjects, or had a large number of operational dives (Huggins, 2004). Profiles were rated as “high risk” if they produced cases of DCS or high Doppler bubble scores, “moderate risk” if there was no DCS and moderate Doppler bubble scores, and “low” risk if there was no DCS and no or low Doppler bubbles detected. Dive computer decompression responses to the profiles were compared to the decompression schedules. Conclusions about the decompression algorithm were based on the dive computer’s response to the profile (Table 1).

Table 1. Risk rating versus dive computer response to profile (from Huggins, 2012).

Dive Computer Decompression Requirements	Profile Risk Rating		
	“High” Risk DCS High VGE	“Moderate” Risk No DCS Low to Moderate VGE	“Low” Risk No DCS No VGE
Less than tested profile	Algorithm too Liberal High Risk	Algorithm too Liberal Moderate Risk	Algorithm risk > profile risk Unknown Risk
Greater than tested profile	Algorithm risk < profile risk Unknown Risk	Algorithm risk < profile risk Unknown Risk	Algorithm Conservative

On the “high risk” decompression dive, none of the computers tested would allow the profile to be performed and, therefore, none received a ‘high risk’ rating. All of the computers went into decompression violation at some point while following the profile. On the “moderate risk” decompression dive, all of the computers tested cleared their decompression requirements within 4.5 min of reaching 10 msw. For the no-decompression multi-level dives, the dive computers that required additional decompression from the dives were ranked “low risk.” For the dive computers that allowed more remaining no-decompression time, no assessment of the risk could be made because the outcome of following these dive computers to their limits had not been tested. What is unknown is the risk associated with following the dive computer decompression schedules, since those profiles have not been tested.

Establishing a battery of previously tested dive profiles against which to run dive computer decompression algorithms would permit evaluation of decompression algorithms without the need of human subject tests and could provide a rudimentary baseline for dive computer comparisons. Note that in Table 1 half of the cells indicate “unknown risk.” Estimates of these unknown risks could be made without human subject tests by analyzing the decompression requirements from the computers with decompression risk models (Nishi and Lauchner, 1984; Gerth and Thalmann, 2000). This would allow general and relative risks to be computed for dive computer responses and the previously tested dive profiles. If such risks were established, then the inclusion of dive computers with acceptable decompression algorithms in the commercial diving toolbox should greatly increase the efficiency of multi-level dives of the type done on fish farm pens.

#### ***The need for dive computer validation, normatives and standards***

Although dive computers are now universally accepted for recreational diving, their permissible use in commercial diving varies between countries and industrial sectors. Many countries, such as Norway, legislate against their use because of a lack of information as to how different models compute decompression. The perception of a lack of verifiable safety stems from the absence of standards or normatives specifically for dive computers that would allow assessment of their functional safety.

The topics discussed at the AAUS Dive Computer Workshop (Lang and Hamilton, 1989) included which decompression models should be used, how validation should be carried out, what the acceptable risks were, what limits should be imposed on dive computers, what should happen in the case of a dive computer failure, and operational reliability. Most of these questions are still not answered in 2012 for past or present dive computer models, and continue to form the basis for study. In 1989, the need for standardization of dive computers was recognized and normatives were suggested by Ralph Osterhout (Lang and Hamilton, 1989) for:

1. the type of information displayed;
2. the manner in which the information is displayed;
3. the manner in which information is recalled;

4. the decompression models employed; and,
5. a uniform means of telling when a dive computer is in a failure mode, incorporating tests of both the hardware and software.

Sieber (2012) described functional safety as part of the overall safety relating to the system under development; an emergent property of a system that must not endanger human life. The safety of system components, hardware and software alone is meaningless. In most cases, reliability is a necessary prerequisite for safety. Therefore, design methods of reliability engineering are not sufficient for the design of safety critical systems (Leveson, 1995). Applied to dive computer functional safety, this not only means that the device performs according to the requirements, but also that in case of a failure, no harm occurs.

Is a dive computer a safety-critical system (Sieber 2012)? A dive computer gives information about the dive depth and the dive time but also suggests how to perform a dive, i.e., when to ascend, ascent rate, and the decompression schedule to follow. While technical divers and commercial divers tend to use tables, depth gauges and timers to carry out dives, recreational and scientific divers value the features of dive computers that provide continuous tracking of tissue tensions and are able to calculate decompression schedules with wide flexibility. As many divers depend completely on a dive computer while in the water, it is obvious that if incorrect indications are given, DCS, or in worst case, even death, can occur. Therefore, the dive computer is a safety-critical system. This conclusion is also strengthened by a large number of manufacturers categorizing their dive computers as personal protective equipment (PPE).

Within the European Union, CE marking of products is a key indicator of a product's compliance with the EU legislation requiring the protection of the public interest by having safe and reliably functioning products in the common market. Dive computers are an indispensable means to ensure the health and the safety of divers. However, as a product, they do not fall into any of the broadly formulated product groups covered by the Directives that require CE certification, yet certification is necessary because several of their components have to be CE certified. Herein lies part of the complex problem in devising 'global' standards and normatives for dive computers (Sieber, 2012).

It is the manufacturer's responsibility to identify the set of standards that the product has to meet and then assess the conformity of the components. Risk assessment is a key component of this stage and documentation detailing the checks made has to be compiled. The manufacturer also has to assess whether a 'Notified Body' has to be involved to achieve certification, but ultimately, it is the manufacturer that affixes the CE marking to their product, and thus assumes the sole responsibility for compliance, and therefore also liability in the case of an accident.

Inspection of the dive computers sold in the European Economic Area and their user manuals (Table 2) shows that only one manufacturer wholly complies with the requirements for CE certification and carries out checks for conformity with all relevant directives and harmonized standards (Sieber, 2012). The safety of dive computers is not guaranteed to the full extent because of two types of omissions made on the part of the manufacturers. First, some manufacturers confine their tests to a number of Directive requirements. Second, they fail to perform tests on crucial parts covered by other Directives. However, manufacturers often wrongly seek compliance with requirements for a product that they do not integrate in their dive computer.

Table 2. Visual inspection of some dive computer models and their manuals for CE mark and normative/directive compliance (NA: not applicable). From Sieber et al., 2012.

Manufacturer/ Model	CE mark	Air integ.	EN250	EN13319	PPE 89/686/EEC	EMC 89/336/EEC	other
Uwatec Galileo Sol	CE0474	wireless	Y	Y	Y	no	
Uwatec Aladin Tec 2G	CE 0474	-	NA	Y	Y	no	
Mares Nemo Excel	CE	-	NA	no	no	no	
Mares Nemo Air	CE0426	Y	Y	no	Y	no	
Suunto D9	CE0430	wireless	Y	Y	Y	Y	ISO 9001
Suunto D4	CE0430	-	Y	Y	Y	Y	
Suunto Cobra 3	CE0430	Y	Y	Y	Y	Y	
Cressi Sub Archimede 2	-		NA	no	no	no	
Oceanic	CE0120		Y	Y	Y	Y	
Apeks Quantum	CE	-	NA	no	no	no	
Delta P VRX	-		Y	Y	Y	Y	EN14143
Seeman XP5	CE	-	NA	no	no	no	
Cochran EMC-20H	-		NA	Y	no	Y	
Tusa IQ950	CE	wireless	no	Y	no	Y	
Tusa IQ900	CE	-	NA	Y	no	Y	

Several standards are currently applied to dive computers but there is no obligatory standard written specifically for dive computers to meet, nor any suggestions concerning their validation. It is only when a dive computer is integrated with a cylinder pressure gauge that it has to be certified according to EN250 and the PPE Directive become mandatory. A number of the directives and standards that can be applied to dive computers/components are listed below:

1. The EMC directive (89/336/EEC): applies to electrical appliances, requires that they neither cause electrical interference, nor are susceptible to it;
2. EN250:2000: a standard for respiratory equipment, falling under the PPE directive;
3. EN13319:2000: addresses depth gauges and depth/time measuring devices. Decompression obligation is explicitly excluded;
4. PPE Directive 89/686/EEC: aims to harmonize products ensuring a high level of protection and safety throughout Europe. Surprisingly, dive computers, which are used by many divers as indicators for decompression obligations and used to perform a decompression schedule or stay within the no-decompression limits, are not listed in the PPE directive under section 3.11 - additional requirements specific to particular risks – safety devices for diving equipment. Many parts of diving equipment fall under the PPE directive and need to be tested according to underlying normatives. Examples are respiratory equipment (EN250:2002), buoyancy compensators (EN1809:1999), combined buoyancy and rescue devices (EN12628:2001), respiratory equipment for compressed nitrox and oxygen (EN13949:2004) and rebreathers (EN14143:2004) or dry suits (EN14225-2:2005); and,
5. ISO9001: general quality assurance standard; not a specific safety standard.

As a rule, CE marking certifies compliance of a product as a whole unit with the essential safety and health requirements of the Directives that require CE marking. It is beneficial because it boosts confidence in the products circulating within the common market and creates trust that corporate compliance and control procedures are in place and functioning. However, it insinuates that the 'whole' dive computer, not just constituent parts, is certified and this may not always be the case. Therefore, there is a need to unify the requirements for safety performance of dive computers as a whole unit. In the case of a diving accident, the CE mark also shifts the burden of proof of non-conformity and non-reliability away from the manufacturer to the consumer, making it difficult for divers to plead their case in court. Thus, a consolidated standard for DC safety should level the playing field between manufacturers and consumers.

CE marking and compliance also impacts on competition between the DC manufacturers. CE self-assessment and verifications by a Notified Body contribute considerable expense in the value chain of the final product. This results in higher manufacturing costs and higher consumer prices. Non-compliance with CE Directives safety requirements constitutes a competitive advantage in terms of lower costs and better final prices. This, however, comes at the cost of divers' health and safety and is unacceptable.

Protection exists against products that do not meet the CE Directives on safety and health requirements. It takes the form of control conducted by the competent national authorities and where non-conformity is found the circulation of the product in the EEA area might be prohibited and the products withdrawn. This can be coupled with fines and in some Member States like the U.K., for example, depending on the gravity of the violation, imprisonment might be likely.

As a proposed method of consolidation (Sieber et al., 2012) offers two suggestions:

1. Include dive computers in the PPE directive under category III. This would make application of good manufacturing practices mandatory for dive computer manufacturers and therefore a safety life cycle for the complete development would have to be followed. This could increase the functional safety to a higher and more uniform level; and,
2. Draft a normative, specific to dive computers. Rather than being design restrictive by describing a "golden (algorithmic) model for decompression theory" we believe that one should address functional safety. In this regard it would be helpful to reference EN61508, which reduces risk in safety critical systems. Because this is a broad standard, derivation or tailoring would be necessary in order to enable small developers' teams to fulfill certification requirements.

Risk and hazard concerns associated with the use of a device allow the comparison of dive computers to medical devices. Therefore, normatives for medical devices such as IEC62304, ISO14971, and ISO13485 could also be used as a model for drafting a normative specific to dive computers. When it comes to a failure, Sieber et al. (2012) also suggest that the safety status of the dive computer must be displayed, in an unambiguous manner, to the diver. This is not a new suggestion, but has still not been implemented. It would be useful if committees that draft and define these standards have participation not only from manufacturing and legislative bodies, but also from consumer groups and diving medical staff, in order to consider a broad perspective of dive computers and their use.

### ***Validation of dive computer algorithms***

Recreational, technical, scientific, commercial and military diving vary in type of exposures and equipment used, but all have in common a low DCS incidence rate and, by and large, rely on decompression schedules evolved from the original compartment model. The safety record of table use by commercial and military divers is very good. Compared to recreational divers, these divers are usually more extensively trained, fit and more focused on a particular task with a reduced chance of making errors. As discussed above, when tables are utilized during dives that are not square in profile, an intrinsic conservatism is automatically introduced. However, the conservatism of tables is often costly in terms of (operational) time.

The alternative to dive tables is dive computers. They track the profile of the dive very closely, but there is no inherent additional conservatism when performing non-square dives. Further, the target market for these instruments are divers who are not always fit people and are less mission-oriented. Therefore, the dive computer models employed are a detuned, more conservative version of tables (primarily achieved by reducing the tolerated supersaturation levels). Despite the additional conservatism in the algorithms themselves, for most practical uses, dive computers will allow for

more bottom time because profiles are hardly ever square and only a fraction of the time is spent at the maximum depth.

At the heart of the dive computer there is a mathematical model that wants to mimic human physiology under hyperbaric conditions and any such model has a limited range of applicability. Using a model outside of the validated range carries obvious risk, but even its use within the validated range needs to be addressed with caution. We cannot assume *a priori* that a multilevel dive computed as an extension of the multi-compartment theory validated via square dives is going to follow the same rules.

The aim of a study by Angelini (2012) was to collect a number of relevant computers from the market and analyze their behavior when subjected to a large number of profiles. The computers included:

1. Cochran EMC-20H;
2. Cochran NAVY AIR III;
3. Delta P VRX;
4. Mares Puck;
5. Suunto Vyper Air; and,
6. Uwatec Aladin Prime.

Each profile was then also “dived” using two commercially available PC-based dive planners. The profiles ranged from square, no-decompression dives to multilevel long decompression dives. This analysis attempted to assess the range of options and provide a guideline for future, separate studies, including human trials, from which judgments on safety could be derived. Two hundred thirty four chamber test dives were carried out with profiles ranging from square to triangular, multilevel forward and multilevel reverse, to a maximum depth of 54 msw with air as the breathing medium for all dives. A first phase considered only no-decompression dives, a second phase considered decompression dives at two levels of PRT (pressure root time) and a third phase considered repetitive dives with various surface intervals.

The VVAL-18 implemented in the Cochran Navy AIR III is supported by a wealth of documentation describing the validation performed by the U.S. Navy (Doolette et al., 2012). No significant details were provided by any of the other manufacturers about the decompression algorithms incorporated into their dive computers.

Of the very wide offering of dive computers on the market today a representative portion was sampled. Angelini (2012) found that while some computers are more conservative and some are more liberal, there were several in astonishing agreement throughout all tested profiles, especially when it came to the first dive of a series (non-repetitive dive). Furthermore, this agreement was found within the three brands that cover well over 50% of the worldwide market. Given the millions of dives performed every year using these computers, and the very low DCS incidence rate in recreational diving, one might infer that there is such a thing as a standard reference. Most of these dives, however, fall far short from stressing the underlying models, so a conclusion as to the actual conservatism, or lack thereof, cannot be reached in any of these computers. Repetitive dives with short surface intervals (one hour or less) provided less agreement between the various computers, even among the three that otherwise agreed extensively. Angelini (2012) concluded that whereas a relatively standard Haldanean implementation was at the core of these computers, different types of mathematical manipulations were employed to account for residual nitrogen. This indicates that the true impact of residual nitrogen is not fully understood.

The range of applicability may indeed be the key question when assessing dive computers. Since dive tables are of limited range, one cannot extrapolate beyond them. As long as the tabulated dives have been validated (or at least tested with some measured outcome), using tables should produce a safe or at least known outcome. A dive computer on the other hand continues to calculate and may be well out of its area of competence before an out-of-range message, if any, is displayed. We can only comment on the relative conservatism of dive computers and PC-based dive planners. To go beyond this, one would need to devise a test plan with human trials, possibly drawing from this study when trying to identify which profiles to test (Angelini, 2012).

#### ***U.S. Navy dive computer validation***

If on diving under water, gases in the tissue reach a supersaturated state, then upon decompression bubbles may form and there will be potential for DCS to occur (Doolette et al., 2012). In order to manage the risk of DCS, dives are conducted according to depth/time/breathing gas decompression schedules derived with decompression algorithms that implicitly or explicitly limit bubble formation by slowing decompression, typically by interrupting ascent with “decompression stops” to allow time for tissue inert gas washout. Practical decompression algorithms balance the probability of DCS ( $P_{DCS}$ ) against the costs of time spent decompressing. Modern, diver-carried dive computers sample *ambient pressure* at frequent intervals and use this as input to simple decompression algorithms that provide decompression schedules updated in real time.

The principal requirement for a dive computer is that it provides decompression profiles with a low incidence of DCS. For the military and commercial communities, decompression should also be efficient, because time spent decompressing is unproductive (costs money) and prolongs exposure to a hostile environment. Requirements will be specific to diving practices and to particular populations of divers because no decompression algorithm is suitable for all types of diving. Validation of a system such as a dive computer is simply a demonstration that it matches its requirements, so it should entail measurement of the incidence of DCS, or estimation of  $P_{DCS}$  by some other method, associated with its decompression guidance (Doolette et al., 2012).

Validation could be accomplished by subjecting a dive computer to many different depth/time dive profiles and evaluating the  $P_{DCS}$  of resulting decompression guidance. Such validation could be done without knowledge of the underlying decompression algorithm. Alternatively, the decompression algorithm can be validated separately from the dive computer, by measuring  $P_{DCS}$  associated with another implementation of the algorithm. The latter would then be the “gold standard” implementation. In this case, validation of the dive computer would follow from verification that it is a faithful implementation of the decompression algorithm by comparison of the dive computer behavior to the gold standard implementation. In this approach, understanding of the decompression algorithm can guide the validation process. It is this latter approach that is used by the U.S. Navy.

The U.S. Navy Dive Computers (NDCs) are built by Cochran Undersea Technologies (Richardson, TX) but implement the Thalmann Algorithm, a decompression algorithm developed at the U.S. Navy Experimental Diving Unit (NEDU). There are now several configurations of the NDC tailored to the requirements of different diving communities within the U.S. Navy and different diving operations breathing open-circuit air or constant  $pO_2$ . The history of the development of the original NDC is reviewed in Butler and Southerland (2001).

Doolette et al. (2012) described the VVal-18 Thalmann algorithm as a neo-Haldanean decompression algorithm, similar to many implemented in dive computers. Inert gas uptake and washout is modeled for a set of parallel tissue compartments, but it differs from earlier algorithms in that washout can switch from a normal exponential approach to a much slower linear approach when a compartment is supersaturated, which provides appropriately extended decompression times.

The development process included testing the algorithm via 1,505 air and nitrox man-dives (84 cases of DCS) with the algorithm and parameters being adjusted in response to schedules with high incidences of DCS (Thalmann et al., 1980; Thalmann 1984; 1986). In a more recent test of VVal-18 Thalmann Algorithm air decompression, 192 dives to 170 feet sea water (fsw) for 30 minutes bottom time resulted in only three cases of DCS (Doolette et al., 2011). The MK 16 MOD 1 N<sub>2</sub>-O<sub>2</sub> VVal-18 Thalmann Algorithm decompression tables were validated with 515 man-dives that resulted in seven cases of DCS (Johnson et al., 2000; Southerland, 1998). All of these man-dives were conducted in the wet pot of the Ocean Simulation Facility at NEDU under conditions relevant to occupational divers: divers worked on the bottom and were at rest and cold during decompression - conditions shown to increase the risk of DCS (Van der Aue et al., 1945; Gerth et al., 2007). In carrying out these manned dives, the algorithm was validated under operationally relevant conditions that demonstrated acceptable P<sub>DCS</sub>.

The NDC was then tested to verify that it was operating on a faithful implementation of the Thalmann Algorithm. This was done using functional testing of NDCs, and comparing their behavior to “gold standard” decompression schedules (Doolette et al., 2012). These gold standards exist in two forms: the gold standard printed VVal-18 Thalmann Algorithm decompression tables (Thalmann, 1984) and the MK 16 Mod 1 N<sub>2</sub>-O<sub>2</sub> decompression tables (Johnson et al., 2000) that have appeared in several revisions of the U.S. Navy Diving Manual. The gold standard software implementations are the Thalmann Algorithm Decompression Table Generation Software and the Navy Dive Planner. The latter software package is designed specifically to complement the NDC and is convenient for generating multilevel dives and decompression schedules of any complexity against which to test the NDC.

Finally, a sample of 10 to 30 of each configuration of the NDC was functionally tested by exposing them to simulated dive profiles in a small, flooded test chamber and comparing the NDC prescription to the gold standard Navy Dive Planner decompression schedules (Southerland, 2000; Gault and Southerland, 2005; Gault, 2006; Southerland et al., 2010). Doolette et al. (2012) describe this type of functional testing as “black box” testing because the tester has no access to internal data structures and computer code. It is essential that black box testing uses a suite of dive profiles that exemplify all expected operational uses of the dive computer. The outcome of dive computer testing only remains valid while the system remains unchanged and by agreement with the manufacturer, no hardware or software changes are made to any configuration of the NDC after it has passed validation testing at NEDU. Every NDC unit undergoes a simple functional test of pressure sensor accuracy at purchase and subsequently every 18 months.

When using decompression tables, schedules are selected on the maximum depth reached at any time during the dive and may require round-up to the next deeper depth and longer bottom time. Avoiding this costly round-up procedure is a principal motivation for using dive computers, which calculate decompression debt in real time. As a result, dive computer guidance is generally expected to present greater risk of DCS than using printed tables calculated using the same decompression algorithm.

Doolette et al. (2012) reported that the U.S. Navy had not collated data on the incidence of DCS using NDCs; to date, the NDCs have been used principally to keep dives within no-stop limits, with little DCS expected and none reported. Going forward, NDCs will be used to conduct dives to no-stop limits and to conduct decompression dives. Recently, 92 decompression dives were conducted in open water using NDC guidance and no DCS was reported. However, this is a small sample and the U.S. Navy relies on probabilistic model estimates and the outcome of laboratory trials of the VVal-18 Thalmann Algorithm to quantify the expected incidence of DCS when NDCs are used to conduct dives to no-stop limits and to conduct decompression dives.

The U.S. Navy experience with validating NDCs can serve as general guide for validating a commercial-off-the-shelf (COTS) dive computer as illustrated in Figure 2 (from Doolette et al., 2012). For practical purposes, this framework may need to be modified for a COTS dive computer. Validation must occur within a configuration control framework, or via a 'configuration manager' (represented by the diamond in Figure 2), that ensures re-validation if any changes are made to the dive computer software or hardware configuration after it has initially been brought to market.

#### ***The use of venous gas emboli to validate dive computers***

Many decompression models use DCS as a measurable endpoint, but often it is not practical to commit the time or money to the large number of dives necessary for validation, nor is it particularly ethical to provoke DCS. Venous gas emboli (VGE) nearly always accompany DCS, although their presence does not have a direct relationship with clinical symptoms. However, VGE are an accepted indicator of the level of decompression stress that a diver is subjected to. In this way, VGE can be used as a tool to help in the validation process.

The task of validation should be as simple as testing whether the computer provokes DCS or not, and complete enough dives to determine a certain level of risk. However, many dives are necessary primarily as DCS is such a rare event. The U.S. Navy NDC validation process was both lengthy and costly, as such a large number of human dives had to be made to test the algorithm incorporated (Doolette et al., 2012). Gerth and Vann (1996) suggested that a suitable acceptance of DCS incidence was two cases in 142 trials, which would impart a 0.17 - 5% risk of DCS. However, it is very unlikely that the Norwegian Authorities would ever accept a 5% risk of DCS, even in the initial stages of a trial, meaning that the level of risk needs to be reduced even further. To do this, far more dives would be necessary. Gutvik (2011) claims that to achieve a 1% risk at a 95% binomial confidence level, 369 symptom-free dives would have to be made, and if one DCS hit were recorded, the total would rise to 558 dives. If it is accepted that around 500 dives are needed to test one profile in order to bring it to an acceptable level of DCS risk, then it becomes apparent that a huge number of dives are necessary, as more than one profile needs to be tested on the computer.

Many dive profiles would need to be tested, including shallow long exposures, deeper shorter exposures and multilevel dives, but a conservative estimate of the number of bottom time/depth exposures that need to be tested might come to approximately 10 permutations (Gutvik, 2011). Workload and where the work is performed (bottom phase/deco phase), water temperature and insulation, repetitive exposures and type of gas all need to be taken into consideration. Gutvik (2011) suggested that if five different values for each of these parameters were tested, then the total number of dives that should be performed could be calculated as 500 (dives to test one profile) x 10 (profiles) x 5 (workloads) x 5 (temperatures) x 5 (gas types) x 5 (repetitive exposures) = 3,125,000 total dives to be made. After this, multilevel exposures should also be taken into account, including triangular dives, recompression spikes, yo-yo diving and the like. There are so many variations that would need be tested on the computers that it is simply impossible, so a different approach is necessary. Blogg and Møllerløkken (2012) suggest that perhaps measuring VGE would help resolve the problem.

## U. S. Navy Dive Computer      COTS Dive Computer

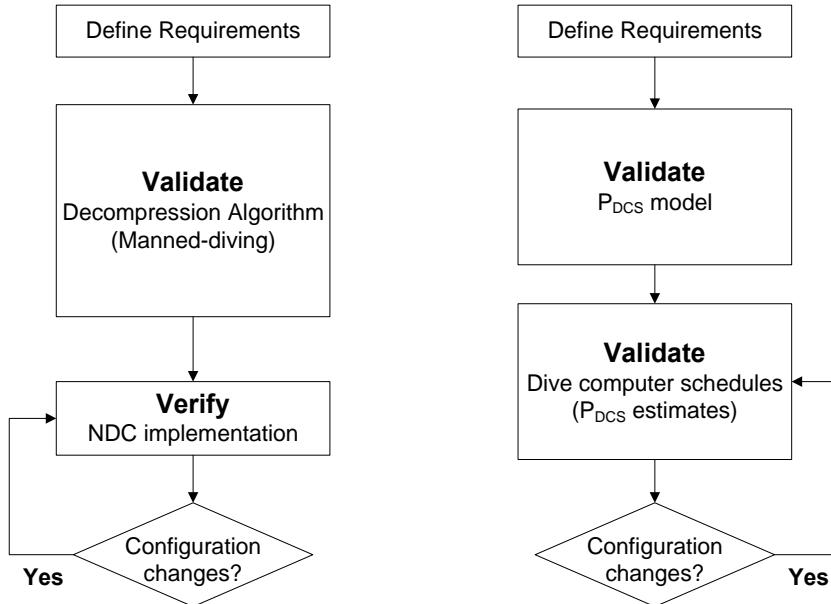


Figure 2. Outline of validation of the U.S. Navy Dive Computer and a proposed framework for validation of a COTS dive computer (from Doolette et al., 2012). The size of the boxes is intended to indicate the level of effort. Development, validation, and documentation of the Navy VVal-18 Thalmann Algorithm was a large effort. Consequently, verification of the NDC implementation of the algorithm can be a substantially smaller effort. Development and validation of a probabilistic decompression model ( $P_{DCS}$  model) is a substantial effort, but many already exist. Many dive profiles would need to be generated with an undocumented COTS dive computer decompression algorithm and then evaluated using the probabilistic decompression model.

Historically there has been dispute over the relationship between VGE and DCS, but it can be summed up by saying that ultrasonic measurement of VGE has a higher sensitivity with a very low specificity. Eftedal et al. (2007) opined that the data strongly suggest that for some saturation diving the absence of detectable bubbles is a good indicator of decompression safety, but the occurrence of bubbles, even higher grades, is a poor predictor of decompression sickness. Gutvik (2011) argues that in order to exploit the characteristics of the VGE, a method based on Bayesian statistics be used. It essentially uses *a priori* statistics on VGE and DCS to analyse VGE-only data for DCS risk, greatly reducing the number of test dives that have to be made. It should be noted that when carrying out trials using this method there is often no occurrence of DCS, so if validation were to be made from the point of view of DCS, then obviously nothing would be learned at all. Previously established relationships can be used to determine point risk estimates of the exposures and also credibility intervals that are narrower than looking for DCS exclusively (Gutvik, 2011). In this way, the higher sensitivity of the VGE measurement can be exploited. The point of the Bayesian method is to gain an accurate prediction with as low a sample size as possible. Success does depend to some extent on drawing a fortuitous subset from pre-existing data, but it seems that far less exposures are necessary to draw the same conclusions.

If the number of dives that have to be made to validate this method were reduced significantly, a huge number of dives would still have to be made. Weathersby et al. (1984) worked with probabilistic modeling. Instead of specifically validating a procedure, computer or schedule, this method attempted to predict the behavior of a model and it is now used by the U.S. Navy to predict risk of DCS, P(DCS). There are several obvious advantages: the first is that any type of dive can and should be included for calibration. Historical data can be used, while a predictive model also provides a better risk assessment and gives a more consistent risk of control because optimal procedures can be used (Gutvik, 2011). The disadvantages include that a significant amount of DCS data must be present in order to make the predictions valid, because if there is no DCS, even huge amounts of data will not reveal anything. Another disadvantage is the lack of diversity in the historical data that is available, which makes it difficult to assess entirely new decompression profiles.

Gutvik (2011) hypothesized that the high sensitivity of VGE could be exploited in a probabilistic model to better effect than DCS occurrence. This is the reasoning behind the Copernicus model, which, instead of predicting the risk of DCS, predicts the amount of VGE produced after any dive exposure. The problem is viewed via a physiological approach and a model produced to predict VGE load using parameter estimation. The set of parameters to be defined by the model are identified, the model is excited with a specific exposure, a measure is made and the outcome can then be estimated. In the case of Copernicus, the endpoints of this exposure are VGE. The model estimation of VGE can then be compared with actual measurements and a large range of exposures used to calibrate the model. The aim is to draw a map comparing the real world outcome and the model. The crucial factor with this kind of predictive modeling approach is that for best results, the model should be excited with as much diversity as possible. If the model is not excited enough, then it will give a perfect fit to the limited data it is tested against, but will start to fail the moment that it is extrapolated.

It must be noted that the use of VGE could lead to excessive conservatism within a model. If the ultimate goal is to dive to a certain level of DCS risk, bubble loads are indicative of decompression stress, but there exists no definable linear relationship with DCS occurrence. A consensus agreement on endpoints, whether they are occurrence of DCS or degree of VGE load, remains elusive. For models such as Copernicus, at some point a bubble grade will have to be agreed upon as an endpoint, so that a level of conservatism will be implicit that is not binary in nature (Gutvik, 2011). For example, Defence Research and Development Canada (formerly DCIEM) has selected a limit of Kisman Masurel (KM) grade II or greater in 50% of subjects to discriminate between stressful and acceptable procedures (Nishi and Eatock, 1989). Eftedal et al. (2007) have previously suggested that by designing decompression procedures so that less than 50% of the subjects have bubble scores of III and IV, the DCS risk should be less than 5%, while Pollock (2008) suggested that VGE data should be interpreted conservatively, with an analytical focus on the most meaningful Doppler grades – III or higher – on standard scales. Therefore, in some cases it is anticipated that decompression profiles may be discarded when using a VGE endpoint that otherwise might have been accepted if using DCS, albeit having had to perform many more dives to reach that outcome. However, if the aim is to test different algorithms or dive computers against one another, to find the one that provokes the least physiological decompression stress for a particular depth/bottom time combination, then this approach would be ideal (Gutvik, 2011).

### ***Dive computer program management***

Dive computer validation procedures, normatives and standards, and algorithm validation provide the foundation that allows Diving Control Boards to consider approval of dive computer use by scientific divers. There is an operational need for an ongoing, systematic, methodical monitoring of dive computer use by scientific divers. An exemplar of dive computer program management by a scientific diving program is provided here.

Lang (2012) described the Smithsonian Scientific Diving Program (SDP) as a large U.S. civilian scientific diving program through which, since 1990, approximately 140 active scientists logged over 3,400 dives annually in a multitude of locations around the world. In 2005, the need was identified to develop a management tool to assist in compiling and monitoring diving activities: a web-based virtual dive office, DECOSTOP. Launched in 2007, it has provided an efficient mechanism to submit diver applications and dive plans, maintain diver medical, equipment, training and certification records, enter dive log information, and review and authorize diving projects under Smithsonian auspices. Besides the benefit of paperless-database functionality, dive profile information collected through the dive log upload function has proven superior to previously collected data. Since 2010, all Smithsonian-authorized diving requires the use of a Smithsonian-issued dive computer from which all dive profiles are now directly uploaded to a database in DECOSTOP for review and collation. Former dive log information submitted as “shells” (i.e., maximum depth and time) provided no measure of the physiological stress level of a particular dive nor any abnormalities considered to be triggers for DCS such as rapid or multiple ascents, violation of ceilings, or inadequate decompression. In the future, it may be beneficial to look at the percentage loading of the model (i.e., how far a dive profile pushes the algorithm towards its limits) and add this functionality to the software.

The SDP diving safety regulations pertaining to dive computers have been continuously updated since 1990 and were derived primarily from the output of diving safety research projects conducted specifically for the scientific diving community by the SDP (Lang and Hamilton, 1989; Lang and Egstrom, 1990; Lang and Vann, 1992; Lang and Lehner, 2000; Lang, 2001). The SDP has long maintained that the ultimate responsibility for safety rests with the individual scientific diver. Only those makes and models of dive computers specifically approved by the program’s Scientific Diving Control Board (SDCB) may be used. Since 1990, the program has approved SUUNTO, UWATEC, and Orca Industries models and since 2010, has implemented the SUUNTO ZOOP as the standard required dive computer to be worn on all Smithsonian scientific dives. Each diver relying on a dive computer to plan dives and indicate or determine decompression status must wear his/her own unit and be proficient in its use. It is strongly recommended that each diver also dive with a back-up dive computer, because they do occasionally fail. A diver should not dive for 18 hours before activating a dive computer to use it to control his/her diving. Once the dive computer is in use, it must not be switched off until it indicates complete offgassing has occurred or 18 hours have elapsed, whichever comes first. Only one dive in which the no-decompression limit of the dive computer has been exceeded may be made in any 18-hour period. On any given dive, both divers in the buddy pair must follow the most conservative dive computer. If the dive computer fails at any time during the dive, the dive must be terminated and appropriate surfacing procedures initiated immediately. In an emergency situation breathing 100% oxygen above water is preferred to in-water air procedures for omitted decompression.

Ascent rates are controlled at 10 m/min from 20 msw and do not exceed 20 m/min from depth. A stop in the 3-10 msw zone for 3 to 5 minutes is required on every dive and multi-day repetitive diving requires that a non-diving day be scheduled after multiple consecutive diving days. Reverse dive profiles for no-decompression dives less than 40 msw with depth differentials less than 12 msw do not lead to a measurable increase in DCS risk. A PO<sub>2</sub> of 1.6 atm is the maximum limit for enriched air nitrox for which standard scuba equipment is approved for up to 40% oxygen content.

Scientific divers are further cautioned about exceeding model and/or tested dive computer limits, blindly trusting the dive computer (i.e., the brain still needs to be turned on to make decisions from the dive computer numbers being displayed), ignoring decompression requirements, continuing to dive with a dive computer that malfunctioned on a previous dive or switching dive computers during a day of diving, and that repetitive multi-level, multi-day diving needs allowances to adequately offgas slow tissue half-times.

Much consideration was given to the selection criteria of a dive computer that would meet scientific diving needs. Dive computer operation should be effortless through easy-to-use push buttons, wet switch activation and a straightforward menu-based user interface. A dive computer with metric/imperial unit option, date and watch function of 12/24 hours, water resistance to 100 msw and light weight were prioritized features. A bright phosphorescent LCD display and an option of wrist unit or console-mount assist in ease of reading displayed data. Multi-mode versatility should include a programmable function for enriched air nitrox (EANx) mixtures of 21% to 50% O<sub>2</sub> and adjustability for partial pressures of oxygen (pp O<sub>2</sub>) between 1.2 - 1.6 bar, CNS% and OTUs (oxygen toxicity units).

Further considerations included the type of algorithm and documented experience with it (the SUUNTO RGBM algorithm in SDP's case). Ascent rate and available no-deco time need to be displayed graphically with clear color-coded indicators and the availability of visual and audible alarms when necessary was also a desirable feature. The dive computer had to be powered by a user-replaceable 3V lithium battery, and have a power indicator and low battery warning. Because of the SDP's polar and tropical diving work, dive computer operating temperatures should range between 0°C to 40°C, and have a storage temperature between -20°C to 50°C. Other functions had to include altitude adjustability, ascent rate monitor, dive planner, decompression data, log book memory, maximum depth of 100 msw, 3-30 sec sampling rate option, safety stop countdown, and temperature recording.

The implementation logistics started with the establishment of policy that required use of SDP-issued ZOOP dive computers. A dive computer training module was developed and the SUUNTO ZOOP user guide was made available on the SDP web site. Scientific divers are required to log all dives via dive computer download on DECOSTOP, using web browser interfaces to interact with an SQL database through a relational database management system provided by the Smithsonian Office of Information Technology. It is recognized that it would be preferential if dive computer manufacturers standardized their dive profile download software for all dive computer types.

The overall issue with dive computers remains the mechanism of repetitive dive control. On balance, the 28-year operational experience with dive computers has demonstrated that their advantages over table use outweigh the disadvantages. The large range of dive computer variability demands that the establishment of their selection criteria meets a particular diving community's specific needs. An important element of this approach is the characterization of a community-specific universe of 'safe' dive profiles for which the computer is effective through use of a dive computer monitoring program. Dive computer validation to the specific model's limits, as has been traditionally tested with dive tables via human subjects testing, is not likely to occur because of the time and expense involved and the infinite combination of dive computers and settings.

## **Discussion**

The EUBS Validation of Dive Computer Workshop (Blogg et al., 2012) involved discussion leading to a set of consensus findings and recommendations that were delivered to the Norwegian Labour Inspection Authority. General community-specific requirements were outlined as follows: acceptance that at present decompression sickness is the measurable negative outcome; specification of an acceptable level of DCS risk and how it is measured; definition of a window of applicability for the dive computer; requirement of the support of a dive planner for the dive computer; and, the need for documentation and verification of equipment functionality/functional safety.

The Workshop agreed on specific findings applicable to commercial diving: A dive computer is a risk management tool. The operational risk of DCS in the recreational and scientific diving communities is no worse than previous experience with sub-no-decompression diving compared to table use, primarily because the dive computers are not pushed to their model or algorithm limits. There is no evidence that multi-level dives with dive computers are more risky than square dives following the same algorithm; documentation of theory (i.e., logic and equations) is required to answer what's in the box?; this documentation must include methods to test the implementation of the theory in the dive computer; use a DCS-risk indicator model to validate the algorithm, or manufacturers may produce a dive computer with a validated and documented algorithm; specify platform technical requirements; and, develop and implement a configuration control plan.

The workshop recommended and advocated that a validated dive computer would be a useful tool for providing real-time decompression guidance for working divers; that a mechanism including judgment be part of the system; and, institution of a Configuration Control Board to assess conformance with validation requirements, monitor dive computer operational performance, and specify diver education and training.

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## Reef Check California: Applied Ecosystem Monitoring as a Training Tool for AAUS Programs

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### Abstract

Ecosystem-based strategies have become an important aspect of marine resource management in California over the last decade. This development has greatly increased the need for long-term environmental monitoring data to properly assess management outcomes and adapt accordingly. To address this need Reef Check California (RCCA) trains recreational volunteer scuba divers and AAUS scientific divers as citizen scientists to conduct subtidal surveys of the near-shore rocky reefs. RCCA partners with AAUS programs, providing a valuable teaching tool to these institutions while strengthening its statewide monitoring program through the involvement of scientific divers. Currently, RCCA partners with seven AAUS dive programs at universities and aquaria throughout California, training around 60 new AAUS Reef Check volunteers per year. These programs have in turn adopted 13 survey sites and have provided assistance for the remaining 67+ sites surveyed by RCCA. The divers learn fundamental subtidal monitoring techniques while collecting data that is provided to the state's marine management agencies. These collaborations have made the RCCA protocol one of the prime examples of subtidal research that students in California's marine undergraduate programs are exposed to. It provides them with the hands on experience of collecting useful data that will serve them well as they go on to develop future research projects.

Keywords: citizen science, diving, kelp forest, marine management, rocky reef, subtidal monitoring

### Introduction

There has been a fundamental shift during the past decade in the methods in which California's coastal resources are being managed. Marine management has moved from a focus on single species to ecosystem-based management strategies (Ruckelshaus et al., 2008; Stokstad, 2010). This shift has increased the need for long-term high-resolution monitoring data to properly assess management measures and to adaptively manage resources (McLeod et al., 2005). Because of the increasing need for broad, long-term datasets, paired with shrinking budgets, policy makers and scientists alike are beginning to rely more heavily on data collected by community members trained as citizen scientists (Levrel et al., 2010). Reef Check California (RCCA), a program of the Reef Check Foundation, has been training community members since 2006 to scientifically monitor nearshore rocky reefs and kelp forests to provide data to aid marine management and policy decisions in California.

### Methods

#### *RCCA protocol*

Reef Check volunteer citizen scientists conduct annual monitoring surveys at over 80 coastal sites from Mendocino to San Diego counties. A survey consists of eighteen 30m x 2m x 2m belt transects

for fish, six 30m x 2m benthic transects for invertebrate and algae, and six 30m substrate characterization transects (UPC), as well as an urchin size frequency survey. Transects are distributed in a stratified random design across depth zones to sample from five to 18 meters depth. Along each transect, seventy-four fish, invertebrate, and seaweed species that were chosen as indicators based on their ecological or economic importance are counted and sized. Reef Check trains experienced scuba divers to conduct these transects through classroom and field training (Shuman et al., 2011). After extensive testing in all four survey types, divers can take part in those types of surveys that they are qualified for. After the initial training, volunteers must participate in an annual recertification to collect data in subsequent years.

### ***Partnerships with AAUS programs***

Since its inception RCCA has partnered with AAUS diving programs throughout the state. Currently the Reef Check monitoring protocol is taught as part of the Science Diver training class at seven universities and aquaria: Humboldt State University, University of California Santa Cruz, Moss Landing Marine Laboratories, California State University Monterey Bay, Monterey Bay Aquarium, University of California Santa Barbara, and Long Beach Aquarium of the Pacific, training around 60 AAUS Reef Check volunteers per year. Through this approach, students learn a common monitoring technique and become familiar with many of the most conspicuous organisms seen while diving. After completing the training, students have the opportunity to practice the tasks required to conduct marine field work as they organize surveys, dive to collect data and enter it into an online database. In turn these programs have adopted 13 sites that are surveyed each year, and many of their divers assist with the remaining 67+ statewide Reef Check sites. Surveys provide a way for students to maintain their required AAUS dives and gain scientific skills beyond the scope of their training. At the same time, diving with RCCA involves them in the collection of data that is used for marine management and is available to students to investigate research questions in the rocky reef and kelp forest habitat.

Each participating AAUS program generally conducts one training per year providing Reef Check with a pool of highly trained and competent divers at minimal expenditure. Because of their AAUS certification RCCA can utilize these volunteers when using state research vessels that require AAUS certifications (e.g. Department of Fish and Game or university vessels). Partnering with AAUS programs essentially reduces RCCA programmatic costs while not only increasing the total number volunteer divers but also providing opportunities for resource sharing with other monitoring and research programs. The integration of the RCCA program into AAUS diving programs provides Diving Safety Officers (DSOs) with a readily available curriculum and teaching tools to introduce their students to subtidal ecosystem monitoring. Reef Check's work with AAUS programs has made the RCCA monitoring protocol one of the prime examples of subtidal research that students in California's universities are exposed to and gives them hands on experiences that will serve them well as they go on to develop research projects.

One challenge in working with AAUS programs is that it can be difficult to keep students involved in doing surveys after they are trained. To address this, it is important that the DSO or an associate of a program is trained as an RCCA instructor and participates in surveys. This is not only so that they can instruct trainees but also to inspire students to take part in surveys later. Ideally, students contribute to at least one actual survey during their Science Diver training course, so that upon completion of the course they are confident in their abilities to survey outside of class time.

### ***RCCA data***

Reef Check data has been used in the design as well as in the baseline and long-term monitoring of California's new and growing network of marine protected areas (MPAs). During the creation of MPA regional networks, stakeholders were able to utilize Reef Check's monitoring data for the North/Central, Southern, and North Coast planning processes. After MPA implementation, RCCA

joined a consortium of research programs to collect and evaluate baseline ecosystem data for MPAs in all regions. These data will describe the state of the ecosystem at the time of MPA implementation and serve as a baseline against which to measure management successes or failures and adapt management appropriately. RCCA's involvement in the MPA monitoring also generates the opportunity for community members to remain involved in the MPA management process beyond the stakeholder-driven implementation phase.

Often there is a distrust in the quality and reliability of volunteer collected data in the scientific and management communities (Conrad and Hilchey, 2011). To address this, RCCA's protocol was designed with the oversight of academic and government agency scientists, uses similar metrics and focuses on many of the same species as the protocols used by most prominent academic and agency monitoring groups in California (including the Partnership for Interdisciplinary Studies of the Coastal Oceans (PISCO) and the CRANE protocol used by researchers and the California Department of Fish and Game). To insure the quality of the data and investigate its potential for integration with other datasets Reef Check continuously collaborates with academic and agency monitoring programs. In 2012, Gillett et al. found that RCCA data describes the rocky reef ecosystem in southern California similar to professional monitoring programs for many of the monitoring metrics and concluded that datasets from both professional and citizen scientists could be integrated and are useful for informing marine management.

## **Discussion**

Citizen science programs such as Reef Check are becoming an increasingly important part of marine management and conservation. RCCA demonstrates how engaging community members in monitoring can provide a cost-effective solution to the growing need for environmental data as well as inspire public support of science-based management. Partnering with AAUS programs provides RCCA with well-trained volunteer divers and opportunities to work with university research programs and share resources. Recently, teams of students have begun to monitor sites in their regions independently and this is a trend RCCA will further promote in the future. One graduate student used RCCA protocol to investigate seasonal variation in fish abundances for her thesis (Prindel et al., 2012), thus indicating the benefits of monitoring sites more frequently and spurring an interest in biannual or quarterly monitoring of adopted sites by several AAUS groups. RCCA is aimed at forming additional partnerships with AAUS programs particularly in regions of the state that are currently underrepresented. The integration of the RCCA into AAUS diver programs has provided DSOs with teaching tools and an applied protocol to introduce students to subtidal monitoring. Taking part in the program installs a sense of stewardship and an opportunity to support marine management and conservation efforts in California. Participating students gain valuable research skills and are trained by collecting useful data preparing them for future research projects.

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## “SeaPhoto:” Central California Marine Life Featured in New Free iPhone, iPad App

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### Abstract

The objective of this talk is to present divers, teachers, students, researchers and others with the wealth of information about central California marine life available through the new iOS application released by NOAA's Monterey Bay National Marine Sanctuary. The free "SeaPhoto" app includes more than 1,300 photos of marine life, some with detailed ecological information. In addition to the photos of more than 550 species of marine life, the app includes an extensive, searchable glossary of common and scientific names. Users can save their favorite photos and share them via Twitter® and email. Developed in partnership with the Monterey Bay National Marine Sanctuary Foundation, SeaPhoto can be downloaded from the Apple App store ([wwwitunes.com/apps/Seaphoto](http://wwwitunes.com/apps/Seaphoto)) onto an iPhone®, iPod Touch® or iPad®. The app is a mobile extension of an even larger online photo library that contains over 4,200 photos of seascapes and marine life that can be accessed at [www.sanctuarysimon.org/photos](http://www.sanctuarysimon.org/photos). These photos can be downloaded for free for non-commercial use. Monterey Bay National Marine Sanctuary stretches along the central California coast and encompasses more than 6,094 square miles of ocean. Renowned for its scenic beauty and remarkable productivity, the sanctuary protects one of the world's most diverse ecosystems.

Keywords: app, ecology, iPhone, photos, species, Twitter

### Introduction

The confluence of advances in digital camera technology and internet infrastructure has created an opportunity to develop a rich pool of online and fully searchable digital photographs of central California marine life, seascapes, and human uses. In 2003, the Monterey Bay National Marine Sanctuary launched the Sanctuary Integrated Monitoring Network (SIMoN) website, the main purpose of which is to collate and disseminate metadata of long-term monitoring projects occurring within the Sanctuary.

To fill a regional need for high quality photos of marine life and Sanctuary resources, staff started acquiring imagery, both subtidal and topside. Select images were indexed by species (primary, secondary, and tertiary), location and keywords and uploaded to an online server with a corresponding database. Users can now browse or search through more than 4,200 digital photos at [www.sanctuarysimon.org/photos](http://www.sanctuarysimon.org/photos).

With the great success of this online digital photo library, the next step in its development took it mobile. The first generation of "SeaPhoto" was developed on the Apple mobile operating system, or "iOS" as an application or "app." SeaPhoto represents a distillation of the most relevant and best photos that SIMoN has to offer, with more than 1,300 photos and 550 species. The app is only 4 MB, thus can be downloaded over a cellular connection. Species can be browsed alphabetically by

common name or Latin name within a major category (marine mammals, invertebrates, algae, etc.) or searched for by dynamic text input. All photos are subsequently downloaded “on demand” before becoming permanently stored on the device. Photos can be marked as favorites, emailed, or even tweeted through embedded Twitter® services. Detailed life history information is included for 140 species, as well as a glossary of terms, and links to Sanctuary websites.

SeaPhoto is a relatively simple app, but provides streamlined mobile access to a wealth of central California marine life photos and associated information. In an effort to keep the development costs low, and thus, the app free to the public, Sanctuary staff developed all content for SeaPhoto, and the majority of the programming was completed by an outside contractor. SeaPhoto will be expanded and refined into the future, with additional species, photos, and features, and at some point, an Android® version will be developed. SeaPhoto will run on any iOS device (iPhone®, iPod Touch®, or iPad®) that is running iOS 4.2 or later, and can be downloaded from [www.itunes.com/apps/SeaPhoto](http://www.itunes.com/apps/SeaPhoto).



Figure 1. The loading, or “splash” screen that appears when SeaPhoto is launching.



Figure 2. From left to right: Users can browse by main group; Users can search or browse by common or latin name; Up to 5 photos are available for viewing for each species.



Figure 3. When the device is rotated to landscape, the photos will also rotate to landscape.



Figure 4. From left to right: Users can share photos through email; users can “tweet” photos through Twitter®; Detailed life history information is available for 140 species.

## Acknowledgments

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## Growth and Distribution of the Invasive Bryozoan *Watersipora* in Monterey Harbor, California

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### Abstract

Invasive species are common inhabitants of harbors along the coast of California. Tunicates, sponges, and bryozoans are among the more common invertebrates found in fouling communities on floating docks and pilings. An invasive bryozoan, tentatively identified as *Watersipora subtorquata*, has been in Monterey Harbor since the early 1990s, but only recently has it been detected outside of the harbor. Since relatively little is known about *Watersipora* and its interactions with other sessile species in California, sanctuary staff studied the growth and distribution of *Watersipora* in Monterey Harbor beginning in 2010. Sanctuary science divers used monthly fixed photo quadrats to collect percent cover data from cement pier piling surfaces in four orientations and at two depths. Colony growth of the invasive bryozoan was rapid (up to 0.33 mm/d) and exhibited differences by piling, orientation, and depth. Percent cover of several native invertebrate species was correlated with the presence/absence of *Watersipora*, and the invader has the potential to form monocultures, smothering all other species. Sanctuary staff will continue to characterize the spread of this invader within the harbor and collaborate with academic researchers to determine its ecological impact in nearby kelp forests.

Keywords: bryozoa, invasive species, photo quadrats, *Watersipora*

### Introduction

Global homogenization has increased at an alarming rate over the last 20 years (Cohen and Carlton, 1998). San Francisco Bay, which is home to a thriving shipping industry and thousands of recreational sailing vessels, is often characterized as the most invaded bay in the world (Cohen and Carlton, 1998). In general, the bays and estuaries of California have undergone dramatic change in the latter half of the 20<sup>th</sup> century, in part due to extreme habitat loss and modification, but also because of an increasing number of invasive species that have established and spread from one embayment to the next, usually via ballast water exchange and hull fouling. Although invasive species are widely recognized as key contributors to significant changes in native community structure and function (reviewed in Grosholz and Ruiz, 2009), examples of successful eradication or management efforts to minimize their impacts and rate of spread are few (but see Miller et al., 2004; Anderson, 2005).

Recent research has focused on the impacts of invasive species on native communities, and in particular species interactions. In some cases, invaders contributed to the decline of endangered species (Gurevitch and Padilla, 2004) or modified community structure, thereby facilitating the establishment of other invasive species (Simberloff and Von Holle, 1999). In contrast to studies focused on the negative impacts of invasive species, some studies suggest positive impacts on the native community by providing a new resource, such as food or shelter. For example, Hooton (2012) found that native fishes preferentially utilized habitat provided by the invasive Asian kelp *Undaria*.

*pinnatifida*, and that densities were higher in the presence of the invader as compared to the native habitat.

Monterey Harbor in central California has several invasive species. Presumably, the majority of these were introduced via hull fouling since container vessels containing ballast water are too large to port there. The floating docks and pier pilings in the harbor are covered with native and invasive invertebrates and algae. A deep red bryozoan, tentatively *Watersipora subtorquata* (d'Orbigny, 1852), has been in the harbor since at least the early 1990s. In the last 10 years, sanctuary divers noted increasingly dense patches of the invasive bryozoan in certain sections of the marina and an apparent expansion into sections lacking *Watersipora*.

Relatively little is known about *Watersipora* interactions with fouling communities native to Monterey Harbor. Building upon an undergraduate study (Traiger, 2010) focused on *Watersipora*, sanctuary staff continued to monitor its expansion and used fixed photo quadrats on cement pier pilings to determine if *Watersipora* distribution varied by piling location, depth or orientation, and to calculate *in situ* growth rates of undisturbed colonies. Here we present preliminary findings from this ongoing study.

## Methods

### *Study site*

Located in central California, Monterey Harbor is one of four municipal marinas between San Francisco Bay and Morro Bay. With just over 400 berths, Monterey Harbor is a small port of call with less than a dozen commercial fishing vessels (<20 m long) and no access for large (>25 m) ships. Most of the vessels are private sailboats (<15 m long) and used infrequently. The marina has nine floating docks, tiers A through I, which are enclosed and protected on two sides by cement sea walls. The tiers are anchored in place by cement pier pilings at 5-m intervals, which have four sides (60 cm wide), generally facing the cardinal directions (N, S, W, E), and extend vertically 3 to 5 m below the surface. Subtidally, the pilings are densely covered throughout the year with fouling invertebrates (e.g., tunicates, anemones, bryozoans, bivalves, barnacles) and seasonal algal cover.

Tier A (36.604178 N, -121.891821° W) is 40 m from the main entrance to the marina and receives the brunt of incoming tidal flow (Figure 1). The adjacent commercial wharf, which is supported by wooden pilings, is the putative source of *Watersipora* larvae and lies upstream of the marina entrance. Substantial colonies of *Watersipora* persist year-round on the wooden pilings of the wharf, and in some areas completely cover pilings. We monitor six pilings along a linear spatial gradient, but for this paper focused on the two pilings on tier A closest to the marina entrance since they were covered with relatively high densities of *Watersipora* and likely represented a focal area for subsequent spread.



Figure 1. Satellite image of Monterey Harbor, Monterey, CA. ‘A’ indicates the western end of tier A and the white arrow denotes the marina entrance. Inset shows the location of Monterey Bay. Satellite image by Google.

#### ***Fixed photo quadrats***

Each piling was wrapped with clothesline at two heights above the bottom (2 and 3.5 m), both of which were well below the lowest intertidal section of the piling (5 m). The clothesline was quickly overgrown and remained fixed in place but was still visible to divers. During each dive, digital photographs were taken of the same area at 16 locations on each piling.

A PVC quadrat frame was attached to an underwater camera housing (Subal 300D) with a fixed distance of 0.5 m, lens to subject (Figure 2). Using a 50 mm macro lens, the image captured  $0.025 \text{ m}^2$  of the piling. The photo quadrat framer was placed in the same orientation prior to each photo: the left frame upright was aligned with the left edge of a piling face at a vertical height both above and then below the fixed clothesline. Images above and below the line were taken on each of the four faces, starting with the north face, and then east, south and west faces, for a total of 8 images. This was repeated at the second vertical height, totaling 16 images per piling.

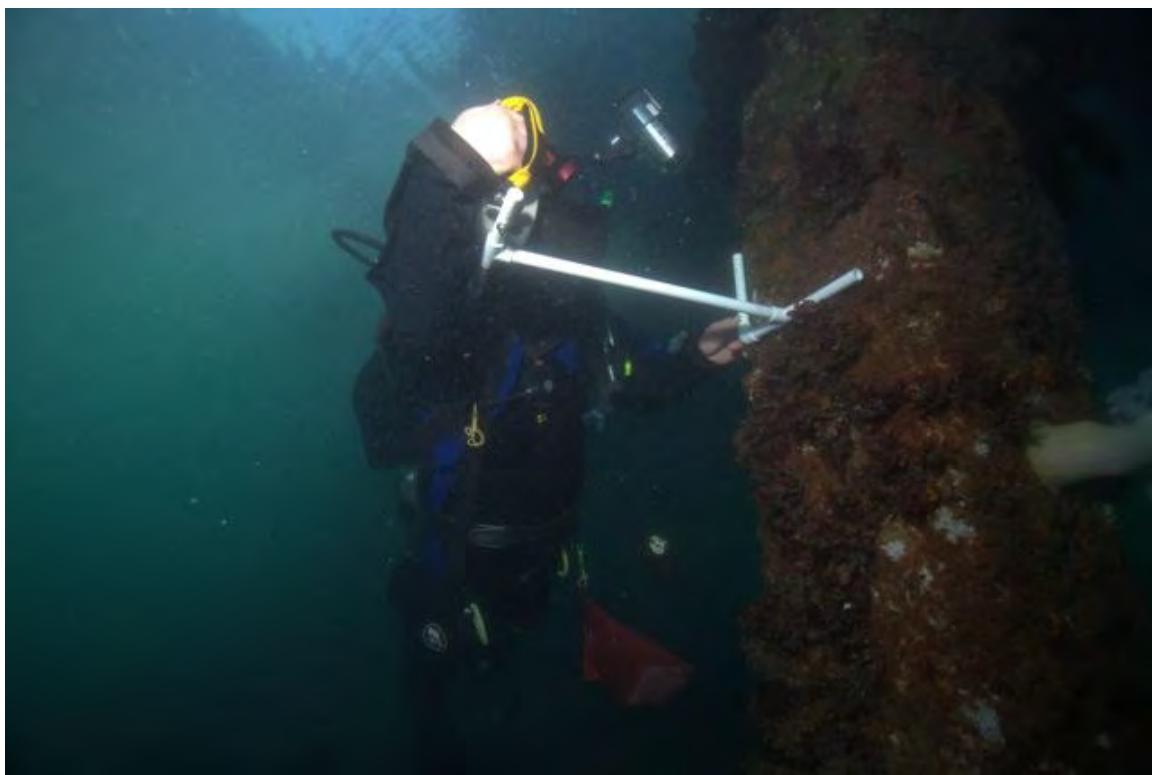


Figure 2. Diver taking digital image of a fixed photo quadrat on a cement piling in Monterey Harbor. Image courtesy of Chad King, NOAA MBNMS.

Prior to photographing a quadrat, large mobile invertebrates were removed (e.g., *Pisaster*, *Pugettia*) and broad algal blades (e.g., *Dictyoneurum*) draped over the area were moved aside. Images were taken at two-week intervals from 22 February 2010 to 18 March 2010, and at monthly intervals thereafter.

#### ***Estimating percent cover***

To estimate percent cover of the piling community we used a point sampling technique and overlaid a grid with 49 uniformly distributed points stretched over the entire image (Figure 3). Any point where the picture was out of focus, shadowy, or could not be identified was recorded as “unknown.” We included only the top layer of sessile organisms in the percent cover estimate, so each photo quadrat had a maximum value of 100% cover. Points intersecting small mobile invertebrates (e.g., shrimp, hermit crabs) were recorded as “unknown.”

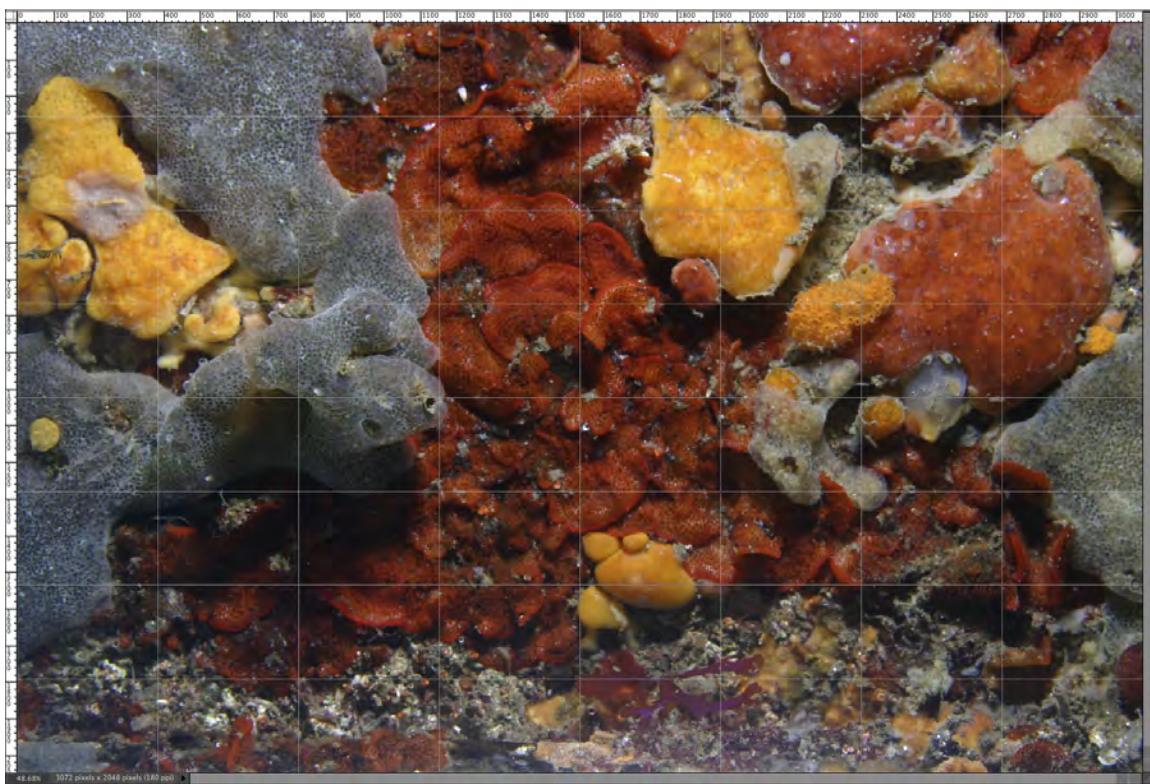


Figure 3. Digital image of a photo quadrat ( $0.025 \text{ m}^2$ ) with grid lines overlaid. Percent cover was estimated by identifying organisms under the 49 intersections. *Watersipora* is the bright red, foliose organism in the center.  
Photo by Steve Lonhart.

### **Growth estimates**

Collecting images of a fixed location over time provided an opportunity to measure growth rate of an unmanipulated colony of *Watersipora* *in situ*. Using a fixed reference point within the photo quadrat and measuring software (PixelStick by Plum Amazing), the distance a *Watersipora* colony increased was measured over four sampling periods spanning 39 d. Since *Watersipora* colony growth is asymmetric, the same angle was used each time to connect the fixed point and the leading edge of the colony.

### **Analyses**

Percent cover data (square-root transformed) were analyzed using PRIMER-E version 6. Initially a permutational multivariate analysis of variance (PERMANOVA) was used to determine if there were patterns of dissimilarity associated with piling, depth, or direction. This was followed by similarity percentage (SIMPER) analysis to compare dissimilarity among pairs of depth and piling for all types of cover. In particular, comparisons were made within pilings (deep vs. shallow) and between pilings (deep vs. deep).

## **Results**

### **Percent cover patterns**

Images were collected on four sampling dates (22 February, 05 March, 18 March, and 02 April) in 2010, with an average of 13 d between sampling dates. During each sampling date, all 16 fixed

quadrats were photographed on each piling. For this preliminary analysis, a total of 64 images for each piling was analyzed by displaying the image in Adobe Photoshop Elements at 100% magnification. The 49 uniformly distributed points were draped over each image and assigned to one of the following 39 categories:

- 9 ascidians (*Diplosoma listerianum*, *Ascidia ceratodes*, *Distaplia occidentalis*, *Botryllus schlosseri*, *Botrylloides* sp., and 4 unidentified species)
- 7 bryozoans (*Watersipora* dead and alive, *Rhynchozoon rostratum*, *Bugula neretina*, and 3 unidentified species)
- 4 mollusks (*Hermissenda* egg cases, *Mopalia* sp., *Lottia* sp., and *Pododesmus cepio*),
- 4 annelids (*Serpula columbiana*, *Salmacina tribranchiata*, an unidentified serpulid and an unidentified chaetopterid)
- 4 cnidarians (*Ectopleura* sp., unknown hydroid, unknown anemone, and *Corynactis californica*)
- 4 algae (juvenile laminariales, *Botryocladia pseudodichotoma*, unknown calcareous crust and an unknown red)
- 1 phoronid (*Phoronis* sp.)
- 1 echinoderm (*Strongylocentrotus purpuratus*)
- 5 miscellaneous (CaCO<sub>3</sub>, detritus, unknown, filamentous diatom, and PVC)

The distribution of *Watersipora* differed significantly by piling, depth and orientation (side). The piling effect was particularly striking (Figure 4), with distinct differences between the two pilings, which were separated by only 5 m.

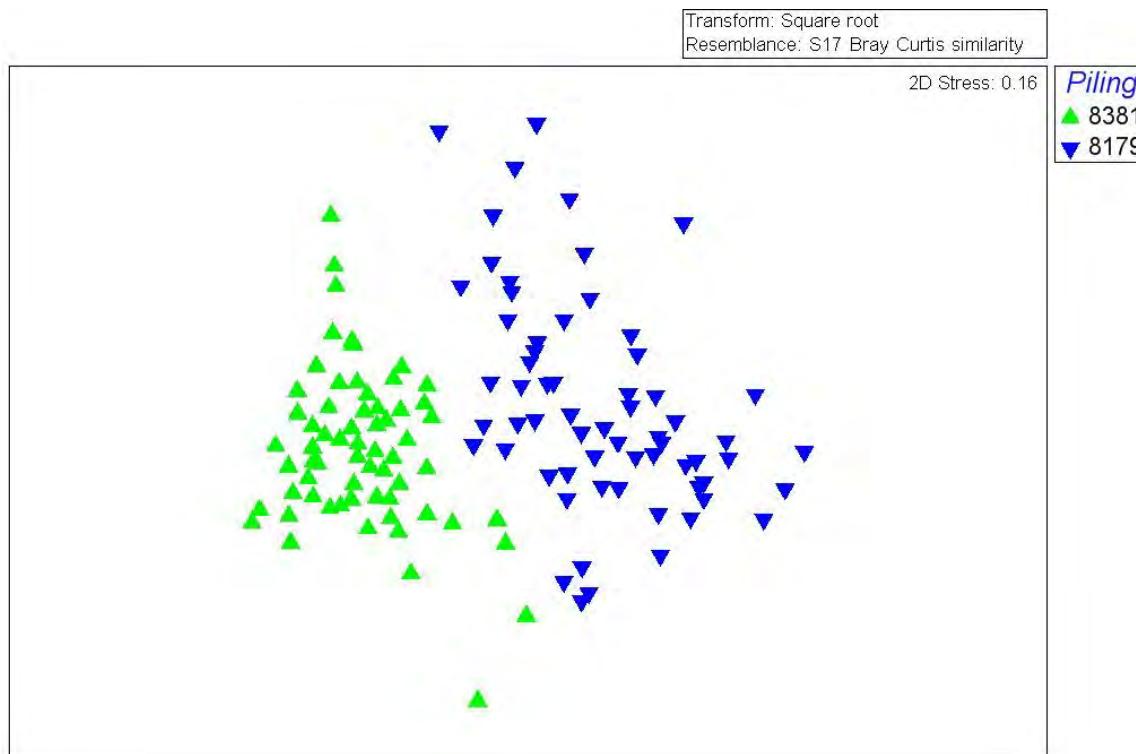


Figure 4. MDS plot showing differences in communities of sessile organisms on two pilings (8381 closest to the marina entrance, and 8179 slightly farther away). Data were square-root transformed to reduce the effect of an abundant species.

The community of sessile organisms inhabiting the pilings, the piling by depth effect was different between the two pilings, with the piling closest to the marina entrance showing more overlap by depth, whereas the more distant piling showed relatively little overlap (Figure 5). For piling 8381, which was the western-most piling and closest to the marina entrance, live *Watersipora* and CaCO<sub>3</sub> (dead but unidentifiable calcareous species) drove the dissimilarities by depth. For piling 8179, the differences were driven by the invasive tunicate *Diplosoma listerianum* (shallow depth), detritus and the strawberry anemone *Corynactis californica* (deep).

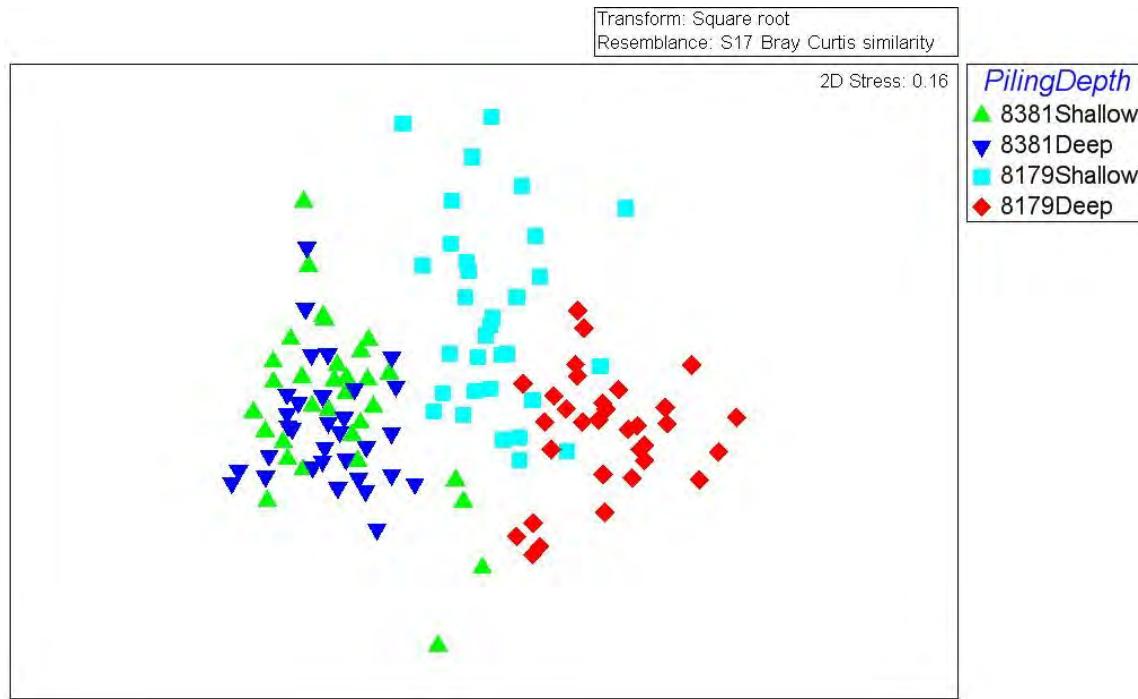


Figure 5. MDS plot showing differences in communities of sessile organisms on two pilings (8381 closest to the marina entrance, and 8179 slightly farther away) by depth (shallow vs. deep). Data were square-root transformed to reduce the effect of an abundant species. 8381 had fewer differences by depth, whereas 8179 showed little overlap.

### Colony growth rate

*Watersipora*, like all bryozoans, grows the colony through the addition of separate zooids (asexual reproduction) rather than by enlarging an individual. These zooids are individual units (~350 µm long, 125 µm wide) that filter feed with an eversible lophophore but remain connected to adjacent individuals within the colony. Once the ancestrula (i.e. parental larva) has settled, it reproduces asexually by budding off new zooids and the margin of the colony expands outward by adding hundreds to thousands of zooids. Growth is irregular and can remain crustose or can develop into foliose ‘heads’ that superficially resemble a coral.

For one particular colony, there was a single, natural, fixed feature in the photo quadrat that served as a reference point. Between the first and second sampling intervals (11 d), the colony expanded 1.9 mm (Figure 6). Measuring with the same fixed point and angle, the colony extended an additional 4.7 mm during the subsequent 13-d interval. Over the last sampling interval (15 d), the colony expanded an additional 6.1 mm. In a total of 39 d the colony advanced, in one direction, 12.7 mm, which averages to 0.33 mm per day of colony growth.

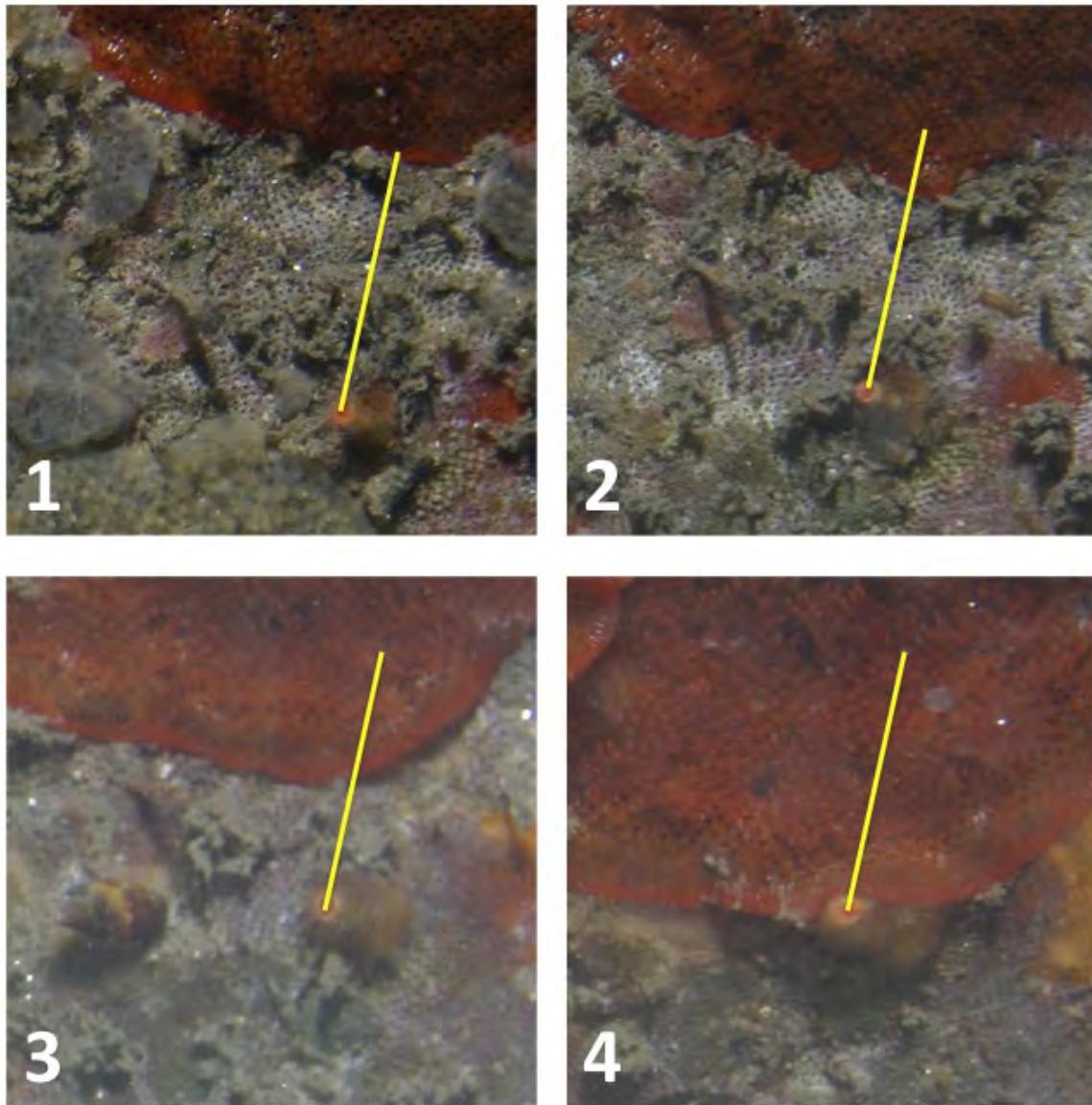


Figure 6. Series of images capturing the growth of a *Watersipora* colony *in situ*. In all panels, the yellow line is at the same angle and distance, and is fixed in place. Panel 1: this is an enlargement of an image taken at the start of the photo quadrat series. Panel 2: after 11 d the colony expanded 1.9 mm along the axis of the yellow line. Panel 3: after 13 d the colony added 4.7 mm. Panel 4: during the last interval (15 d) the colony added 6.1 mm. Overall the expansion rate of the colony was 0.33 mm per day along this axis. Photos by Steve Lonhart.

## Discussion

*Watersipora subtorquata* is an invasive bryozoan, that until very recently has been confined to harbors, bays and estuaries. As part of an ongoing study that includes other pilings, the goal is to determine if the invasion and spread of *Watersipora* on pilings in the Monterey Harbor varies as a function of the three variables: piling location, depth, and orientation (side). Even though the cement pilings are virtual replicates of one another, their relative location and intrinsic history of colonization by fouling invertebrates and algae is idiosyncratic. Differences in *Watersipora* (and overall community structure) by depth may be a function of algal cover, which generally declined with depth

(personal observation). Even the differences due to the sides of the four-sided pilings (not presented here) were not surprising given recent work in Australian harbors by Glasby and Connell (2001), who showed that the orientation and position of substrate strongly impacts the epibiotic assemblages that colonize them.

Ongoing field studies along the open coast in kelp forests, where *Watersipora subtorquata* has recently been reported (Watanabe, pers. comm.), may broaden our understanding of how it interacts with native species. Although almost all of the species found on pier pilings also occur in kelp forests, their relative densities are extremely different, perhaps with the exception of *Corynactis californica* (personal observation). With collaborators from the Smithsonian Environmental Research Center, we are examining species and habitat associations in the open coast. In the future we plan to compare and contrast these open coast interactions with those found within the harbor.

We did not initially intend to measure the growth rate of *Watersipora*, but the data collected in fixed photo quadrats afforded a unique opportunity to track colony expansion in an unmanipulated colony *in situ*. Measurements did not necessarily target the edge displaying greatest colony growth. Therefore, colony expansion rates are likely conservative. This is, to our knowledge, the first estimate of growth for *Watersipora subtorquata* in the field. With a conservative expansion rate of 0.33 mm per day, this approximates the addition of another zooid daily. It is not known if this estimate varies seasonally and ongoing studies are addressing this potential source of variation.

### Acknowledgments

Conducting science dives in the harbor could not have been completed without the support of the Monterey Harbor staff, including Scott Pryor, Brian Nelson, and Harbormaster Steve Scheiblauer. This project is, in part, a continuation of a senior thesis project initiated by Sarah Traiger while at UC Santa Cruz. Chad King, Monterey Bay National Marine Sanctuary, provided invaluable dive support. I am indebted to Dr. Pete Raimondi, UC Santa Cruz, for analyzing the data and providing useful feedback on the project, and to helpful comments provided by Drs. Lisa Lobel and Diana Steller.

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## Seasonal Variability of Kelp Forest Fishes and the Implications for Sampling Frequency in a Citizen Science Monitoring Program

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### Abstract

A significant challenge for most programs engaged in monitoring California's kelp forest ecosystems is the limited frequency at which kelp forest fishes are sampled, often due to limited funding. Citizen-based monitoring programs are often better able to expand their monitoring efforts to capture seasonal or random variations in species abundances than agency or academic programs. We evaluated the citizen-based Reef Check California (RCCA) fish survey protocol for its potential to capture seasonal variations in kelp forest fishes by monitoring multiple times per year at a single location. Diver surveys were replicated in each major oceanographic season from March 2009-July 2010 in the Monterey Bay, California. We examined the difference in fish populations between the two seasons by conducting t-tests upwelling and non upwelling months for all species. Results indicate that 1) the local abundance of selected fish species and/or species groups was subject to substantial temporal variation among oceanographic seasons, and 2) that RCCA could expand monitoring efforts to capture continuous seasonal patterns, change between oceanographic seasons and within season variability in kelp forest fishes. This type of higher frequency sampling, combined with long-term monitoring would better inform marine management decisions.

Keywords: Ecological Monitoring, Kelp Forest Fish, Citizen Science, Seasonal Variation.

### Introduction

Ecological monitoring enables our understanding of ecosystem change and is fundamental to the development of sound management, but it is also difficult to sustain. For instance, a significant challenge for most programs engaged in monitoring California's kelp forest ecosystems is the limited frequency at which kelp forest fishes are sampled, often due to limited funding. Fish communities fluctuate naturally as a function of a variety of environmental and biological factors. Characterizing these variations is necessary to first understand, and subsequently to monitor, the ecological processes that drive ecosystem change. If not characterized, natural temporal variability could jeopardize the accuracy of the data being collected (Stephens et al., 1984; Maxwell and Jennings, 2005).

Citizen-based monitoring programs have a long history in terrestrial environments, and are now in ascendance in the marine environment. Because the costs of citizen science programs are mitigated by the use of volunteers, they are better able to expand their monitoring efforts to capture seasonal or random variations in species abundances than agency or academic programs. The citizen-based monitoring agency, Reef Check California (RCCA) aims to inform marine management through scientific data collection and enhance the footprint of SCUBA-based monitoring along the coast (Dawson and Shuman, 2009). We evaluated the Reef Check California protocol for its potential to characterize seasonal variations in kelp forest fishes by increasing its sampling frequency. The objectives of this study were to evaluate the implications of seasonal variation in fish communities for

monitoring data collected in each major oceanographic season.

## Methods

### ***Sampling procedure***

SCUBA surveys were conducted approximately once every four weeks from March 2009-July 2010 using the RCCA fish survey protocol (Dawson and Shuman, 2009). Surveys consisted of eighteen 30 m band transects: nine inshore and nine offshore. Fish in a given three-dimensional volume (30 m long x 2 m wide x 2 m tall) were recorded on transects along the bottom of the seafloor. Divers focused on any of the 33 fish species on the RCCA species list, and where possible fish size (in three categories) and sex were also recorded. A minimum of 5 m visibility was required to complete any transect based on the RCCA protocol. In a preliminary survey we evaluated the effect of visibility from 5 m - 10 m and found it to have no effect on fish observations for any of the species observed during this study.

### ***Statistical Methods***

An alternative to sampling at a rate that fully captures seasonal changes is to sample once during each oceanographic season. In Monterey, California there are two generally accepted separate oceanographic seasons: nonupwelling (Oct-March) and upwelling (April-Sept) (Hallacher and Roberts, 1985; Graham, 1993). We investigated if there was a statistical difference between the populations recorded by the RCCA protocol during the two oceanographic seasons. We identified four response variables: total abundance, species richness, family group abundance, and individual species abundance, because they have consistently been shown to be important indicators of population change (Stephens et al., 1984; Ebeling et al., 1986; Anderson, 1994). To do this analysis we grouped monthly surveys into these upwelling and nonupwelling months and conducted t-tests for each response variable. To assess whether the assumption of normality was met we used the Shapiro-Wilks test (Shapiro and Wilks, 1965) and examined normal QQplots (Neter et al., 1985). Species that showed non-normal distributions were square-root transformed to satisfy normality requirements.

The seasonal recruitment pulses of young of the year *Sebastodes mystinus* can cause large variations in the population (Carr, 1991). To remove the variability that can be introduced by this we re-ran all analyses after excluding small *S. mystinus* observations from the dataset and qualitatively compared the results.

## Results

T-tests revealed that there was a significant difference ( $p<0.05$ ) between upwelling and nonupwelling seasons for several species and groups (Table 1). For all groups, counts were higher in the upwelling season. Results of t-tests between upwelling and nonupwelling seasons when small *S. mystinus* counts were removed showed a significant difference for Total Abundance, Scorpaenidae, small *S. mystinus* by themselves, and a less significant difference ( $p<0.1$ ) for adult *S. mystinus* (Table 2). The results of these analyses indicate small *S. mystinus* were not solely responsible for the seasonal differences seen in these groups.

Table 1. A test for seasonal variation in response variables. T-tests show significance of the differences in abundance between the oceanographic seasons for each species and group.

	<i>t</i>	<i>df</i>	<i>Probability</i>
Total Abundance	-2.03	10.39	0.07
Scorpaenidae	-2.27	12.51	0.04
Embiotocidae	-1.49	12.74	0.16
<i>Sebastes chrysomelas</i>	-2.35	12.96	0.04
<i>Sebastes mystinus</i>	-2.14	12.73	0.05
<i>Embiotica lateralis</i>	-5.06	10.72	0.0004
<i>Rhachochillus toxotes</i>	-2.27	9.87	0.05

Table 2. A test for seasonal variation in response variables excluding small *S. mystinus*. T-tests show significance of the differences in abundance between the oceanographic seasons for each species and group.

	<i>t</i>	<i>df</i>	<i>Probability</i>
Total Abundance	-2.15	12.7	0.05
Scorpaenidae	-2.3	10.37	0.04
<i>Adult Sebastes mystinus</i>	-2.14	12.73	0.08
<i>Small Sebastes mystinus</i>	-3.01	11.25	0.01

## Discussion

Our study results clearly indicate that the local abundance of these species and/or species groups was subject to substantial temporal variation among oceanographic seasons. We found that RCCA can provide critical information on the seasonal differences in populations of both Scorpaenidae and Embiotocidae families by sampling in each oceanographic season. RCCA would then be able to treat seasonal variation as a process with structure in order to identify patterns of change at a scale equivalent to the natural variation in the population. RCCA currently conducts two surveys in Monterey, once during late summer in the upwelling season, and one during spring, which usually falls in the non-upwelling season. These results stress the importance of establishing target survey dates within both the upwelling and nonupwelling seasons, so that these patterns can most accurately be identified.

This additional information can be used to characterize the relevant temporal patterns of indicator species to aid effective monitoring. The information we provided here can be used to make decisions on how to expand monitoring efforts and ultimately better inform management. The benefits RCCA gains by utilizing an efficient survey protocol coupled with cost effective volunteers, enables them to expand their monitoring efforts and provide information on natural seasonal fish variations. This information, combined with information from other professional organizations ultimately can better inform marine management decisions.

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## Using a Diver-operated Suction Dredge to Evaluate the Effects of a Top-predator on Subtidal Soft-sediment Infaunal Bivalve Communities

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### Abstract

In many unconsolidated substrate ecosystems, the majority of biomass available to top predators such as the sea otter (*Enhydra lutris*), exists as infaunal bivalves. While the effects of sea otter predation in hard-substrate systems are well documented, their effects in soft-sediment environments are less studied. Here we describe a method to sample subtidal clams in Glacier Bay, Alaska. The patchy nature of infaunal communities in soft-sediment systems makes them difficult to sample with traditional line transect methodology, where sampling may extend well beyond the edge of a clam bed, leading to induced error and exaggerated variance in the sample. In order to compensate for the spatially heterogeneous distribution of clam beds we used a suction-dredge method and developed a “spoked wagon-wheel” sampling design, where radiating transects begin at a focal point within the estimated center of a clam bed. We utilized the uneven spatiotemporal pattern of sea otter colonization within Glacier Bay to document changes to subtidal clam communities in areas with and without sea otters, both before and after colonization. This design provided a rigorous methodology to sample infaunal species that are of social, commercial, and ecological significance.

Keywords: clams, dredge, infauna, sea otters, soft-sediment

### Introduction

Sea otters have been shown to have profound impacts on their environment and are one of the best-documented examples of top down forces influencing the structure and function of the nearshore marine environment in the north pacific (Kenyon, 1969; Estes and Palmisano, 1974; VanBlaricom and Estes, 1988; Riedman and Estes, 1990; Estes and Duggins, 1995). Most studies have examined the relationship between sea otters and their environment in hard-substrate systems while less is known about their impact on unconsolidated habitat, where the process is thought to be similar (Kvitek et al., 1992) but studies in this system are not as common. An opportunity to study this process, as a prime example of an ecosystem where sea otters began colonizing soft-sediment habitat, arose in Glacier Bay National Park and Preserve, Alaska in 1993 (Bodkin et al., 1999). Investigations were developed to examine the effect of sea otter foraging within the park where changes could be monitored over time; specifically before and after sea otter colonization, to obtain a better understanding of how sea otters interact with soft-sediment ecosystems.

The majority of available biomass in this dynamic system consists of infaunal bivalves, which sea otters consume with high frequency (Bodkin et al., 2002). By rigorously documenting changes in species composition, abundance, and size distributions of shallow subtidal benthic invertebrate prey before and after colonization in areas previously occupied and unoccupied by sea otters we can

properly describe the changes caused by sea otters in a soft-sediment environment. Here we describe the sampling methodology used to accomplish the goal of accurately documenting soft-sediment infaunal bivalve communities.

## Methods

### ***Site Selection***

Due to the patchy distribution of clam beds, specific sites were selected within the Glacier Bay study area. Site location was determined by the following criteria: 1) proximity to areas occupied by sea otters, 2) spatial separation from other sites, and 3) relatively high clam densities. To evaluate clam densities and bed size, reconnaissance dives were conducted alongside drop camera transects to observe the presence of clam siphons or shell litter (Bodkin et al., 2002; 2003). Due to the logistical constraints of working underwater in an area with substantial tidal swings, sites were restricted to depths no greater than 12 meters at high water even though sea otters are capable of diving up to 100 m (Bodkin et al., 2004). When a location met all three criteria, GPS coordinates were recorded to mark the site. Thirteen sites were established within the study area: nine in 2001 and four in 2002. The four sites in 2002 were added as control sites in areas that otters would not likely colonize over the course of study. The original nine sites were within areas occupied and not-yet-occupied by otters. Because sites were not selected randomly or systematically, no inference can be made beyond each site. All sites were initially sampled in 2001/2002 and post-treatment sampling was conducted in 2011 at eleven sites.

### ***Sampling Design***

The sampling protocol is developed and modified from a subtidal clam sampling protocol used in Prince William Sound, AK (Bodkin et al., 2002). Power analyses from preliminary dredging showed that a minimum of 20 quadrats ( $0.25 \text{ m}^2$ ) would be required to detect a 50% change, in clam abundance, with 90% confidence at a site. Initially, a  $50 \text{ m} \times 0.5 \text{ m}$  ( $25 \text{ m}^2$ ) line transect was used to acquire 20 quadrats placed at random. However it was found to be unsuitable due to the fact that the transect may extend beyond the boundaries of the selected clam bed leading to induced error and inflated variance at the site. To account for the variable size and shape of clam beds, and reduce sampling variance, the design was modified into a  $20 \text{ m} \times 20 \text{ m}$  grid ( $400 \text{ m}^2$ ). The center of the grid, referred to as ‘the origin’ is the focal point within the bed with 12-10 m transects radiating out on compass headings from  $0^\circ$  around to  $330^\circ$ , spaced  $30^\circ$  apart; giving the appearance of a wagon-wheel (Figure 1). To determine quadrat locations, the ‘wheel’ is overlaid onto the  $20 \text{ m} \times 20 \text{ m}$  grid and cells within the grid are selected at random, wherever the transect lines and a selected cell intersect, and the selected location is no closer than 2 m to another selected cell, is where the quadrat will be sampled. This is repeated until 20 quadrat locations are selected. This modified sampling design increases the area sampled ( $314 \text{ m}^2$ ), reduces variance among quadrats, and requires less time to sample. (see Figure 1; Bodkin, 2002)

### ***Sampling Protocol***

We began sampling on the boat prior to departure. To ensure that the work went as efficiently as possible, we assessed all gear required before heading out to a site. We found it most useful to have two skiff platforms, one as a dive skiff and one as the dredge skiff. Inflatable boats worked very well as they are low to the water and the ability to use multiple d-rings for securing the dredge is essential to keep it stationary. Below is a list of equipment and a description where necessary:

- 1 – handheld GPS
- 2 – sturdy sand anchors

- 1 – suction dredge: a gasoline powered motor operated on the surface which pumps water through a large diameter hose to the bottom where it connects to a Venturi nozzle, creating suction that draws sediment and deep-burrowing organisms into mesh exhaust bags.
- 1 – small mushroom anchor to keep exhaust hose in place.
- 1 – clipboard with check-off sheet for all quadrat locations
- 3 – 10 m fiberglass tapes
- 2 – 0.5 m x 0.5 m quadrats: solid aluminum bands 5-6 inches deep work best
- 20 – pre-labeled tags on snap clips to attach to exhaust bags
- 20 – exhaust bags: sturdy mesh bags to hold dredge exhaust
- 8 – small goodie bags with wire mouth to contain invertebrates collected by hand
- 1 – marker buoy: to temporarily mark the origin
- 1 – signal float: clearly identifiable Styrofoam float on a line connected to the dredge nozzle used to communicate from the divers to surface tender
- 1 – running line: short line to connect skiff anchor to 2nd anchor at the origin
- 4-6 – lift lines: lines with floats on one end and clips on the other to raise exhaust bags

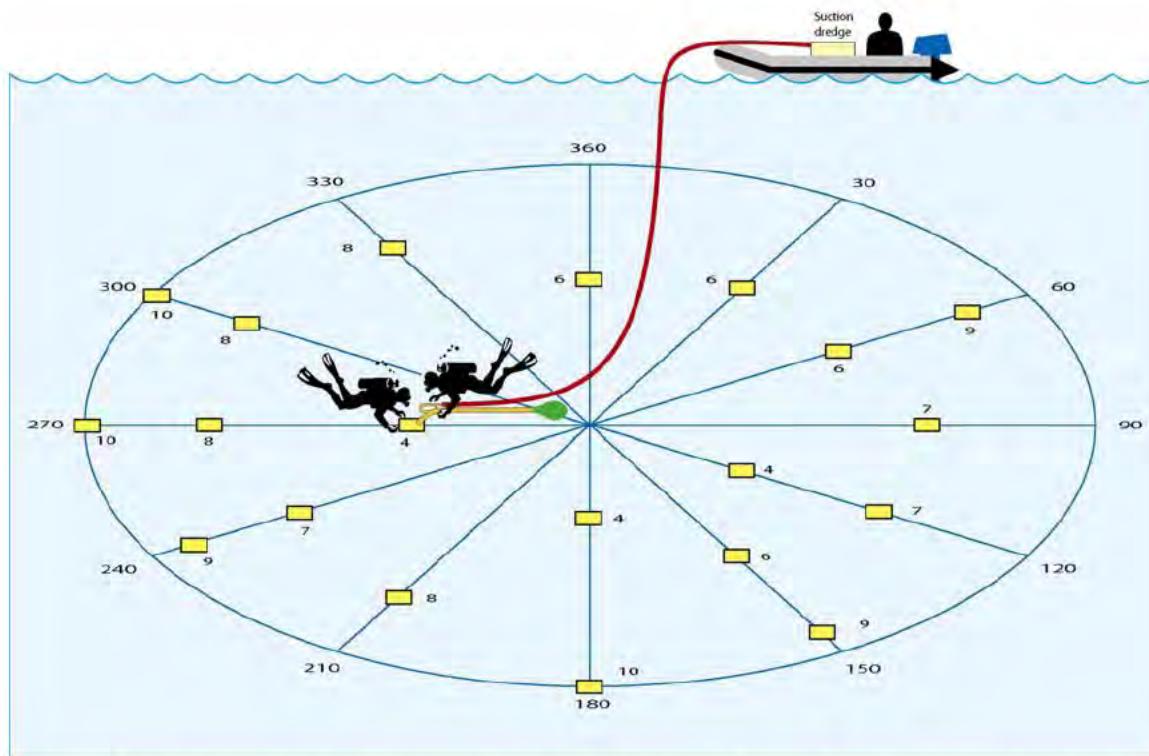


Figure 1: Site layout showing transect spokes radiating every 30 degrees from the origin and randomly selected quadrats along each 10 m transect spoke. The dredge skiff is anchored at the origin so each quadrat can be reached easily with the dredge (Bodkin, 2002).

We used the first dive at a site is used to establish proper location and placement of the origin. Divers descended and placed a sand anchor at the center of the wheel and swam out 10m at N, E, S, and W compass headings to ensure that the sampling circle was centered over the clam bed. When necessary

the origin was moved and new GPS coordinates were taken to mark the location. A temporary marker buoy was then clipped onto the origin so that it could be found quickly over the course of sampling which could take from 1-5 days depending on the number of dives it was possible to conduct due to cold, tides/currents, number of divers as well as substrate type and the difficulty of dredging. Once the origin was marked, a second sand anchor was installed to attach sampling equipment to when it was left on the bottom between dives and also to affix a running line from the secondary anchor to the skiffs anchor line so that divers could easily navigate to the origin in little to no visibility. In areas of high current a Danforth anchor, used to also anchor the skiff, was used to secure gear to.

On subsequent dives, divers would swim out the transect spokes from the origin in an order depending on current such that the exhaust cloud would drift down current and visibility could be maximized where possible. Working in buddy pairs, one diver (diver #1) would swim out the tape and place the quadrat at the predetermined sampling location. The second diver (diver #2) was the dredge operator and would swim the dredge along the tape to the quadrat. However, in some cases it was useful for both divers to move the dredge together to avoid impairing the visibility. At the quadrat, siphon counts were made, surface substrate classified, and all urchins and crabs collected in a small mesh goodie bag. The dredge diver would then signal to the surface tender to start the dredge and begin excavation by pulling 3 times on the signal float. The dredge consists of an 8 horsepower gasoline fired engine outfitted with a centrifugal pump (Keene Engineering, Inc., Chatsworth, CA) that circulates sea water through a 2" diameter, 100' long fire hose at 350 gallons per minute. Suction is created by movement of water from the fire hose through a suction nozzle, which sucks sediment into the exhaust stream that flows into the mesh exhaust bag. While diver #2 vacuums the quadrat, diver #1 pulls out any visible clams and places them into the goodie bag. A quadrat is excavated down to a depth of 25 cm or until no remaining clams or siphons are visible. Diver#1 then swims the length of the exhaust hose to remove the now full exhaust bag and place their goodie bag inside of it, affix the quadrat label clip, tie the bag securely shut, and attach the lift line so that the bag could be hoisted up to the surface after the dive. Two to four quadrats could be sampled per dive depending on substrate type and air consumption. Usually diver #1 will get colder from sitting still and diver #2 will breathe air at a faster rate; it was found that by alternating duties between dive buddies, bottom time could be maximized.

Post-dive, the mesh bags are sorted through a sieve with 10 mm mesh to recover all clams and urchins that were not hand-collected into the goodie bag. All clams, crabs, and urchins were identified to the lowest possible taxa, counted, and measured to the nearest millimeter using calipers. Any individuals smaller than 14 mm would not be counted as they would be small enough to fit through the sieve screen.

## Results

The methodology used for this study proved successful at sampling clam beds in Glacier Bay in years 2001/2002 and again in 2011. Results are will be formally presented in reports from USGS in 2012 and 2013. Here we present data to show the success of this method as an effort to sample infaunal organisms. Table 1 displays species composition and frequency found in all samples from the initial sampling in 2001 and 2002. Table 2 shows species composition and frequency found in all samples from the post-treatment sampling in 2011.

Table 1: Species composition and frequency of organisms >14 mm successfully sampled using the suction dredge methodology during the initial sampling effort in 2001/2002.

Clams	Frequency	Percent
<i>Clinocardium nuttalli</i>	1377	0.37%
<i>Hiatella spp.</i>	11125	2.98%
<i>Humilaria kennerleyi</i>	119	0.03%
<i>Lucinoma annulatum</i>	0	0.00%
<i>Mactromeris polynyma</i>	21073	5.65%
<i>Macoma spp.</i>	37026	9.92%
<i>Modiolus modiolus</i>	4994	1.34%
<i>Mya spp.</i>	26287	7.05%
<i>Panomya ampla</i>	323	0.09%
<i>Parvalucina tenuisculpta</i>	0	0.00%
<i>Prototheca (Leukoma) staminea</i>	121468	32.56%
<i>Saxidomus gigantea</i>	128023	34.31%
<i>Serripes groenlandicus</i>	19172	5.14%
<i>Tellina spp.</i>	137	0.04%
<i>Yoldia spp.</i>	1991	0.53%
<b>TOTAL</b>	<b>373115</b>	

Table 2: Species composition and frequency of organisms >14 mm successfully sampled using the suction dredge methodology during the post-treatment sampling effort in 2011.

Clams	Frequency	Percent
<i>Clinocardium nuttalli</i>	145	0.07%
<i>Hiatella spp.</i>	3900	2.01%
<i>Humilaria kennerleyi</i>	133	0.07%
<i>Lucinoma annulatum</i>	14	0.01%
<i>Mactromeris polynyma</i>	7921	4.08%
<i>Macoma spp.</i>	31481	16.23%
<i>Modiolus modiolus</i>	670	0.35%
<i>Mya spp.</i>	52815	27.23%
<i>Panomya ampla</i>	37	0.02%
<i>Parvalucina tenuisculpta</i>	52	0.03%
<i>Prototheca (Leukoma) staminea</i>	7538	3.89%
<i>Saxidomus gigantea</i>	77988	40.22%
<i>Serripes groenlandicus</i>	7887	4.07%
<i>Tellina spp.</i>	0	0.00%
<i>Yoldia spp.</i>	3345	1.72%
<b>TOTAL</b>	<b>193926</b>	

## **Discussion**

The methodology used for this study allowed us to successfully sample and resample our sites in Glacier Bay National Park, Alaska. We found the technique to be very intensive and also thorough for sampling infauna in unconsolidated substrates. While suction dredges have been used extensively for field sampling, we have developed methodology for improving the efficiency and effectiveness of subtidal community sampling. This method could be used in other places to enhance sampling efforts and monitor infaunal bivalve populations that are of social, commercial, and ecological significance.

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## Managing California's Marine Protected Area Network: From Outreach to Research

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### Abstract

California has a coastwide network of 124 coastal and estuarine marine protected areas (MPAs) each with unique boundaries, coordinates, and regulations. The regional planning process to implement the Marine Life Protection Act has been nearly completed, with the exception of San Francisco Bay. We present here an overview of the California Department of Fish and Game's (CDFG) approach to managing the implementation of state MPAs, including MPA designations, allowed uses, MPA education and outreach efforts, and monitoring efforts. We discuss how CDFG is managing research efforts within MPAs via the scientific collecting permit (SCP) process. This includes details of the SCP application process, the types of research permitted in MPAs, methods for conducting various research activities within MPAs, and our efforts to determine the cumulative effects of research conducted within MPAs. Special emphasis is placed on providing information to the scientific diving community regarding research within California's network of MPAs and the various triggers that would require an SCP.

Keywords: California Department of Fish and Game, marine protected area, monitoring, outreach, risk assessment model, scientific collecting permit

### Managing Implementation

The [Marine Life Protection Act](#) (MLPA) of 1999, directs the California Department of Fish and Game (CDFG) to reevaluate and redesign California's system of marine protected areas (MPAs) to increase its coherence and its effectiveness at protecting the state's marine life, habitats, and marine ecosystems (CDFG, 2012). The goals of the act strive to improve recreational opportunities, as well as educational and scientific opportunities to study marine ecosystems subject to minimal human disturbance. A regional planning approach was used to effectively implement the MLPA, resulting in five management regions, the Central Coast (implemented in 2007), North Central Coast (implemented in 2010), South Coast (implemented in 2012), North Coast (to be implemented in 2013), and San Francisco Bay (has yet to undergo the planning process). This report provides an overview of the CDFG's approach to managing implementation of the improved network of MPAs, including MPA designations, allowed uses, education and outreach efforts, and monitoring efforts. We also discuss how the CDFG is managing research efforts within MPAs via the Scientific Collecting Permit (SCP) process.

### Description and Overview of MPA Designations and Allowed Uses

California has a coastwide network of 124 coastal and estuarine MPAs, each with unique boundaries, coordinates, and regulations (Figure 1). California's MPAs are classified as follows:

- State marine reserve, which does not allow take

- State marine park, which allows limited recreational take
- State marine conservation area, which allows limited recreational and/or commercial take
- State marine recreational management area, which allows for waterfowl hunting but may restrict the take of most, if not all, marine organisms
- Special closure, which protects breeding seabird and marine mammal populations from human disturbance

Scientific research and non-consumptive uses are allowed in all categories except special closures, which are also smaller in size than other classifications. Access to special closures is usually prohibited for most user groups, except CDFG employees or employees of the United States Fish and Wildlife Service, National Park Service, or United States Coast Guard while performing official duties. In state ocean waters, from the shoreline to three nautical miles offshore including offshore islands, some of California's 16 special closures have seasonal restrictions limiting access only during certain times of the year.

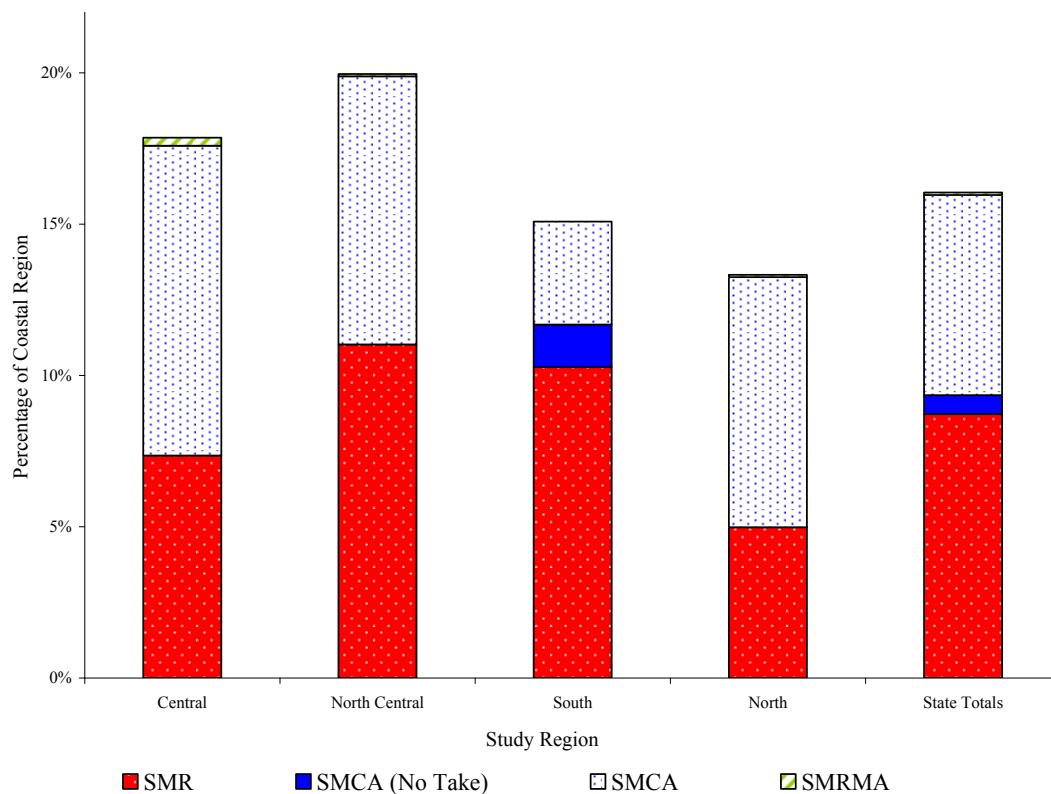


Figure 2. Marine protected area designation percentage by coastal region<sup>1</sup>. Designations include state marine reserve (SMR), state marine conservation area (SMCA), and state marine recreational management area (SMRMA). State marine parks (SMP) and special closures comprise less than 0.1% of California ocean waters and are not included in the figure. Data Source: California Department of Fish and Game - Marine Region, Geographic Information System; 2012.

<sup>1</sup> Cambria SMCA, in the Central Coast region, is currently the only MPA also designated as SMP by the State Parks Commission (CDFG 2008). For purposes of reporting, it is shown here as SMCA only

## **Education and Outreach Efforts**

The CDFG is responsible for providing MPA regulations to the public. The recently formed MPA Outreach Coordination Project works with outside partner organizations and agencies to produce accurate educational and outreach materials. Several outreach and educational tools are available from the Marine Life Protection Act website ([www.dfg.ca.gov/mlpa](http://www.dfg.ca.gov/mlpa)), including the MPA Mobile website ([www.dfg.ca.gov/m/MPA](http://www.dfg.ca.gov/m/MPA)) which allows anglers, divers, and other ocean users to gather MPA information with computers, smart phones, tablets, and other portable Internet-enabled devices. Specifically, this website allows the public to access information by these methods:

- Search for any current MPA by name, county, or general area to find the MPA's boundaries and regulations
- Use an interactive map to locate and learn more about any MPA
- Find and track the current location using the Global Positioning System on a mobile device, determine whether the current location is in an MPA, and locate the nearest MPAs

The CDFG has also produced regional MPA guidebooks that provide details about MPAs including coordinates, regulations, uses, and maps. The guidebooks are available at CDFG offices, online, and at various distribution points throughout each region.

## **Monitoring and Research**

The MPA network planning and design process has been completed, except San Francisco Bay, and the CDFG is now focused on MPA implementation, monitoring, research, and adaptive management. To facilitate adaptive management, the CDFG is collaborating with the MPA Monitoring Enterprise (ME) to develop a comprehensive monitoring program to measure performance of MPAs relative to stated regional objectives and MLPA goals. The ME was created through the State's Ocean Protection Council and the Ocean Science Trust (OST) to coordinate the development of the MPA monitoring program, to house and analyze monitoring data, and to synthesize results in a manner that assists managers and policy makers in adaptive management decisions. The ME is developing monitoring priorities and a monitoring framework for the regions and the statewide network of MPAs.

## **Managing Research through a Scientific Collecting Permit Program**

The CDFG administers SCPs as one mechanism to ensure research is not detrimental to marine resources. The increased interest and need for research and monitoring in MPAs creates a unique challenge in managing research and controlling the issuance of SCPs. Researchers must inquire about obtaining SCPs if they anticipate injury, damage, take, or possession of any living, geological, or cultural marine resource while working in an MPA. The CDFG operates under the regulatory definition of "take", defined as "to hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture, or kill" (Section 86, Fish and Game Code). While these requirements are broad, issuing SCPs helps the CDFG manage activities within MPAs more effectively. SCPs are issued on a case-by-case basis and the time allocated to process each SCP depends on the complexity and significance of the project. Applicants should plan ahead and be sure to submit SCP applications at least 12 weeks before either the expiration of their existing SCPs or before their projects are due to start.

Recently, the CDFG's Marine Region increased its efficiency in processing SCPs so that that research or educational projects will not be hindered by a lag in processing SCPs. Applicants can facilitate the processing of their SCPs by including all the information listed in the application instructions. The general guidelines require the applications be filled out accurately and with adequate specificity; that

is, excluding any details not directly pertinent to the collecting component of the research (i.e., details of lab work, deoxyribonucleic acid protocol analyses). Applicants should include these details:

- **Purpose of the research:** A clear, succinct purpose statement is necessary for review staff to understand what is proposed
- **Methods:** Include a description of the sampling gear and methods used to collect organisms
- **Species and numbers to be collected:** When listing organisms to be collected, arrange species by major taxonomic groups and, to the extent practical, by the lowest taxonomic level
- **Collection locations:** Include all the locations where you plan to collect, specifying all MPAs if applicable
- **Justification for collecting within an MPA:** Clearly describe why your project must be done in an MPA and not elsewhere
- **Disposition:** Describe the organisms' fate (e.g., sacrifice, catch and release, salvage)

Research within MPAs may be conducted for a variety of objectives by agencies, academia, or other organizations and may not be exclusive to MPA monitoring. Many research activities require direct sampling that may be lethal to marine organisms, while other research activities may be non-lethal. Determining the condition of the ecosystem in an MPA can be more difficult when monitoring or research disturbs habitat. Therefore, the CDFG is investigating options for improving the MPA research management process by seeking answers to questions such as 1) What level of extractive research is acceptable?, 2) Can cumulative effects occur in an MPA from research and other allowed uses such as fishing?, and 3) At what point do scientific research or monitoring activities disrupt communities or ecosystem function?

Currently, the CDFG is working with selected members of the OST Science Advisory Team to address these questions. The primary function of this work group is to develop a risk assessment tool to help the CDFG improve its management strategy for research in MPAs. The outcome will also ensure that CDFG is meeting the MLPA goal to protect the state's marine life and habitats, marine ecosystems, and marine natural heritage while still providing for educational and study opportunities.

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## Speciation with Gene Flow in Coral Reef Fishes

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### Abstract

Recent genetic evidence has highlighted the possibility of speciation with gene flow. In marine systems, dispersive larvae accompanied by the paucity of marine barriers, greatly decrease the chances for reproductive isolation. Even when a small number of cases of speciation with gene flow have been documented in coral reef fish, this mode could represent an important alternative for explaining the observed diversity in these systems. In this work we present a brief review of the main mechanisms of speciation that operate in the marine environment, examples of groups that are known to hybridize, as well as current genetic techniques for analyzing speciation with gene-flow. We give a brief explanation of the molecular work we have done so far with grunts of the *Haemulon* genus, from the Tropical Eastern Pacific and Western Atlantic. In addition, we highlight the importance of scientific diving for collections in complex environments such as coral reefs, as well as its role in allowing observation of specific behaviors that help elucidate the speciation of fishes.

Keywords: Genetics, isolation with migration, molecular evolution, natural selection, sister species, speciation genes,

### Introduction

A common reproductive strategy among marine organisms is to produce thousands of pelagic larvae with great potential for dispersal. This reduces competition and allows re-colonization of extirpated areas as well as colonization of new sites. Phylogeographic studies have demonstrated pelagic larvae can maintain genetic connectivity across the greatest oceanographic extents. This great potential for connectivity, added to the paucity of physical barriers in marine systems, raises an interesting question, how did the great diversity of coral reef fish originate?

The most “traditional” view of speciation is via allopatry. In this mode two populations are separated by a strong physical barrier that impedes reproduction. With time, the effects of mutation and drift will cause the two divergent lineages to become different species. For marine systems, one of the most famous examples is the Isthmus of Panama, where the rise of a land mass approximately 3mya divided populations in the Caribbean and Eastern Pacific (Lessios, 2008). In other cases, rare dispersal events can lead to the colonization of distant sites, which leads to restricted gene flow with central populations. This is observed in islands of the Central Pacific with high rates of endemism, such as the Hawaiian Islands, Eastern Islands and the Marquesas (Allen, 2008). Other barriers are considered “soft”, as they do not confer isolation for all species. For example, the Amazon freshwater plume causes the isolation of the surgeonfish *Acanthurus bahianus*, distributed in southern Brazil, and its sister species *Acanthurus tractus*, of the Greater Caribbean (Bernal and Rocha, 2011).

Meanwhile, the closely related *A. coeruleus* and *A. chirurgus* show no genetic structure between populations of the Caribbean and Southern Brazil (Rocha et al., 2002).

There are seven strong physical barriers that separate biogeographic provinces in coral reef systems (Rocha et al., 2007), and many more instances where local oceanographic conditions can cause isolation. However, speciation has also been demonstrated to occur in the absence of vicariance. In parapatric speciation, two populations are present in adjacent locations with different environmental conditions. Over time, the two populations become very well adapted to their local environments, which causes reproduction between individuals of the two sites less probable. Considering the vast distances and gradual changes in environmental conditions, this mode has been considered the prevalent mechanism of speciation for reef fishes (Rocha and Bowen, 2008).

Speciation can also occur when two lineages are present in the same area, that is, in sympatry. In these cases lineages become reproductively isolated by behavioral or ecological differences. Considering the low number of barriers and the potential for larval dispersal, this mode could be significantly important in reefs. Examples of this mode of speciation can be seen in wrasses (Rocha et al., 2005), gobies (Munday et al., 2004; Taylor et al., 2005), seahorses (Jones et al., 2003) and triplefins (Wellenreuther et al., 2007). However, the main issue with this mode of speciation is that it is very challenging to discern true sympatry from range expansion after allopatric speciation (Coyne and Orr, 2004).

### ***Speciation with gene flow***

Considering the great potential for connectivity in marine systems, as well as the role of selection in parapatry and sympatry, some of the observed diversity in marine systems could occur in the presence of gene flow (Arnold and Fogherty, 2009). The main idea behind this process is that lineages are still able to diverge without genome-wide reproductive isolation. Under this scenario, genes that cause ecological, sexual or post-mating isolation can have restricted exchange in the event of hybridization between young or nascent species (speciation genes; Wu, 2001; Wu and Ting, 2004). Meanwhile, genes that have no effect on fitness may be exchanged freely between the divergent lineages. Over time, association of “speciation genes” with the rest of the genome can lead to reproductive isolation and the formation of separate species (Wu and Ting, 2004).

This mode of speciation is believed to provide a unique signal in the genome of the studied species. If enough coverage of the genome is obtained, areas under disruptive selection should show higher divergence than areas under no selection. Thus, the largest divergence between two lineages should be localized in very specific spots in the genome. Meanwhile, if species have diverged via mutations and drift, large differences should be found randomly across the entire genome. These patterns have been observed when contrasting genome scans of marine vs freshwater lineages of sticklebacks with scans of allopatric populations of the same environment (Hohenlohe et al., 2010).

### ***Groups of Interest Among Coral Reef Fish***

In the particular case of coral reef fish, several groups have been identified as candidates for the study of hybridization and speciation with gene flow. One of the groups with most described cases corresponds to angelfishes of the Holocentridae family. Here, Pyle and Randall (1994) described 11 cases of extensive hybridization in over 5 different genera (*Apolemichthys*, *Centropyge*, *Holacanthus*, *Pomacanthus* and *Chaetodontoplus*). Following this morphological survey, genetic evidence has shown extensive introgression between different species of the genus *Centropyge* (Shultz et al., 2007; DiBattista et al., 2012). In this group species level designation corresponds to coloration, and in many instances these differences are not supported by genetic markers. The only differences at the genetic level are observed between geographic regions, where different color morphs of the same area are

more closely related than individuals of the same color morph from distant sites (DiBattista et al., 2012).

One group that has received considerable attention is the hamlets of the *Hypoplectrus* genus. The group consists of 12 species with overlapping distributions across the Tropical Western Atlantic. The species can be identified only by their coloration, as they show no differences in morphology (Fischer, 1980). Organisms preferentially mate with individuals of their same color pattern (Puebla et al., 2012), but hybridization produces viable offspring (Ramon et al., 2003, Puebla et al., 2008). Hybrid progeny have intermediate color patterns with respect to the parental morphs, which reduces the chances of successful reproduction (Puebla et al., 2012). In this case, genes that control color patterns may drive differentiation even in the presence of gene flow (Holt et al., 2011).

A group that is of particular interest for our own research is the *Haemulon* genus. The phylogeny of the group shows that physical isolation by the Isthmus of Panama and the Amazon plume played a minimal role in the radiation of the group, as most of the sister species have overlapping distributions (Rocha et al., 2008; Tavare et al., 2012). In addition, some of the closely related species show very shallow differences with mitochondrial markers, but show substantial divergence with nuclear DNA (Rocha et al., 2008). In this case, as well as in the angelfishes and hamlets, the observed pattern could be related to rampant introgression across divergent lineages (Arnold, 2006). The difference between this and the former examples is that hybrids are not found in nature. Thus the current challenge is determining whether introgression occurred after speciation or if it was present during the divergence process.

## Discussion

The study of evolution is undergoing a rapid change mainly due to the amount of information that is now possible to obtain. With the advent of next generation sequencing there is a chance to validate potential cases of speciation with gene flow. Analyzing thousands of loci greatly enhances the possibility of understanding patterns of introgression and disruptive selection that are typical under this mode of speciation. However, it is very important to highlight that even with the advent of new sequencing techniques and powerful computer analyses, diving plays a key role for understanding speciation in coral reefs. Getting access to samples in this complex environment is routinely done with SCUBA, as collecting from the surface would result in highly un-selective sampling. Considering the available tools we have today for the study of speciation, we are confident in making progress towards a better understanding of speciation with gene flow and its relevance in marine systems in the near future.

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## Going the Distance: Use of Diver Propulsion Units, Underwater Acoustic Navigation, and Three-Way Wireless Communication to Survey Kelp Forest Habitats

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### Abstract

Here we describe a kelp forest survey technique using an underwater acoustic navigation system coupled with diver propulsion units (DPUs). The surveys characterized kelp forest habitats and macro-biota along the inshore sections of five routes proposed for deploying temporary underwater seismic cables in San Luis Obispo County, California. The total distance surveyed was nearly 5 km (3 mi) over a period of five days. Survey depths ranged between 18 m (60 ft) and 3 m (10 ft) MLLW. Acoustic transponders set to transmit separate acoustic frequencies were attached to temporary drop buoys, and using GPS were sequentially positioned up to 200 m apart along the cable routes. The acoustic signals received by a transponder interrogator unit on a DPU enabled the lead diver to accurately navigate from one transponder to the next and to record predominant habitats and macro-biota while en route. A dive buddy with a video camera mounted to a second DPU videotaped sections of the cable route while also transiting. For safety and improved communication, we used a wireless 3-way communication system with full face masks. Using typical kelp forest survey protocols, such as meter tapes and swimming compass courses underwater, would have been especially difficult over these depths and distances.

Keywords: kelp forest habitat characterizations, SCUBA, underwater navigation, videotaping

### Introduction

This study was conducted to characterize benthic habitats and macro-biota in kelp forests along the San Luis Obispo County, California coastline where the routing of five temporary seismic cables with geophones is proposed as part of a high energy nearshore seismic survey (Figure 1). Our habitat characterization work using SCUBA and based on direct observations and video documentation was completed along the cable route sections passing through kelp forests. A continuation of the same cable corridor extended offshore into deeper water where the habitat characterization and videotaping was completed using a remotely operated vehicle (ROV). The inshore characterizations needed to be completed using SCUBA because the tethered ROV could not be operated in the dense forests of giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*) that were common inshore. The proposed offshore and inshore sections of the cable routes were aligned to occur on sand flat habitat where possible, based on substrate maps prepared from multi-beam sonar surveys. However, rocky habitat that is colonized more densely with invertebrates and kelp could not be avoided in many areas, particularly inshore where kelp forests predominate. The total distance to be surveyed using SCUBA was nearly 5 km (3 mi), along a 3 m (10 ft) wide corridor centered on the planned cable alignments. Survey depths extended to 18 m (60 ft) mean lower low water (MLLW) and underwater horizontal visibility distance was often limited (<4 m, [<15 ft]).

Completing surveys in kelp forests using SCUBA along transects to characterize benthic habitats and macro-biota can be challenging, especially when transects (typically meter tapes on reels) must be deployed according to specific start and end coordinates. Deploying transects from a boat in kelp

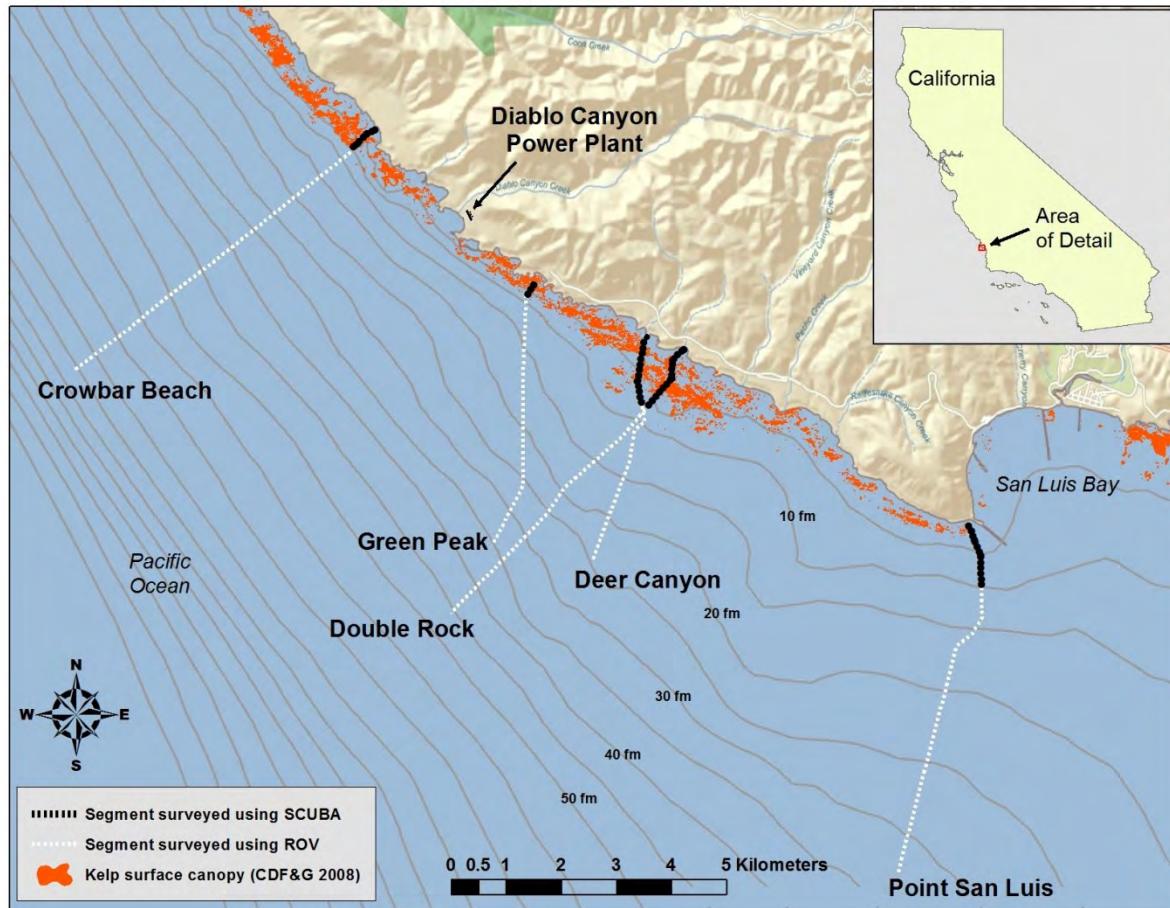


Figure 1. Seismic cable routes proposed for temporary placement of geophones and surveyed using SCUBA and ROV.

forests is generally not possible, due to propeller entanglement with kelp and interference from surface and mid-water kelp fronds that prevents the meter tapes, or even weighted lines, from sinking to the bottom. The typical option is then to deploy the meter tapes using SCUBA on headings underwater using a dive compass. This method can work well if the transects are relatively short (i.e., <50 m, 164 ft), but dive compass navigation can be inaccurate and difficult if underwater horizontal visibility is limited and if currents are swift moving. Divers also need to re-wind the tapes back to the starting point, which results in added bottom time, air consumption, and fatigue.

Due to the long distances and precise routes that needed to be surveyed, we instead used a combination of a wireless underwater pinger-receiver navigation system, diver propulsion units (DPUs), 3-way wireless underwater communication, and SCUBA to navigate accurately in straight lines over these long distances. Survey data included direct observations of substrates, habitat types, and macrofauna, and a videotape record of the proposed cable corridors.

## Methods

The underwater observations and video were completed by a team of two SCUBA divers working with a 2-person boat crew that also functioned as a second dive team. The research vessel was a 28-ft Munsen craft equipped with dual GPS systems and a precision depth finder. Divers used an underwater navigation system to ensure that they followed directly along the proposed geophone alignment corridors. Alignment coordinates were provided by the Pacific Gas and Electric Company.

The underwater navigation system consisted of acoustic transponders/pingers (RJE International Model ATT-400) attached to temporary buoys (Figure 2). Each was set to transmit a unique frequency. A transponder interrogator unit (pinger receiver, RJE International DTI-300, Figure 3) was monitored and operated by the lead diver. The transponder interrogator displayed the bearing and distance from the interrogator unit to the transponders/pingers within an accuracy of one meter.

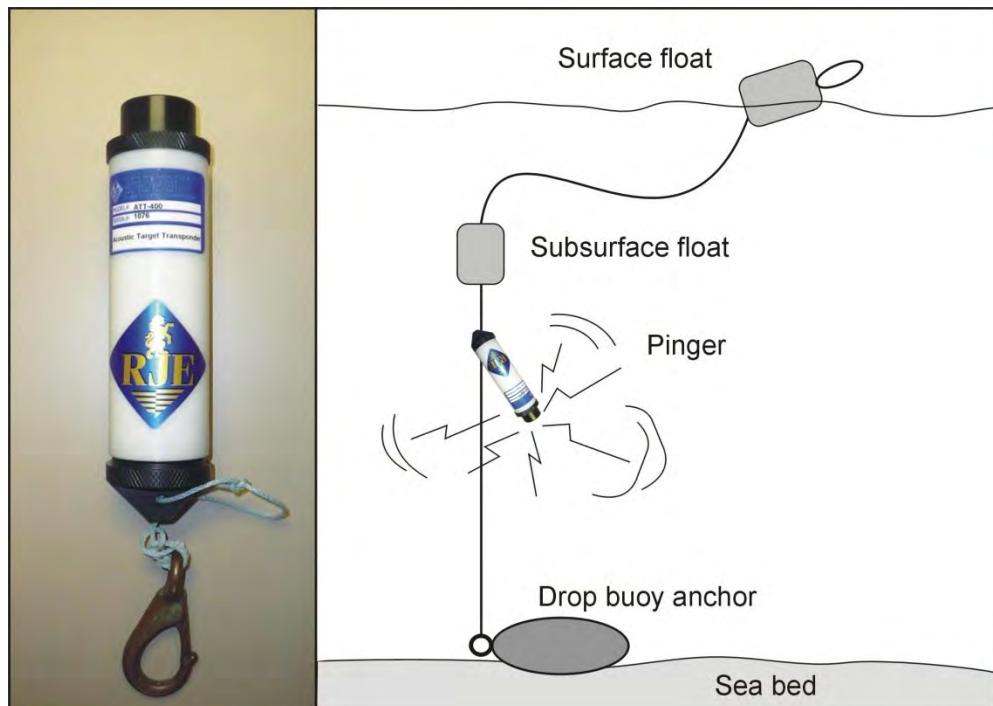


Figure 2. Pinger and drop buoy system used to maintain the pinger directly above the drop buoy anchor.

The work along each cable route began with the boat crew positioning the transponders on temporary buoys at specific locations along the cable route, starting at a pre-determined offshore point near the -18 m (-60 ft) MLLW isobath. Two or three transponders were then set at distances no greater than approximately 200 m (656 ft) apart along the cable route towards shore using an onboard GPS-based software navigation system for positioning (Figure 4). Each diver used a hand-held DPU (Seadoo VS) on which either the transponder interrogator unit or video camera was mounted (Figure 3). Divers descended to the bottom at the starting buoy from where they began navigating and completing observations. Because each pinger had a unique sending frequency, the divers were able to continue from point to point along the cable route without surfacing, depending on air consumption. As the team proceeded, the lead diver wrote observations on a pre-printed underwater data sheet, noting the distance to the next pinger as a method to provide a navigational fix on any features of interest. The

diver operating the video camera recorded representative habitat features and biota at various points along the cable route. Both divers used DTS full face masks with integrated communication hardware for wireless communication between the divers and boat crew.

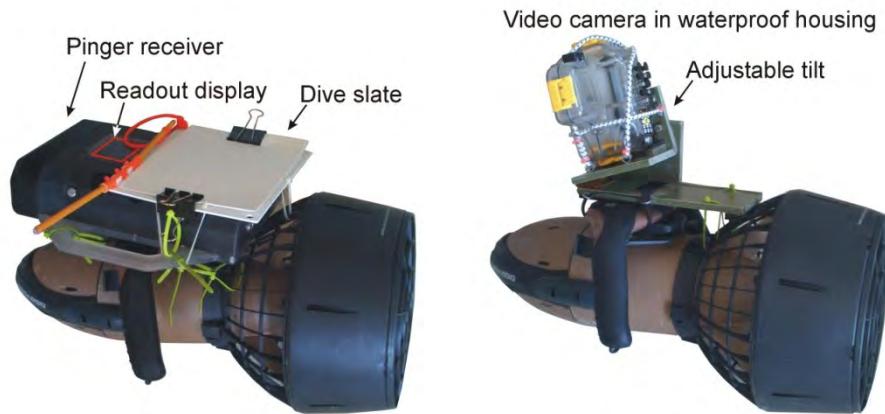


Figure 3. Underwater navigation and videotaping system consisting of a diver propulsion unit (DPU) equipped with an RJE International DTI-300 transponder interrogator and another with a Bonica Snapper HDDV/1080P HDDV video camera.

The surface support vessel followed the dive team as they proceeded underwater towards the shore. The cable routes were surveyed into the shallowest depths indicated on the alignment maps or to the shallowest depths that were considered safe for the divers, based on swell height and underwater visibility, and safe for boat operations.

## Results

We completed all of the planned work over five days in August 2011, which consisted of noting and videotaping representative habitats and macro-biota within and proximate to kelp forests. The total distance covered was nearly 5 km (3 mi). Two dive teams of two people working each day could complete 1 km (0.6 mi) of cable route surveying using a total of 4-6 72 ft<sup>3</sup> SCUBA tanks per day. The total combined bottom time to complete all of the work was 14 hours.

The observations did not reveal apparent alternative routes in the areas of kelp forests to align the seismic cables over sand versus rock. The substrates on all but one of the routes were predominantly boulder and moderate relief bedrock with stands of giant kelp, bull kelp, and the subcanopy kelp *Pterygophora californica*. Kelp canopy, at the time of our survey, was largely absent along one route, due to the seabed being largely sand and eroded sandstone. None of the surveyed routes included sensitive macro-invertebrates, such as gorgonians, hydrocorals, or emergent abalone that would be disturbed by deploying or retrieving the geophones.

## Discussion

Our work presented here focuses on the survey methodology we used to characterize and document kelp forest habitats. The pinger-receiver underwater navigation system was invaluable for the divers to maintain accurate positions along the cable routes. This methodology was also very efficient. Fourteen hours of total bottom time was expended to complete all the work. The amount of time that would have been required to complete the same work otherwise, using the more conventional method of deploying and retrieving meter tapes and navigating according to compass headings, would have taken several times longer to accomplish. Also, because much of the work was at depths up to 18 m (60 ft), surfacing for re-orientation was not practical. The pinger navigation system allowed the divers to remain near the bottom and travel on specific headings over long distances (~200 m [656 ft]).

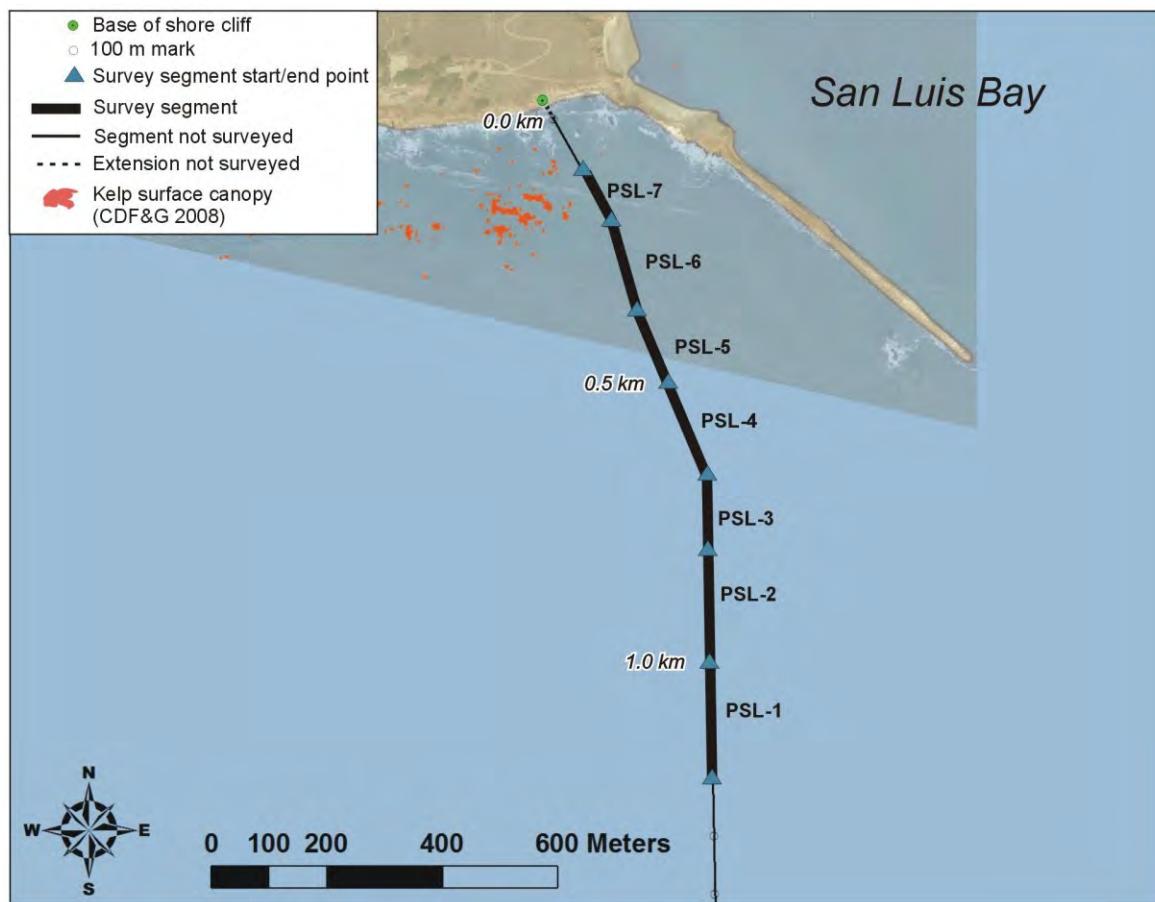


Figure 4. Inshore cable route and waypoints used for deploying pinger drop buoys.

Although we used a wireless 3-way communication system for diver-diver/diver-boat/boat-diver communication, we rarely needed to talk to each other once the surveys were in progress. Conventional hand signals were generally sufficient for communication between the divers, and the boat operator used the diver's bubbles to track their progress and follow along. However, the wireless communication system was used occasionally, and would have been especially important had an emergency situation arose.

The DPUs also helped to conserve air, reduce diver fatigue, and therefore reduced the number of tanks that would have otherwise been needed, including total dive time, number of divers, and number of dive days. Surface intervals for changing tanks and repositioning pinger units were sufficient to keep the divers within no-decompression limits. The DPUs were also useful on the surface, as the divers could more easily and rapidly approach the dive boat, versus the boat operator having to carefully maneuver the boat to pick up divers.

The methodology we used to complete our kelp forest habitat characterization allowed us to obtain descriptive information on the general characteristics of the benthic habitats and macro-biota along the seismic cable routes surveyed. More detailed biological information could have been collected if the underwater navigation system was used in a quantitative (quadrat-type) sampling design, but this would have added significantly more bottom time and survey days. The navigation system we used is not limited to subtidal biological surveys. For example, the same equipment and methodology can be used in search efforts where areas need to be canvassed in a systematic fashion and to readily locate underwater targets that have a pinger attached.

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## Population Dynamics of a Sponge Disease on Caribbean Reefs

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### Abstract

Sponges are important ecological components of Caribbean reefs and they are increasingly affected by diseases which threaten biodiversity and ecosystem services. *Aplysina* Red Band Syndrome (ARBS) affects sponges of the genus *Aplysina* and is widespread throughout the Caribbean basin. We have monitored the population dynamics of *Aplysina cauliformis* in the Bahamas to elucidate impacts of ARBS on this species. Temporal and spatial variability in sponge size and condition have been monitored using digital maps of two reefs in the Bahamas. We used spatial statistics to characterize the distribution of disease and identify patterns of transmission. Our results found that ARBS affects approximately 10% of *A. cauliformis* on Bahamian reefs. Diseased sponges occur in a clustered distribution on reefs and typically occur in close proximity to diseased sponges identified in earlier surveys. However, some diseased individuals occur away from other affected sponges, suggesting multiple mechanisms of transmission. Field and laboratory experiments confirmed contact as an efficient mode of transmission. ARBS is widespread in populations of *A. cauliformis* and the major mode of transmission for ARBS appears to be contact. However, ARBS is likely transmitted by other mechanisms either in the water column or by alternative vectors.

Keywords: Bahamas, disease transmission, population modeling, sponge disease, sponges

### Introduction

With global coral cover declining and a shift towards sponge dominance, particularly on Caribbean reefs (Maliao et al., 2008), diseases of sponges have been gaining increasing attention (Gochfeld et al., 2012). One such disease is *Aplysina* Red Band Syndrome (ARBS), an infectious disease that affects sponges in the genus *Aplysina*. ARBS causes tissue necrosis, reduced growth and increased probability of breakage, resulting in an increased sponge mortality rate. This disease has been recorded throughout the Caribbean at infection rates as high as 15% of the *A. cauliformis* individuals within a population (Olson et al., 2006; Gochfeld et al., 2012). This study investigates the spatial dynamics of ARBS in two shallow *A. cauliformis* populations in the Bahamas over a three-year period, and analyzes the pattern of the diseased individuals over time to characterize the mechanism of disease transmission within the population and predict the impact of this disease on populations of *A. cauliformis*.

### Methods

Permanent 100 m<sup>2</sup> meter grids were set up on two shallow patch reefs (Big Point and Rainbow Gardens) near Lee Stocking Island in the Exuma Cays, Bahamas. Within each grid, digital images of

each 1m<sup>2</sup> were taken to produce a photo-mosaic of the reef. Within each 1 m<sup>2</sup> quadrat, the location of each *A. cauliniformis* was recorded, its length was measured, its health status was assessed, and if the sponge was diseased, the number of lesions was counted. Grids were sampled yearly from 2009 to 2011 in July, and the Big Point grid was also sampled in May 2011.

Spatial analysis was performed on each grid at each time point to investigate spatial patterns and discern a process from the observed patterns. To monitor spread of the disease between sampling times, join counts were performed on the basis of contact between sponges. This allowed us to track the suspected origin of a diseased sponge in one sampling time to a diseased sponge in an earlier sampling time. Each sponge was assigned a specific location within the grid using the join tool in ArcGIS. The sponge length (from the *in situ* measurements), and its number of branches (from the photographs), was used to account for all sponge interactions within single sampling times and between sampling times. Interactions were quantified between diseased and healthy sponges as well as between diseased sponges. Using this method we tracked spread of the disease between sampling periods.

Field and laboratory experiments were performed to determine whether ARBS was transmissible via contact. Diseased sponges were attached with cable-ties to healthy sponges for 30 days, after which they were removed and the healthy sponges were examined for signs of ARBS. Controls, in which healthy sponges were attached to other healthy sponges, were also examined.

## Results

This study examined two populations of *Aplysina cauliniformis* to investigate disease dynamics of ARBS in the Bahamas. The disease prevalence was variable at the study sites ranging from 3.5% - 10.9%. The sponge population at Big Point exhibited varied responses in terms of spatial autocorrelation; the 2010 and July 2011 time points did not exhibit any patterns amongst diseased sponges, while the May 2011 time point showed significant spatial patterns indicative of clustering amongst disease sponges. In contrast, multi-distance spatial cluster analysis indicated clustering of diseased sponges on scales of less than 1 meter and between four and six meters. The diseased sponge population at Rainbow Gardens showed significant spatial autocorrelation in both the 2010 and 2011 grids. In addition, this diseased population showed clustering on scales of less than 5.5 meters, but the entire population clustered at a scale of less than 4.5 meters.

The majority of diseased sponges in the two populations were within contact range with other diseased sponges on the reef. At Big Point, contact explained 68% and 75% of the diseased sponges in the May 2011 and July 2011 sampling times, and at Rainbow Gardens contact explained 57% and 53% of the diseased sponge in the 2010 and 2011 sampling times. Sponges are much more ephemeral than other organisms on the reef (such as corals), so often when a sponge dies it leaves no evidence behind. Thus, it was sometimes difficult to account for all individuals between years. Sampling yearly, we could track the fate of approximately 58% of diseased individuals, while sampling over two months allowed us to track the fate of 95% of diseased individuals. Within this 2 month period we saw 10 sponges recover from the disease, and seven new individuals become infected. This indicates that the relevant temporal scale for studying this disease may be much less than annual sampling, allowing for understanding of disease dynamics in a few months rather than a few years. One additional factor to consider when interpreting these results is that the study areas were not self-contained areas. They were portions of a larger reef, so organisms occurring on the edges of the grids were able to interact with organisms outside the grid. This likely explains some of the incidence of the disease found along the edges of the grid not explained by contact with sponges inside the sampling grid.

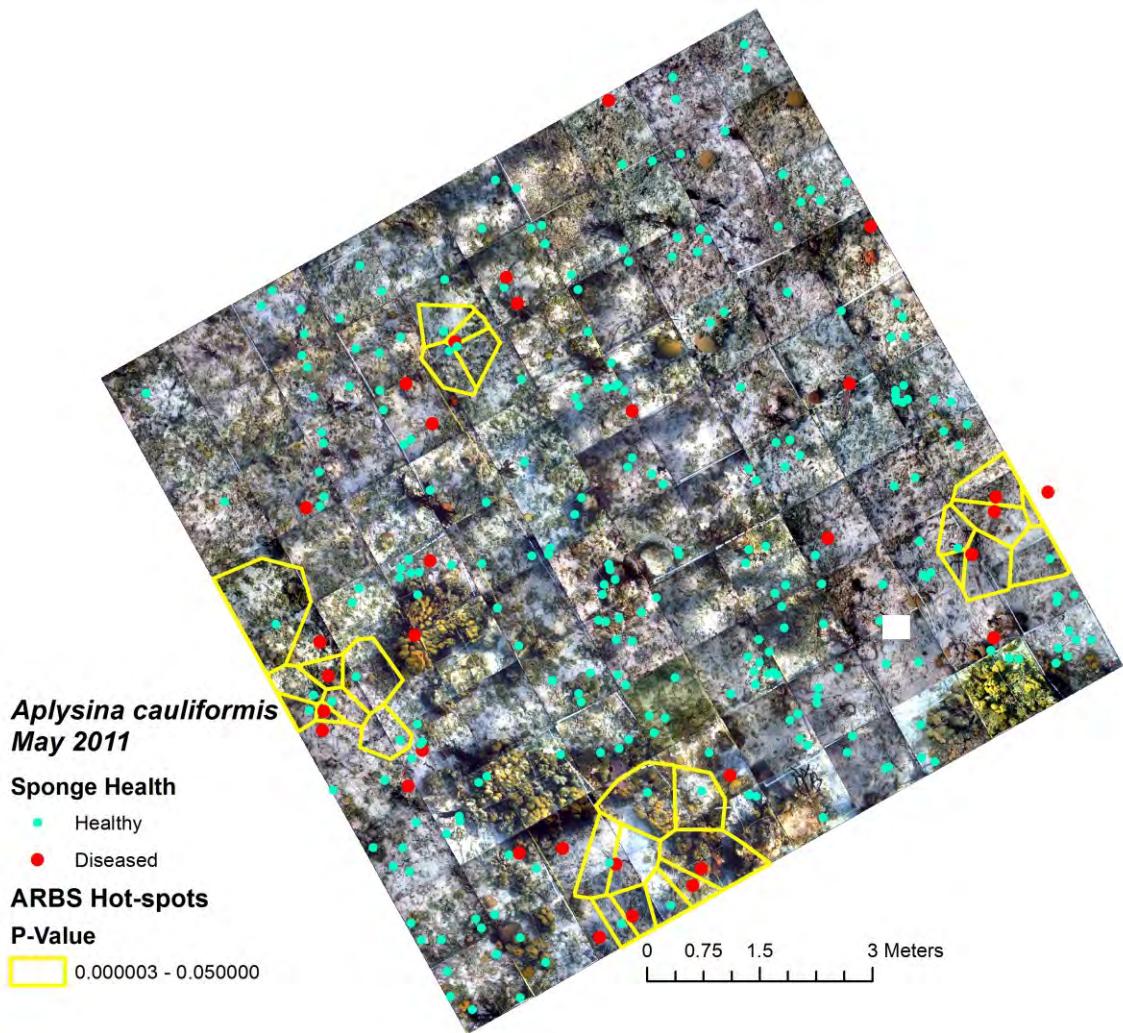


Figure 1. Representative photo-mosaic of the May 2011 grid from Big Point, Bahamas, showing the locations of 236 healthy *Aplysina cauliformis* (blue dots), 31 diseased *A. cauliformis* (red dots) and the locations of significant clusters of diseased sponges (yellow lines) as determined by spatial hot-spot analysis.

Field and laboratory experiments confirmed that contact is an efficient mechanism of ARBS transmission in sponges. In these experiments, contact with a diseased sponge resulted in transmission of ARBS to the healthy sponge after 30 days in nearly 100% of cases, whereas controls did not show any evidence of ARBS.

## Discussion

Spatial analysis offers a powerful tool for studying disease dynamics in a population. These techniques allow for translation of patterns in a population to a process of disease transmission. For ARBS, contact seems to be the major driver of disease spread within a population on a reef. This was revealed through a variety of spatial statistics, including spatial autocorrelation in many of the time

points at the study sites, and clustering of diseased sponges at some scale at every site. This study shows the importance of using a variety of spatial analysis techniques when investigating characteristics in a population. In addition, this study has found that understanding your study organisms and system is very important in determining what the relevant sampling period is for a study using spatial analysis. With a proper sampling time frame, spatial analysis can help discern a mechanism for disease spread from spatial patterns observed in a population.

### Acknowledgments

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## Hyperbaric Chambers for Fish

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### Abstract

The Monterey Bay has extensive continental shelf habitat where the fish populations can be numerous and diverse, especially in the rockfish group (*Sebastes* spp.). These shelf rockfish have been under-represented in the Monterey Bay Aquarium's exhibits due to the difficulty in collecting these physoclistic fish. Previously aquarium divers vented rockfish airbladders as the fish came up long lines from deep water. Recently, Jeff Smiley of Hubbs-SeaWorld, brought large rockfish straight to the surface from depths over 100 meters. These fish were quickly recompressed in pressure vessels, then decompressed and acclimated to surface pressure. Inspired by these efforts, we have developed two types of hyperbaric chambers: One is stainless steel and is pressurized with oxygen gas; the other is PVC pipe components, includes a staging chamber, and is pressurized with a water pump. Our chambers work well for rockfish up to 40cm, are portable, and inexpensive. We routinely collect rockfish using hook and line or traps from depths to 130 meters. More than 10 species of shelf rockfish have now been successfully acclimated, some of these have only rarely, if ever, been previously exhibited. The increased post-barotrauma survivorship has implications for fish conservation, recreational fishing, and aquarium collecting.

Keywords: barotrauma, hyperbaric, recompression, rockfish

### Introduction

Rockfishes (*Sebastes* spp.) in the Monterey Bay can show high species diversity and abundance. In near-shore waters less than 30 m, eighteen rockfish species may be encountered (Love et al., 2002). Using "routine" scuba or hook and line collecting, these rockfishes will often show an over-buoyant condition when brought to the surface. Rockfishes are physoclistic, meaning they have a swim bladder with no connection to the gut. Traditionally collectors have relieved this condition using a hypodermic needle to "vent" the swim bladder with good success. In deeper water (30 to 200 m, the continental shelf) there are an additional twenty species, again some of these quite abundant. When these shelf rockfish are brought to the surface using typical fishing methods they will show barotrauma to a varying degree, a few are recoverable with venting, but most will not survive in cold seawater holding at surface pressure. External signs of barotrauma include stomach eversion, exophthalmia, corneal emphysema and subcutaneous emphysema; internal signs include arterial embolism, emphysema in the heart ventricle, swim bladder rupture and emboli in the rete mirabile, hematoma, hemorrhage, and organ torsion (Jarvis and Lowe, 2008; Pribyl et al, 2011). Some success in avoiding or reducing barotrauma in these collections can be achieved by placing scuba divers at 20 m under a fishing boat to vent airbladders of fish coming up a line from depth (Starr et al, 2000; J'Osullivan pers. com., 2012). Somewhat surprisingly, many rockfishes showing severe barotrauma (and sometimes a moribund appearance) can fully recover if quickly returned back to depth (Jarvis and Lowe, 2008; Hannah and Matteson, 2007) or with recompression in hyperbaric chambers (Smiley and Drawbridge, 2007). Smiley collected large cowcod rockfish (*Sebastes levis*) with hook and line from as deep as 146 m, recompressed them to 90 m, and then slowly decompressed them on a

schedule based on the U.S. Navy Diving Manual for eventual holding at surface pressure. At the Monterey Bay Aquarium (MBA), using hyperbaric chambers for fish was first conducted by aquarist K. Cross in an attempt to treat exophthalmia in exhibit fishes. This chamber was based on a design by J. Landesman from the Cabrillo Marine Museum. The MBA's collecting department adapted Landesman's and Smiley's chamber designs (Smiley and Drawbridge 2007) along with other ideas to build portable inexpensive chambers intended for small boat fishing excursions on Monterey Bay targeting shelf rockfish.

## Methods

### *PVC Chambers*

The two-stage chambers have a main body of 20 cm (8 inch) or 30.5 cm (12 inch) poly vinyl chloride (pvc) pipe, with a 7.6 cm (3 inch) or 10.2 cm (4 inch) valve and pipe attached to form the upper chamber (Figure 1). Associated plumbing is either 95 mm (3/8 inch) or 127 mm (1/2 inch), all pipe, fittings, and components pressure rated to a minimum of 9 ATA (130 psi). The key component is a “backpressure” or “pressure relief” valve that maintains and easily adjusts upstream pressure. Bypass valves allow upper chamber pressurize/depressurize cycles, water source changes, or other flow adjustments without disturbing a steady pressure in the main chamber. A flow sight helps the operator confirm adequate flow through the main chamber. A small DC – powered diaphragm pump pressurizes and circulates water through the chamber while on board the collecting vessel. Water is drawn from the ocean surface or a sump on the deck. In Monterey Bay surface waters and climate conditions are cool enough that sump chiller systems are not needed. These two-stage chambers are ideal for small-boat rod and reel fishing for rockfish up to 30 cm. Fish arriving at the surface are briefly held and sorted in a live well. Target species of appropriate size are introduced into the isolated upper staging chamber, locked in and recompressed to match the pressure in the lower chamber, the large valve is then opened, and a push rod is used to “gently encourage” downward swimming. Non-target fish are quickly released back at depth with a sinking release device.



Figure 1. PVC Chamber

### ***Stainless Steel Chambers***

These chambers are a single compartment pressure-rated vessel (ASME code) normally intended for industrial applications (Figure 2). They are available in “large mouth” versions in a variety of capacities, and our units are rated to 132 psi. Unlike pvc pipe where manufacturers recommend against pressurization with a gas, these steel vessels can simply be pressurized with pure oxygen. These chambers are useful when multiple fishes arrive on the boat at one time, as with scuba collections or trap fishing; they are helpful when rod and reel fishing for fish somewhat larger or with more severe barotrauma; or on small collecting vessels that cannot accommodate the larger pvc chambers with associated pump and sump. The chamber is filled to about two thirds capacity with sea water, the fish are locked in and recompressed, and then the chambers go into a cooler on ice. Depending on the amount of fish in the chamber, they can go up to 8 hours before pressurized water circulation is needed.



Figure 2. Stainless Steel chamber

### ***Recompression/decompression sequence***

Initial pressure in the chamber is determined by the lowest maximum allowed from two criteria: pressure at depth of capture, or chamber component pressure ratings. With the pvc chambers the supply pump pressure/flow ratings may also determine initial pressure. Initial pressure is maintained in the chambers on the collecting vessel for the ride back to the MBA’s quarantine facility (usually within 5 hours of capture). Here the chambers are attached to a cold seawater pressurized flow-through system powered by a multi-stage booster pump; this system is similar to the “primary manifold” described by Smiley. The chambers are left at initial pressure overnight, and the decompression sequence begins at the start of the next work day. Our sequence is similar, again, to Smiley and Drawbridge. We typically allow a minimum of 8 hours between steps, sometimes allowing overnight periods without adjustments, so that the sequence takes from 3 to 6 days (Table 1). Fish coming out of the chambers are often still slightly over-buoyant, we add them to holding tanks with structures placed on the bottom that the fish can wedge themselves under, and usually within 24 hours the fish will attain neutral buoyancy.

Table 1. Typical Decompression Schedule

Step, $\geq 8$ hr.s between	Chamber psi	Meters of seawater	ATA
Initial	60-80	39-55	5-6.5
1	60	39	5
2	45	30	4
3	30	20	3
4	20	13	2.4
5	15	10	2
6	10	7	1.7
7	7	4	1.5
8	3	2	1.2
9	0	$\leq 1$	1

## Results

We have observed that when bringing up rockfish from a given depth, between and within rockfish species, there can be quite a variation in externally visible barotrauma, amount of pressure needed to regain neutral buoyancy, and time needed once recompressed to return to “normal” ventilation rates and vertical orientation. We have collected with hook and line down to about 130 m and 80% of all the shelf rockfish we treated with the chambers recover well including; boccacio (*Sebastodes paucispinis*), canary (*S. pinniger*), chilipepper (*S. goodei*), cow cod (*S. levis*, Figure 3), greenstriped (*S. elongatus*, Figure 4), greenspotted (*S. chlorostictus*), halfbanded (*S. semicinctus*), rosy (*S. rosaceus*), starry (*S. constellatus*), squarespot (*S. hopkinsi*), and widow (*S. entomelas*). We have also used the chambers for routine collection of common nearshore rockfish species and have mostly eliminated use of the venting method. The one species that does not recover well is the blue rockfish (*S. mystinus*); this schooling inhabitant of the water-column often shows extreme stomach eversion if fished from deeper than 30 m and most these individuals do not survive.



Figure 3. Juvenile cow cod rockfish

Figure 4. Juvenile greenstriped rockfish

### ***Post-recompression visual performance***

Past rockfish researchers have had concerns about visual performance in fish that had experienced exophthalmia and/or corneal emphysema. The MBA hosted and assisted Bonnie Rogers who had previously shown optic nerve stretching from exophthalmia using magnetic resonance imaging (Rogers et al., 2008). Rogers employed an inventive device for fish that tested vision using the “optokinetic reflex test” to assess visual acuity in rockfish immediately upon removal from our chambers. She tested mostly rosy rockfish and showed that they all had “functional” vision and the

vision had improved when tested again a month later. All the tested rosies had previously exhibited exophthalmia and some corneal emphysema (Rogers et al., 2011).

### **Oxygen Toxicity**

Our plans to use pure oxygen gas to pressurize our stainless steel chambers prompted us to do some preliminary testing. We expected partial pressures of oxygen to closely approach levels that had been shown to be lethal in fishes and other vertebrates (D'Aoust 1969, Barthelemy et al., 1981). We subjected rosy rockfish to a minimum of 6 ATA O<sub>2</sub> for over 4 hours in a chamber with a view port, and observed no significant behaviors indicating CNS impairment. Progressively higher oxygen pressures have been used in our stainless chambers to where we now typically pressurize initially to 7 ATA. We have successfully treated barotrauma in many fish with these chambers, and the few mortalities observed do not appear attributable to oxygen toxicity. These chambers need pressurized water circulation within about 8 hours to account for carbon dioxide build up or other water quality issues.

## **Discussion**

### ***Rockfish conservation***

The fact that many fish experiencing “rapid forced decompression” (Pribyl, 2011) or “angling – induced barotrauma” (Rogers, 2011) can fully recover is relatively new news and a “hot topic” with fishers, scientists and fisheries regulators. Efforts in Alaska have shown that yellow eye rockfish (*S. ruberrimus*) fished from depths near 100 m, briefly exposed to barotrauma, tagged and then sunk back down and released, when recaptured months later showed active healthy reproductive organs (Blain et al., 2010). The California Department of Fish and Game, in collaboration with California and Oregon Sea Grant, has published a “Bring That Rockfish Down” brochure (2008) promoting and suggesting methods for fishers to sink unwanted or prohibited species back to depth. This brochure recommends against venting. The National Oceanic and Atmospheric Administration has held barotrauma workshops and has opened a web site (fishsmart.org) also encouraging the use of sinking release devices. These devices range from the simple and home-made to a commercially available pressure –activated unit that we are now using with MBA collecting efforts.

### ***Other applications***

These relatively simple and inexpensive hyperbaric chambers should have applications for other physoclistic fishes outside the rockfish group. These chambers could simplify some tropical fish collections normally requiring logistically challenging deep scuba operations. Looking into deeper water beyond the continental shelf, we've seen some impressive hyperbaric chambers designed to capture and maintain truly deep water fishes (Wilson and Smith, 1985; Drazen et al., 2005), however these chambers may not lend themselves well to long-term animal captivity or to community/habitat exhibits (or to husbandry department budgets). Are there any truly deep water species that can handle this rapid decompression/partial recompression experience as the rockfish do?

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## Tracking Grey Reef Sharks Using a Novel Method for Acoustic Tag Attachment and the “Crittercam”

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### Abstract

A novel and less intrusive method for attaching an acoustic tag to a shark was developed to study the movement patterns of grey reef sharks. The objective was to determine if a viable alternative to surgical implantation or dermal attachment of tags could be developed. The new tagging method simply banded the tag to the caudal peduncle of an adult shark (*Carcharhinus amblyrhynchos*, Pacific grey reef shark). Bands were made of stainless steel braided wire with a corrodible metal crimp. Once tagged and released, the behavior of individual free-ranging sharks was observed by scuba divers and using the "Crittercam". Divers observed that sharks tagged with the bracelets responded by immediately resuming normal behavior and showed no agitation in response to the tag. Videos of the tagging method and shark behavior will be shown at the AAUS symposium presentation.

**Keywords:** acoustic tracking, *Carcharhinus amblyrhynchos*, coral reef, Johnston Atoll, National Geographic Society, Palau, shark dives, underwater technology, Vemco

### Introduction

Acoustic telemetry and the National Geographic Society's Crittercam (an animal borne camera and sensor system) were used to study movement and behavior of *Carcharhinus amblyrhynchos* at two coral reef locations in the Pacific. The focus of the Johnston Atoll (JA) study was to examine contaminant uptake in a top predator and residency patterns in contaminated areas. The focus of the study in Palau was to identify implications of shark residency patterns relative to conservation issues, particularly the domain needed for a marine protected area aimed at reef shark protection. Individual *C. amblyrhynchos* were outfitted with acoustic tags to determine their frequency of return to certain key reef sites where underwater acoustic loggers were deployed. At Johnston Atoll, the sites of concern were where sediment contaminants (e.g. PCBs, dioxins, heavy metals) were greatest. In Palau, the key site was "Blue Corner", one of the main destination scuba dive locations for the ecotourism industry. The question for sharks at both locations was: how long do individuals remain at or routinely visit a particular reef location?

At the present time, there are two commonly used methods for tagging sharks and other fishes with acoustic transmitters. The most common method is to attach the tag using a dermal implant (e.g. Floy tag anchors, spaghetti style dart, etc.) that is harpooned into the muscle tissue, usually near the base of the dorsal fin. The second method is surgical implantation of the tag into the abdomen. A third method, letting the fish ingest the tag (wrapped in bait), is rarely used because ingested tags are regurgitated in a few to several days (e.g. Economakis and Lobel, 1998). For a comprehensive review of shark tagging methods and studies see Kohler and Turner (2001).

While traditional methods for attaching tags using dermal implanted anchors into muscle tissue or by surgical implantation in the abdomen have been used with success for decades, we wanted to develop

an alternative method that would be potentially less traumatic for the study animal. This is especially appropriate given current regulatory requirements regarding animal welfare and the requirement for IACUC (Institutional Animal Care Use Committee) permits. A similar evolution of attachment technologies proceeded with the development of the National Geographic Society's Crittercam; from harpoon implants to dorsal fin clamps on sharks (Marshall, 1998; 2007). This study presents results of trials using a banding method where an acoustic tag is attached to a shark's caudal peduncle. Several of these sharks were also outfitted with the Crittercam so that we could later assess their behavioral response to the handling procedure (see Skomal et al., 2007; Lobel, 2008a for additional details).

The goal was to assess shark behavior and reaction to the tags by means of direct observation (with video) by scuba divers and by means of the Crittercam. The results reported here are observational and in addition to being discussed here, will be shown using videos and photographs at the AAUS 2012 Symposium.

## Materials and Methods

### *Study species*

The grey reef shark, *Carcharhinus amblyrhynchos*, was tagged and observed at two locations in the Pacific Ocean: Johnston Atoll and Palau. *C. amblyrhynchos* is one of the most common coral reef sharks throughout the Pacific and Indian oceans. In recent years, it has also been listed on the IUCN Red List of Threatened Species as Lower Risk- Near Threatened (LR/nt) due to its high site fidelity, restricted habitats, large size at maturity, small litter size and increased fishing pressure (Smale, 2009).

### *Study Sites*

The work conducted at Johnston Atoll (Central Pacific, 16.735°N, 169.528°W) was part of larger study on the atoll marine ecology of the coral reef ecosystem (Lobel, 2003; Lobel and Lobel, 2008). During April 2001, April 2002 and June/July 2003, thirteen grey reef sharks ranging 56-135cm fork length were caught by hand line and brought immediately to the boat. These sharks were tagged with the acoustic-bracelet before release. Crittercam was deployed on six of these sharks (see Skomal et al., 2008 for additional results). The Crittercam deployments at Johnston Atoll were during the final days of the military base being in operation and thus short-termed. The entire Johnston Atoll study ended when the military base ceased operations in September 2003.

The work conducted in Palau (South Pacific, 7.43°N, 134.628°E) was during the period from April 2004 and ended in April 2006. During this time, nine sharks were tagged and four of these were also released with Crittercam.

### *Shark handling and tagging*

Sharks were caught individually using a hand-line comprised of a single shark barbless hook (non-stainless) crimped to stainless steal wire (1m) attached to braided nylon line (8m). Handling the line in the way to control the shark was key. All sharks were quickly inspected for signs of physical injury, hook placement, and tissue damage. The shark was rolled onto its back. The hook was held in place by one person holding the line, while a second person grabbed the tail and rolled the shark onto its back. The shark then rested in tonic immobility. Tonic immobility is well known and widespread physiological phenomenon among sharks (Davie et al., 1993; Henningsen, 1994) and is a natural form of anesthesia. The shark does not struggle or feel pain. Sharks are extremely resistant to pain because they lack the neural apparatus essential for the sensation of pain (Snow et al., 1993; Rose, 2002). Furthermore, sharks, in general, are known for their rapid wound healing capabilities (Reif, 1978). The bracelet tag was attached. The Vemco tags had tiny holes drilled in each end were used with

stainless steel leader cable and a base metal alloy crimp. The tags were banded on adult sharks with some slack for growth (Figures 1 and 2) and all stray leads were trimmed so not to abrade the animal. This method is analogous to banding a bird's leg. The hook was removed, usually by just pushing the hook out using a pipe, other times aided by bolt cutters in order to remove the hook from the shark prior to release (Figure 3).

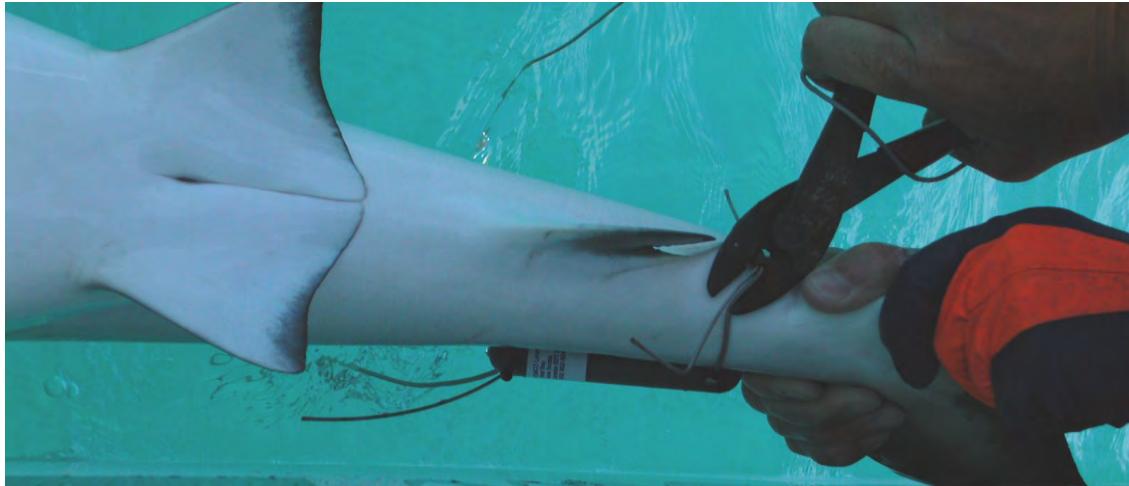


Figure 1. Attaching an acoustic tag by banding to the shark's caudal peduncle (photo by Dave Shogren).



Figure 2. Tag showing band with crimps ready for release (photo by Dave Shogren).

To estimate how long the bracelet tag might remain on a shark, a band was placed in a sealed seawater container and observed periodically for signs of corrosion.

The Crittercam animal-borne imaging system used was a smaller model (7.6cm diameter, 32cm length) but otherwise as described by Marshall (1998). It contained a mini DV tape-based image recording system with 2hr 5min video capacity. The system was placed over the dorsal fin of each shark using a V-style clamp secured together with a programmable electronic burn-wire system and a back-up galvanic magnesium link (Figure 4). The burn-wire was programmed to release after two hours during these deployments.



Figure 3. Crittercam is attached to the dorsal fin. The shark will be released from the barbless hook (photo by Dave Shogren).



Figure 4. The Crittercam is gently clamped to the dorsal fin. It releases when a burn wire activates after a programmed interval (Photo by Dave Shogren).

Using the Crittercam video and video taken by scuba observers, the behavior of the tagged grey reef sharks was recorded in order to evaluate:

- Post release recovery and behavior (see Skomal et al., 2007 for details).
- Habitat orientation
- Shark's reaction to scuba divers
- Behavioral interaction of the Crittercam'ed shark and its conspecifics
- Response of prey fishes to the sharks approach
- Reaction of divers seeing the Crittercam on a reef shark
- Where the shark was going when outside of the range of the acoustic tag recorders

Example videos will be shown at the AAUS symposium presentation.

## Results

### ***Underwater Observations***

The scientific divers were able to video and photograph many of the sharks that we tagged and burdened with Crittercam *in situ* at Blue Corner, Palau. The site logistics as well as the habituation of the sharks to scuba divers made observation easy. Sharks with tags (Figure 5) were seen and photographed on numerous dives over the two-year study period. Sharks with the Crittercam were observed during the two hours of deployment and showed little reaction to having the device temporarily attached, although these individuals were harder to approach closely than sharks with only the bracelet tags (Figure 6). At Johnston Atoll, divers did not easily observe tagged sharks, but crittercam video shows that the sharks resumed their normal swimming behavior often rejoining other groups of sharks (see Skomal et al., 2007 for details).

Documentary of the field research showing tagging method and shark behavior were featured in two television shows of the National Geographic Society's Wild Chronicle series (Palau is episode 130 and Johnston Atoll is episode 135, produced 2004). The Palau episode is viewable at [http://education.nationalgeographic.com/education/multimedia/crittercam-grey-reef-shark/?ar\\_a=1&ar\\_r=999](http://education.nationalgeographic.com/education/multimedia/crittercam-grey-reef-shark/?ar_a=1&ar_r=999). For additional background information about the Johnston Atoll project, see also [http://news.nationalgeographic.com/news/2003/08/0811\\_030811\\_sharkcam.html](http://news.nationalgeographic.com/news/2003/08/0811_030811_sharkcam.html).

### ***Tracking***

Free ranging sharks were tracked using the acoustic transmitters (Vemco coded tags) using an manual acoustic receiver from a boat and an array of 17 underwater receivers (Vemco VR1) deployed at strategic locations along the reef.

### ***Bracelet tag***

In the lab, a controlled corrosion test of a bracelet in a jar of seawater lasted nearly 15 months (which is about the duration of the tag batteries). Further refinement and testing of materials for time-released bands is certainly needed. Initial success reported here indicate the banding techniques viability.



Figure 5. A grey reef shark at Blue Corner, Palau with a banded tag (photo by P. Lobel). The tags were coded with white and black bands to enable easy identification of specific individuals underwater.



Figure 6. An underwater photo of a grey reef shark at Blue Corner, Palau with a Crittercam on its dorsal fin and an acoustic tag banded to its caudal peduncle (photo by P. Lobel). Photo was enhanced to zoom in on the shark which was a distance away.

In Palau, plastic tie-wraps between the metal crimps were used on two occasions in order to try to hasten the pace at which we could band a shark. These were not successful: one tag fell off after a few days and the other tag was dangling on one band (but still holding-on) when it was last observed by divers underwater several days later. These failures were due to the plastic tie-wrap breaking. The

latter tag was still tracked for 3 months by the VR1 underwater detectors. Thus, tie-wraps were no longer used and was replace by using only the steel wire and crimp.

In Palau, where the study duration was longest, nine sharks were harnessed with bracelet tags. The total duration tracking times ranged from 1.7 to 17.8 months with a mean duration of 6.7 months.

## Discussion

The grey reef shark project at Johnston Atoll began in 1992 with study of a female aggregation in shallow water (Lobel, 2003). The first trials assessing different tagging methods on these female sharks started in 1993. This included feeding bait-wrapped tags (Economakis and Lobel, 1998) and surgical implantation (Lobel unpubl.). Sharks that had tags surgically implanted resulted in those individuals leaving the aggregation and not returning. Normally, they would have stayed in the area. This inspired the search for alternative, less intrusive tagging methods.

The damage done to sharks and other fishes using anchors imbedded in muscle is well known and a problem (e.g. Heupel and Bennett, 1997; Heupel et al., 1998; Kohler and Turner, 2001; Dicken et al., 2006). This includes localized tissue breakdown and hemorrhaging independent of any associated capture related injuries. The ulceration from a tag implanted with an anchor in the muscle provides a potential site for secondary infection, although the long-term health effects have not been well defined. Fouling of the tags can also result in skin abrasion and ulceration. A variety of anchored tags as well as the surgical procedure for inserting a tag in the abdomen and then sewing up the incision are shown in Lobel (2008a). These methods all involve invasive handling.

This study presents the results of preliminary trials using a banding method where the tag is attached to a shark's caudal peduncle. The band eventually rusts and falls off but has the potential to last in duration for the battery life of the tag. Thus, an animal is not burdened in the long run with having a tag implanted or externally attached which no longer transmits and becomes fouled. Bracelet banding has two main advantageous features: 1) no injury to the shark is required for tag attachment and 2) it is a rapid technique, requiring less than a few minutes from being hooked to being tagged and released (Skomal et al., 2007). Divers observed that the sharks resumed their normal activity and behavior immediately upon release. The tags have the potential to remain attached for the life-time of the acoustic tag, but will eventually rust and fall off. Clearly, further technical development of a bracelet-tag would only improve its functionality.

The NGS Crittercam is a much larger device than the acoustic tags. The method developed by Greg Marshall is to fasten the Crittercam to a shark by means of a removable dorsal fin clamp. This clamp is equipped with a burn-release switch and does not damage a shark's dorsal fin in any way. This technology should be considered as an alternative to tagging methods that require inserting bolts through the dorsal fin which causes obvious and permanent injury.

The issue of how best to attach tags to wild animals in a humane way and in a way that does not impact their normal behavior is controversial. The goal should be to be as least intrusive as possible and to minimise stress and long term injuries which would also impact behavior of the study animal. There is clearly a need for new and improved technology for tagging sharks and other fishes. Tagging method and handling may have a real impact of the fish's behavior and therefore affect the scientific results of a tracking study. Such considerations are needed today given that many shark populations are "at risk", there are regulatory considerations (e.g. IACUC) and there is public scrutiny from diving ecotourism focused on elasmobranch watching (e.g. Lobel, 2008b).

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## Sea Stars of the Nearshore Aleutian Archipelago

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### Abstract

Sea stars are one of the most diverse groups of epifaunal organisms in the shallow (< 20 m), nearshore region of the Aleutians. For the first time in more than a century scientists probed the Aleutian waters yielding information on sea stars throughout this remote region. Sea stars were collected using open-circuit scuba between 2004 and 2011 during five research surveys that covered all five major island groups spanning approximately 2500 km. Nineteen divers made 841 dives on more than 100 sites. Although sea stars were not the focus of the dive surveys, sea stars were photographed and collected where possible, yielding 6 families, 18 genera, and 53 species. This paper lists those species and highlights some of the unique species found, including several species indigenous to the Aleutian Archipelago.

Keywords: Aleutian Islands, diving, sea stars, taxonomy

### Introduction

Sea stars, a diverse group of marine invertebrates with 4-20+ rays (arms) and a myriad of colors and markings, have intrigued people for centuries, even in Alaska, the “Last Frontier”. The nearshore subtidal community of the Aleutian Archipelago is understudied in comparison to other nearshore regions in North America. The remoteness of the region and adverse weather, coupled with the rocky substratum that limits sampling with standard remote techniques such as trawls or grabs, has resulted in few shallow collections there.

The Smithsonian Institution published an outstanding taxonomic compendium on sea stars entitled “Asteroidea of the North Pacific and Adjacent Waters” (Fisher, 1911, 1928, 1930). Fisher’s three-part treatise was based on specimens collected between 1888 and 1897 mainly by dredge from a broad geographical region, including the Aleutian Islands. In 1914, Yale University Professor A.E. Verrill compiled a taxonomic monograph on the sea stars from the 1899 Harriman Alaska Expedition, although only the eastern Aleutian Islands were covered (Verrill, 1914). The U.S. Fish and Wildlife Service opportunistically collected sea stars near a few of the Aleutian Islands in 1936-38 (Scheffer, 1959). O’Clair (1977) compiled an annotated list of sea stars from the intertidal and shallow subtidal waters of eastern Amchitka Island in the central Aleutians. Vicknair’s (1997) research on western Aleutian sea stars was the first to use open-circuit scuba diving as a method of collection. More recent sea star collections throughout the Aleutians using scuba have led to descriptions of several new species (Clark and Jewett, 2010, 2011a, b; Jewett and Clark, 2011). This paper is the first account of sea stars throughout the Aleutian Islands since Fisher’s treatise. It is not intended so much for taxonomic purposes, but rather, to showcase some of the diverse sea stars we encountered while diving in the shallow, nearshore waters of the remote Aleutian Islands. Undoubtedly we have missed some. Among the list of sea stars several of the interesting and more unique groups and species are highlighted.

## Methods

Sea star photos and subsequent collections were mainly taken to assist research projects with taxonomy and characterizing project dive sites. Additional photos from our dive sites are available in Brewer et al. (2011). Photographs were compiled during five research surveys using open-circuit scuba. In 2004 dive team of scientists funded by USDOE dove around Amchitka and Kiska islands in the west-central Aleutians to sample the nearshore benthic community for possible leaking radionuclides from nuclear detonations that occurred on Amchitka Island in 1965, 1969, and 1971 (Jewett et al., 2006). In 2006 and 2007 a team research divers sampled 50 random sites covering the five island groups (Figures 1 and 2) in the nearshore Aleutians Islands during a contaminant-based USEPA-funded investigation (Jewett et al., 2008). In 2008, a few dives were made at several sites along the Aleutians on two research projects (R. N. Clark and H. Chenelot, pers. comm.). In 2011 USDOE again funded a dive team to sample around Amchitka for leaking radioactivity; Adak Island was the reference island. Dive sites for the 2006-07 research, where most of the photographs were taken, are shown in Figure 2. All digital photos were taken during June and July at depths generally less than 20 m (60 ft).

## Setting

Five main island groups comprise the Aleutian Islands (Figure 1): *Fox Islands*, closest to the Alaska Peninsula, consist of Umnak, Unalaska, Akutan as well as the Krenitzin Chain; *Islands of Four Mountains* includes Carlisle, Chuginadak, Herbert, Kagamil, Yunaska, and Amukta; *Andreanof Islands* include Amlia, Atka, Great Sitkin, Adak, Kanaga, Seguam, Tanaga and numerous smaller islands; *Rat Islands* include Semisopochnoi, Amchitka, Little Sitkin, Hawadax (Rat), Segula, Kiska and Buldir; and the western-most *Near Islands* include Agattu and Attu. A smaller island group of the Semichi Islands, which includes Shemya, is a subset of the Near Island group. Not associated with any of the five island groups is Unimak Island, the largest and eastern-most of the Aleutian Islands.

The southern edge the Aleutian Islands is bounded by the strong Alaska Current flowing in a westerly direction, with the easterly flowing Aleutian North Slope Current to the north of the islands. Significant flow from the Alaska Current occurs through 14 passes (Figure 3), providing relatively fresh surface waters and warm subsurface waters to the Bering Sea (Stabeno et al., 1999). The largest passes between the Alaska Peninsula and Attu Island are Unimak Pass (between Unimak and Tigalda Islands), Samalga Pass (between Umnak Island and Islands of Four Mountains), Amukta Pass (between Islands of Four Mountains and Seguam Island), Tanaga/Amchitka Passes (between Tanaga and Amchitka islands) and Buldir Pass (between Kiska and Agattu islands). All species accounts in the paper are based on observations made between Tigalda and Attu islands.

## Results and Discussion

A total of 19 divers made 841 dives for a total of 581 hours of diving to acquire sea star information during the five research cruises. Sea stars photographed and collected in the nearshore Aleutian Islands belong to 4 orders, 6 families, 18 genera, and 53 species (Table 1). Most species belong to two families, Echinasteridae and Asteridae, with 19 species each. Most species occur in the central Aleutians, i.e., Andreanof Islands and Rat Islands, albeit most effort was devoted to this region. Some species occur throughout the Aleutians (n=13), some only in the eastern Aleutians (Fox Islands, n=5), and others only in the western Aleutians (Near Islands, n=3) (Table 2). Approximately 20 species appear to be endemic to the Aleutian Islands, with the majority of these species newly discovered (Clark and Jewett, 2010, 2011a, b; Jewett and Clark, 2011).



Figure 1. Five major island groups in the Aleutian Islands.

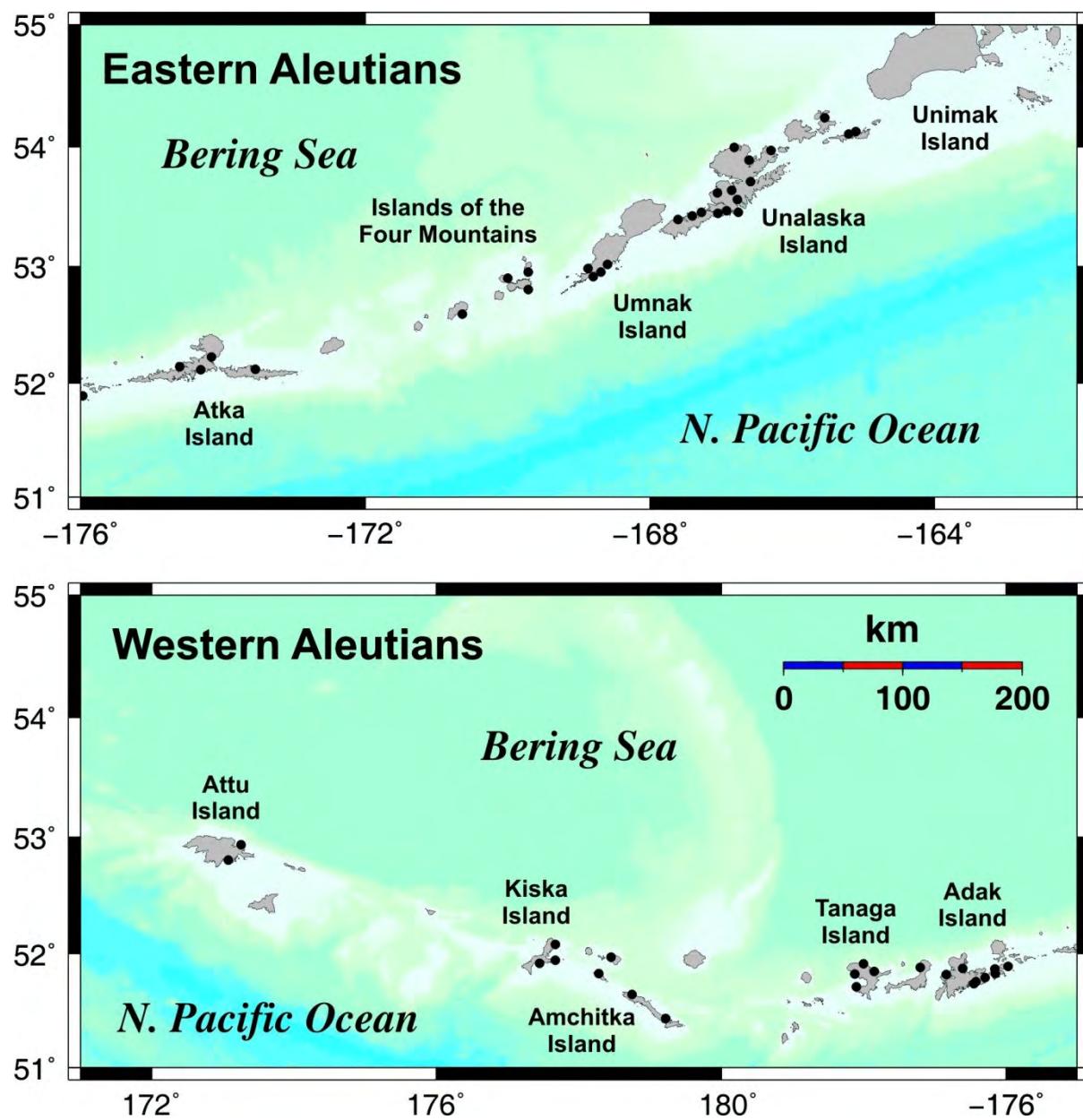


Figure 2. Locations of dive sites for the 2006-07 research, where most of the photographs were taken.

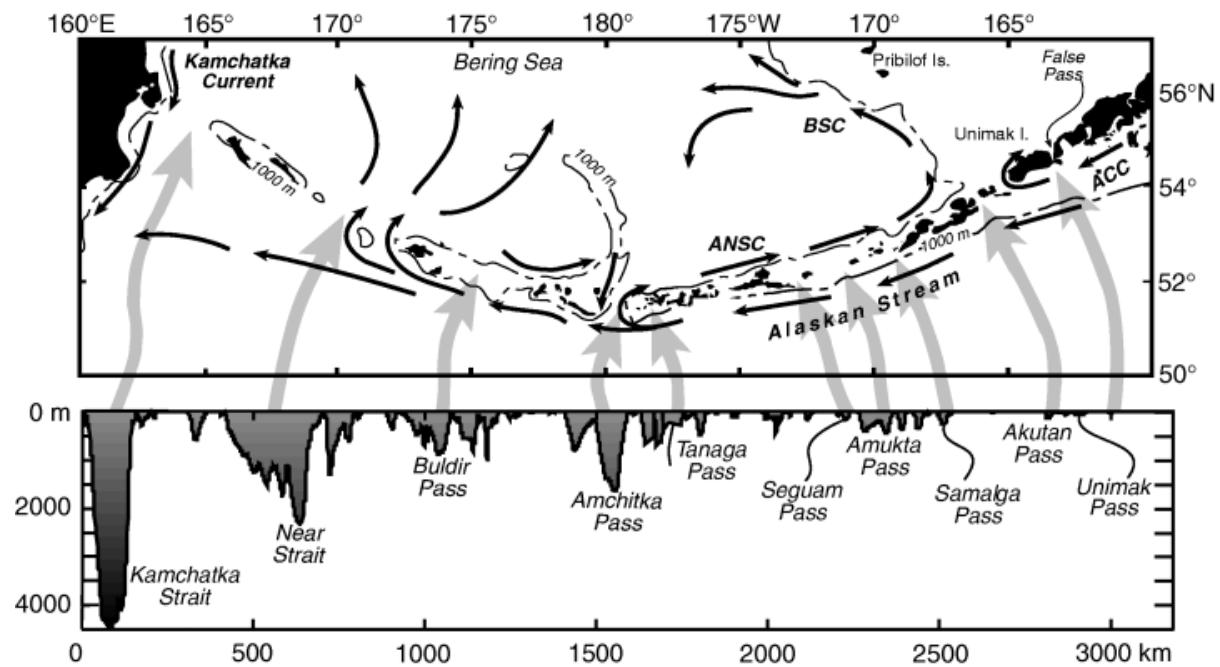


Figure 3. Major ocean passes and currents along the Aleutian Islands (from Stabeno et al., 1999).

Table 1. Nearshore Aleutian Sea Stars

**Order: VALVATIDA**

Family: GONIASTERIDAE

Genus: *Ceramaster*

*C. arcticus* (Verrill, 1909)

Genus: *Gephyreaster*

*G. swifti* (Fisher, 1905)

Genus: *Hippasteria*

*H. aleutica* Clark and Jewett, 2011

**Order: VELATIDA**

Family: SOLASTERIDAE

Genus: *Aleutiaster*

*A. schefferi* A.H. Clark, 1939

Genus: *Crossaster*

*C. papposus* (Linnaeus, 1767)

Genus: *Solaster*

*S. arcticus* Verrill, 1914

*S. dawsoni* Verrill, 1880

*S. endeca* (Linnaeus, 1771)

*S. hexactis* Clark and Jewett, 2011

*S. spectabilis* Clark and Jewett, 2011

*S. stimpsoni* Verrill, 1880

Family: PTERASTERIDAE

Genus: *Pteraster*

*P. militaris* (Müller, 1776)

*P. tesselatus* Ives, 1888

*P. willsi* Clark and Jewett, 2011

Family: KORETHRASTERIDAE

Genus: *Peribolaster*

*P. biserialis* Fisher, 1905

**Order: SPINULOSIDA**

Family: ECHINASTERIDAE

Genus: *Henricia*

*H. sp. A*

*H. asthenactis* Fisher, 1910

*H. echinata* Clark and Jewett, 2010

*H. elachys* Clark and Jewett, 2010

*H. gemma* Clark and Jewett, 2010

*H. insignis* Clark and Jewett, 2010

*H. iodinea* Clark and Jewett, 2010

*H. lineata* Clark and Jewett, 2010

*H. multisepia* Fisher, 1910

*H. oculata* Pennant, (1777)

*H. rhytisma* Clark and Jewett, 2010

*H. sanguinolenta* (Müller, 1776)

*H. tumida* Verrill, 1909

*H. uluudax* Clark and Jewett, 2010

*H. vermillion* Clark and Jewett, 2010

Genus: *Odontohenricia*

*O. ahearnae* Clark and Jewett, 2010

*O. aurantia* Clark and Jewett, 2010

*O. violacea* Clark and Jewett, 2010

Genus: *Aleutihenricia*  
*A. federi* Clark and Jewett, 2010

**Order: FORCIPULATIDA**

Family: ASTERIIDAE

Genus: *Asterias*

- A. amurensis* (Lütken, 1871)
- A. microdiscus* (D'yakonov, 1950)

Genus: *Easterias*

- E. echinosoma* Fisher, 1926
- E. retifera* D'yakonov, 1950
- E. troschelii* (Stimpson, 1862)

Genus: *Leptasterias*

*L.* sp. A

- Subgenus: *Leptasterias*  
*L. hylodes* Fisher, 1930

Subgenus: *Eoleptasterias*

- L. cf ochotensis* (Brandt, 1851)
- L. squamulata* D'yakonov, 1938

Subgenus: *Hexasterias*

- L. alaskensis* Verrill, 1909
- L. aleutica* Fisher, 1930
- L. asteira* Fisher, 1930
- L. dispar* Verrill, 1914
- L. leptodoma* Fisher, 1930
- L. nitida* Fisher, 1930

Genus: *Orthasterias*

- O. koehleri* (de Loriol, 1897)

Genus: *Lethasterias*

- L. nanimensis* (Verrill, 1914)

Genus: *Pycnopodia*

- P. helianthoides* (Brandt, 1835)

Genus: *Stephanasterias*

- S. albula* (Stimpson, 1853)

Table 2 Range of sea stars in the Aleutian Islands, from east to west (right to left)

SEA STARS	Near Is	Buldir Pass	Rat Is	Amchitka Pass	Andreanof Is	Amukta Pass	Is of 4 Mts	Samalga Pass	Fox Is	Unimak Pass
<i>Aleutiaster schefferi</i>	X		X		X		X		X	
<i>Ceramaster arcticus</i>	X		X		X		X		X	
<i>Crossaster papposus</i>	X		X		X		X		X	
<i>Evasterias troschelii</i>	X		X		X		X		X	
<i>Henricia lineata</i> *	X		X		X		X		X	
<i>Henricia tumida</i>	X		X		X		X		X	
<i>Leptasterias dispar</i>	X		X		X		X		X	
<i>Pteraster tesselatus</i>	X		X		X		X		X	
<i>Solaster stimpsoni</i>	X		X		X		X		X	
<i>Stephanasterias albula</i>	X		X		X		X		X	
<i>Lethasterias nanimensis</i>	X		X		X		X		X	
<i>Henricia</i> sp A	X		X		X		X		X	
<i>Hippasteria aleutica</i> *	X		X		X		X		X	
<i>Henricia iodinea</i> *			X		X		X		X	
<i>Henricia oculata</i>			X		X		X		X	
<i>Henricia rhytisma</i> *			X		X		X		X	
<i>Henricia uluudax</i> *			X		X		X		X	
<i>Leptasterias alaskensis</i>			X		X		X		X	
<i>Pteraster militaris</i>			X		X		X		X	
<i>Solaster endeca</i>			X		X		X		X	
<i>Leptasterias</i> sp A *			X		X		?		X	
<i>Henricia insignis</i> *			X		X		X			
<i>Odontohenricia ahearnae</i> *			X		X		X			
<i>Odontohenricia aurantia</i> *			X		X		X			
<i>Solaster spectabilis</i> *			X		X		X			
<i>Pycnopodia helianthoides</i>					X		X		X	
<i>Peribolaster biserialis</i>			X		X		?		X	
<i>Henricia multipina</i>	X		X		X		X			
<i>Aleutihenricia federi</i> *	X		X		X					
<i>Leptasterias hylodes</i>	X		X		X					
<i>Pteraster willsi</i> *	X		X		X					
<i>Henricia asthenactis</i>			X		X					
<i>Henricia gemma</i> *?			X		X					
<i>Leptasterias aleutica</i> *			X		X					
<i>Leptasterias leptodoma</i> *			X		X					
<i>Odontohenricia violacea</i> *			X		X					
<i>Solaster hexactis</i> *			X		X					
<i>Solaster arcticus</i>			X		X					
<i>Henricia elachys</i> *			X		X					
<i>Evasterias echinosoma</i>					X					
<i>Gephyreaster swifti</i>					X					
<i>Henricia echinata</i> *					X					
<i>Henricia sanguinolenta</i>					X					
<i>Leptasterias cf ochotensis</i>					X					
<i>Leptasterias nitida</i>					X					
<i>Henricia vermillion</i> *?								X		
<i>Solaster dawsoni</i>								X		
<i>Asterias amurensis</i>								X		
<i>Leptasterias asteira</i>								X		
<i>Orthasterias koehleri</i>								X		
<i>Evasterias retifera</i>	X									
<i>Asterias microdiscus</i>	X									
<i>Leptasterias squamulata</i>	X									

\* = endemic species

Because sea star species in the nearshore Aleutian Islands are so numerous we have chosen to highlight only a subset, focusing on some with unique attributes, e.g., size, color, markings, and spination. The following species accounts include information on description, distribution and habitat, and ecological notes.

***Ceramaster arcticus* (Verrill, 1909) - Arctic Cookie Star, Arctic Bat Star  
(Figure 4)**

*Ceramaster arcticus* is a stiff, broad, five-rayed star (four- and six-rayed specimens are uncommon) with the aboral coloration showing general shades of reddish, pink or lavender and the oral surface being flesh or cream colored. It is distributed from the Bering Sea to British Columbia, intertidal to about 80 m. In the Aleutians, this species is typically found on rock substrates covered with encrusting coralline algae. We found this species nearly throughout the Aleutians, from the Fox Islands to the Rat Islands, but Vicknair (1997) also found it in the Near Islands (Massacre Bay of Attu Island). *Ceramaster arcticus* feeds by everting its stomach over its prey. Little else is known of the feeding or natural history of this species but it has been reported preying on various species of sponges, including *Suberites concinnus*. The orange cookie star, *Ceramaster patagonicus* (Sladen, 1889) is also found in the Aleutians, but only rarely in less than 20 m. It may be distinguished from *C. arcticus* by having 1) a uniformly bright orange aboral coloration, 2) smaller, and more numerous granules on the aboral surface, with four to eight at the center, and 3) twelve to fifteen marginal, and three to five robust adambulacral spinelets.

***Aleutiaster schefferi* A. H. Clark, 1939 - Scheffer's Dwarf Star  
(Figure 5)**

*Aleutiaster schefferi* is found throughout most of the Aleutian Islands, from Unalaska to Attu, from the intertidal to at least 20 m, on rocks and tubeworm colonies (*Chone* sp.), and amongst *Laminaria* spp. kelp holdfasts. It may feed on detritus and/or epiphytes. This is one of the smallest known sea star in the world. Originally described as a member of the family Ganariidae, it was recently re-assigned to the family Solasteridae (Gale et al., 2009). With its small size, inflated body, six stubby rays and solid white coloration, *Aleutiaster schefferi* is unlikely to be confused with any other species in the Aleutians. However, it is probably easily overlooked because of its small size.

***Solaster Forbes, 1839*  
(Figures 6a, b, c, d, e, f)**

We found six species of *Solaster* in the Aleutian Islands, *S. arcticus* Verrill, 1914, *S. dawsoni* (Verrill, 1880), *S. endeca* (Linnaeus, 1771), *S. hexactis* Clark and Jewett, 2011, *S. spectabilis* Clark and Jewett, 2011 and *S. stimpsoni* Verrill, 1880. A distinguishing feature of this genus is that it typically has more than 8 rays; most are broadcast spawners with lecithotrophic larvae.

*Solaster arcticus*, the Aleutian Sun Star, is a large ten-rayed star; rays broad at base, tapering to a slender point, long to 20 cm (Figure 6a). The aboral coloration of the disc is salmon and the rays are purplish or fuchsia, or yellow-tan, with broad reddish stripes radiating from the disc center. *Solaster arcticus* occurs in the Beaufort, Chukchi and Bering Seas, south to the Aleutian Islands, from the Islands of Four Mountains to Rat Islands. The habitat is at 10-180 m on rocky, sand or shell-hash bottoms. It is assumed that *S. arcticus* is a broadcast spawner with pelagic, lecithotrophic larvae, as is *S. dawsoni* and *S. stimpsoni* (Miller, 2001). *Solaster arcticus* appears to feed mostly on sea urchins of the genus *Strongylocentrotus*. *Solaster arctica* is similar to *S. spectabilis*, but may be distinguished by coloration, and the number of spines on the adambulacral plates.



Figure 4. *Ceramaster arcticus* (Verrill, 1909), Arctic Cookie Star, Arctic Bat Star.



Figure 5. *Aleutiaster schefferi* A. H. Clark, 1939, Scheffer's Dwarf Star



Figure 6. a) *Solaster arcticus* Verrill, 1914, Aleutian Sun Star, b) *S. dawsoni* (Verrill, 1880), Morning Sun Star, c) *S. endeca* (Linnaeus, 1771), Northern Sun Star, d) *S. hexactis* Clark and Jewett, 2011, Aleutian Brooding Sun Star or Six-rayed Sun Star, e) *S. spectabilis* Clark and Jewett, 2011, Spectacular Sun star, and f) *S. stimpsoni* Verrill, 1880, Striped Sun star.

*Solaster dawsoni*, the Morning Sun Star, is a large broad star, with 12-14 rays that are relatively short (about as long as disc width) and slender (Figure 6b). The aboral coloration is orange or brown tones, often with darker markings on disc. The coloration and number of rays (more than any other star in Alaska, except for *Pycnopodia*) will distinguish this star from all others in the region. *Solaster dawsoni* is found from the eastern Aleutian Islands, west to Umnak Island, and south to California, from the intertidal to depths of about 30 m or more on rocky and soft bottoms. *Solaster dawsoni* is a broadcast spawner with pelagic, lecithotrophic larvae (Miller, 2001). This species is a voracious predator that feeds on other sea stars, especially *S. stimpsoni*, but also *Henricia* spp., *Easterias troschelii*, *Crossaster papposus*, *Leptasterias* spp. and even the much larger *Pycnopodia helianthoides* and other *S. dawsoni*. Most stars show a strong fleeing response to contact with *S. dawsoni*. This predator does not move very fast (10 cm/min) and will usually not pursue its faster preys (60-70 cm/min for *C. papposus*; 160 cm/min for *P. helianthoides*). Instead, *S. dawsoni* has adopted an effective ‘lurching’ behavior to capture its preys. It raises its leading rays above the substrate as it cruises along, which allows it to make contact with its prey from above and follow with a quick lurching movement atop the prey (Mauzey et al., 1968). This predator seems to ingest the central disc first, then the rays of its congener preys. In the case of the larger *Easterias troschelii* and *Pycnopodia helianthoides*, only autotomized rays have been found in the stomach of *S. dawsoni* (Mauzey et al., 1968). *Solaster dawsoni* produces planktonic lecithotrophic larvae in late winter-early spring. The scale worms *Arctonoe fragilis* and *A. vittata* are commensal on *S. dawsoni*.

*Solaster endeca*, the Northern Sun Star, is a large, inflated, often “pudgy” appearing star with nine to thirteen (normally ten) rays (Figure 6c). The rays are about as long as disc width, up to 20 cm. The aboral surface is “velvet-like” in appearance and may be solid red, purple, or orange, or red or purple with yellow or orange between the rays. The distribution of *S. endeca* is Arctic, circumboreal, south to Puget Sound, Washington, subtidal to 100 m, on rocky, muddy and sandy substrates. We found this species throughout the Aleutian Islands, except the Near Islands. *Solaster endeca* is a broadcast spawner with pelagic, lecithotrophic larvae, as is *S. dawsoni* and *S. stimpsoni* (Gemmell, 1910; Miller, 2001). *Solaster endeca* in the Pacific feeds mostly on sea cucumbers, bryozoans and sea squirts. In contrast to the strong fleeing response triggered by *Solaster dawsoni*, other stars do not show any predator avoidance behavior in the presence of *Solaster endeca* (Mauzey et al., 1968). The commensal scale worm *Arctonoe vittata* is often found on this species. The rather smooth, velvety aboral surface and relatively short pudgy rays should distinguish this species from other *Solaster* species.

*Solaster hexactis*, the Aleutian Brooding Sun Star or Six-rayed Sun Star, is a small, six-rayed star with rays to 4.1 cm (Figure 6d). The aboral coloration is dull, brick red; the oral side cream colored. This species is endemic to the central Aleutian, from Seguam Pass to Buldir Island on rocky substrates from 10-385 m. This species is the only member of Solasteridae known to brood its young. *Solaster hexactis* is a newly described species (2011) and relatively little is known about its ecology and natural history. *Solaster hexactis* is the smallest and only known six-rayed species of *Solaster*. This species bears a striking resemblance to members of the genus *Henricia*, of the family Echinasteridae, and may be mistaken for a six-rayed specimen of that genus, however, it may be distinguished by the nature of the mouth and adambulacral plates, particularly the two long, slender spines of the adambulacral furrow.

*Solaster spectabilis*, the Spectacular Sun star, is a large ten (rarely eleven)-rayed star (Figure 6e). The rays are about as long (to 20 cm), or slightly longer than disc width. The color is variable, often with yellow/orange disc and purple rays, may be uniformly purple, yellow, or white with pink at ray-tips. This species appears to be confined to the central Aleutians, between Samalga Pass in the east, and Buldir Pass in the west, at depths of 7-212 m on rock bottoms. It is assumed that *S. spectabilis* is a broadcast spawner with pelagic, lecithotrophic larvae, as is *S. dawsoni* and *S. stimpsoni* (Miller,

2001). This species has been observed feeding on the sea urchin *Strongylocentrotus polyacanthus*. As a newly described species (2011), relatively little is known about *S. spectabilis*' ecology and natural history. *Solaster spectabilis* may be distinguished from other *Solaster* spp. by the number of adambulacral spines, and coloration.

*Solaster stimpsoni*, the Striped Sun star, is a large, typically ten-rayed star (Figure 6f). The rays are relatively long to 23 cm, slender, usually noticeably longer than disc width. The aboral coloration has shades of orange or red, with a prominent blue or purple stipe radiating out from the center of the disc to the tip of each ray. *Solaster stimpsoni* is found throughout the Aleutian Islands, and south to southern Oregon, and is particularly common in the eastern Aleutians, where it is found from the intertidal to about 30 m on rocky and sandy bottoms. *Solaster stimpsoni* is a broadcast spawner with pelagic, lecithotrophic larvae (Miller, 2001). Although the diet of *S. stimpsoni* is varied, it primarily feeds on sea cucumbers of the genera *Cucumaria*, *Eupentacta* and *Psolus*. This species ingests its holothurian preys whole. Contrary to *S. dawsoni*, *S. stimpsoni* does not feed on other sea stars. *Solaster stimpsoni* may be distinguished from other members of *Solaster* by the long slender rays and aboral coloration. *Solaster endeca* often has similar coloration, but differs in having relatively shorter, thicker rays.

***Pteraster Müller and Troschel, 1842 – Cushion Stars***  
**(Figures 7a, b, c)**

We encountered three *Pteraster* species during our Aleutian surveys, *Pteraster militaris* (O.F. Müller, 1976), *P. tesselatus* Ives, 1888, and *P. willsi* Clark and Jewett, 2011. Pterasterids species are relatively inflated five-rayed stars and display a prominent osculum in the center of their aboral surface. They also have a distinctive supradorsal membrane that covers their aboral surface. That secondary layer is supported by the pseudopaxillar spines and creates a nidamental chamber. This cavity is used for respiration, defense, and reproduction (Rodenhause and Guberlet, 1946; Johansen and Petersen, 1971; Nance and Braithwaite, 1979; McClary and Mladenov, 1989). When disturbed (by predators, rough handling or extreme water temperatures), this species excretes copious amounts of slime – and should therefore be kept separate from other invertebrates if collected. The mucus is very effective at repelling predation by *Solaster dawsoni* and *Pycnopodia helianthoides*. The mucus contains saponins and other chemicals. In addition, the smothering and gumming effects might contribute to the mucus effectiveness as a defense mechanism (Nance and Braithwaite, 1979). *Pteraster tesselatus* (as *P. militaris* and *P. willsi*) does not carry pedicellariae on its dorsal surface, and a continuous secretion of small amounts of mucus may also help against abrasion and debris settlement (Rodenhause and Guberlet, 1946). *Pteraster* spp. can secrete a protective coat of mucus 6-7 cm thick in seconds. In contrast to other stars, the dermal branchiae of *Pteraster* spp. do not extend into the surrounding seawater but are enclosed in the nidamental cavity. *Pteraster* spp. satisfy their respiratory needs by rhythmically inflating and deflating their central disc and pumping oxygenated sea water in and out the nidamental cavity (Johansen and Petersen, 1971).

Sea stars generally have an indirect development with a larval stage that can be benthic or pelagic, and feeding or non-feeding. *Pteraster* species have an unusual mode of reproduction and are the only documented sea stars that have a direct development (McClary and Mladenov, 1989; McEdward, 1992; McEdward and Janies, 1993). The embryos of *Pteraster militaris* and *Pteraster tesselatus* develop directly into juveniles through an intermediate stage termed mesogen (McEdward, 1992; McEdward and Janies, 1993). Although no data are available on the reproductive mode of *Pteraster willsi*, this species may possibly also undergo direct development.

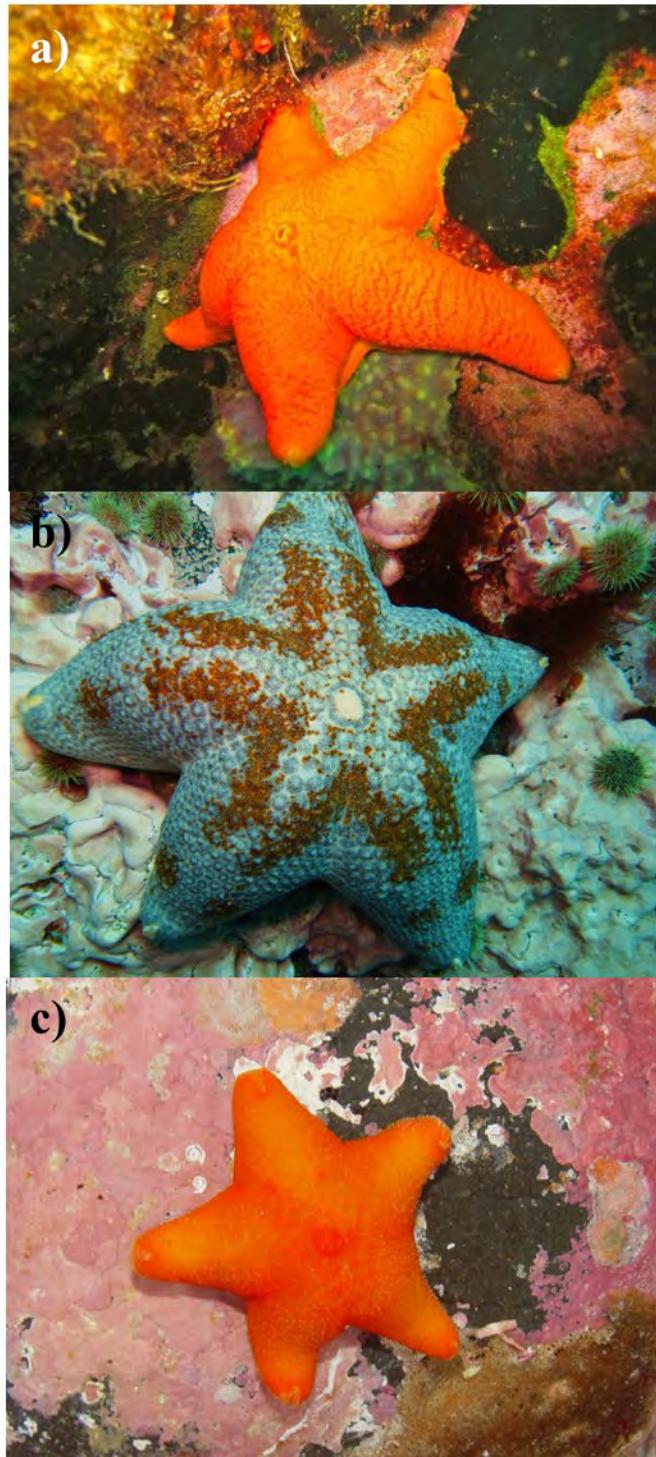


Figure 7. a) *Pteraster militaris* (O.F. Müller, 1976), Wrinkled Cushion Star, b) *P. tessellatus* Ives, 1888, Cushion or Slime Star, and c) *P. willsi* Clark and Jewett, 2011, Smooth Cushion Star.

*Pteraster militaris*, the Wrinkled Cushion Star, is moderately large and inflated with rays to 7.5 cm long (Figure 7a). The texture of the aboral surface is characteristically wrinkled and fleshy. It has a uniform cream, pale yellow, orange or pink coloration. *Pteraster militaris* is circum-boreal and is found from the Arctic south to California on soft and rocky substrates at depths of 3-1100 m. This species feeds primarily on sponges of the genus *Iophon*, and hydrocorals (*Stylaster* and *Allopora* spp.). For many years, *P. militaris* was believed to be an exclusive brooder, but in fact this species displays a mixed reproductive mode by brooding as well as broadcasting both gametes and offspring. This is the first reported case of mixed reproductive mode in an echinoderm (McClary and Mladenov, 1989). Some of the eggs are released into the water through the osculum and/or tears through the supradorsal membrane while some eggs are retained into the female brood chamber. Males release sperm into the seawater from their nidamental chamber through the osculum. Sperm can enter into the female chamber through ambulacral pores. The brooded young emerge from the mother through transient slits in the supradorsal membrane (McClary and Mladenov, 1989; McEdward, 1992).

*Pteraster tesselatus*, the Cushion or Slime Star, is relatively large and rather inflated with rays to 12.5 cm long (Figure 7b). The tip of the rays is typically upturned, revealing the ambulacral furrow. *Pteraster tesselatus* displays polygonal reticulations and yellow, tan, blue or gray colors with brown, black or orange markings. It has shorter arms and a smoother aboral surface than *P. militaris*. *Pteraster tesselatus* is found from the Bering Sea to Washington, from 1-440 m on rocky and soft bottoms and was relatively common sea star throughout the Aleutians. This species feeds primarily on sponges (*Mycale adhaerens* and *Myxilla incrassata*), which both grow on the valves of *Chlamys* spp. scallops, and *Halichondria panacea*, *Craniella spinosa*), but will also feed on colonial tunicates, hydroids, bryozoans and anemones. The scale worm *Arctonoe vittata* is commensal on *P. tesselatus*. It was originally thought that all *Pteraster* species were brooders. However, *P. tesselatus* is a broadcast spawner and does not retain its young in its nidamental chamber. *Pteraster tesselatus* is the only star known to undergo truly direct and pelagic development from embryo to juvenile (McEdward, 1992; McEdward and Janies, 1993).

*Pteraster willsi*, the Smooth Cushion Star, is relatively small and inflated with short (3 cm) rays that are stout and triangular (Figure 7c). The coloration is uniformly white, pale yellow or orange. *Pteraster willsi* somewhat resembles *P. militaris*, but may be distinguished by the rather smooth, aboral surface that lacks the fleshy wrinkles and its smaller size. *Pteraster willsi* seems to be endemic to the Aleutians, where it was infrequently found on rocky bottoms at 10-385 m. Limited information is available about the ecology of this newly described species although specimens from deeper water appear to feed on sponges and hydroids.

***Peribolaster biserialis* Fisher, 1905 - Fuzzy star  
(Figure 8)**

*Peribolaster biserialis* is a small “fuzzy-appearing” star with short rays to about 1.5 cm. The aboral surface is covered with cup-like tufts of divergent, flesh-covered spines, and the actinolateral spines are free, not encased in membrane. It is uniformly white, pale yellow, orange or tan. It is distributed from the southern Bering Sea to southern California, on sandy and rocky bottoms at depths of 23-572 m. We only found this species in the central Aleutian Islands of Amchitka and Adak, but Fisher (1911) found it further east, north of Unalaska. Nothing is known about the ecology or natural history of this small, unique species. *Peribolaster biserialis* somewhat resembles a small *Pteraster*, but may be distinguished by 1) lack of supradorsal membrane and osculum, 2) presence of fleshy tufts of spines, and 3) free actinolateral spines.



Figure 8. *Peribolaster biserialis* Fisher, 1905, Fuzzy star

### *Echinasteridae Verrill, 1867*

#### (Figures 9a, b, c, d, e, f)

The family Echinasteridae is one of the most taxonomically challenging groups of sea stars, aside from the genus *Leptasterias*. We encountered three genera of Echinasteridae in the Aleutians, *Henricia* (15 species), *Odontohenricia* (3 species), and *Aleutohenricia* (1 species). Most members of Echinasteridae have 5 rays and most are brooders with no free-swimming larval stage (D'yakonov, 1950), although some species are broadcast spawners with pelagic, lecithotrophic larvae (Miller, 2001). Echinasterids are generally considered sponge specialists, and this family is capable of suspension feeding and/or predation on sponges (Clark and Jewett, 2010). If echinasterids take advantage of the currents created by its host, they may be regarded as “energy commensals” (Anderson, 1966). Since most members of Echinasteridae in the Aleutian Islands (13 species) were recently described (Clark and Jewett, 2010) and later summarized (Jewett and Clark, 2011), only the remaining six species are presented below. The 13 new species are presumed to be endemic to the Aleutian Islands (Clark and Jewett, 2010).

*Henricia asthenactis* Fisher, 1910, the Ridged Henricia, is a relatively large star with rays usually somewhat inflated and to 11 cm long (Figure 9a). The textured of the aboral surface is rough with ridges of meshwork on aboral surface with 2-5 stout thorn-like, flesh-covered spines. The color is uniformly dark pink, lavender or purple aborally and whitish orally. It occurs in the Bering Sea and Aleutian Islands, south to California, at depths of 10-1250 m on various types of substrates, including rocky, sandy and mud. We found *H. asthenactis* on boulders in the Rat and Andreanof islands. Nothing is known of the biology or feeding of this species. The thorny ridges on the aboral surface and coloration should distinguish *H. asthenactis* from most other *Henricia* species.

*Henricia* sp. A, the Armpit Blood star, is a relatively large star with rays to 13 cm long (Figure 9b). It is red or red-orange, with gray or pinkish patches at base of rays (armpit) (and sometimes covering the disc). It occurs in the Aleutian Islands to California, intertidal to at least 50 m, on rocky substrates. We found this species on boulder substrates throughout the Aleutians, from the Fox Islands to the Near Islands. *Henricia* sp. A is very similar in appearance to *H. vermillion*, with which it co-occurs, and has often been confused with that species (under the name of *H. leviuscula*), so it is likely that some of the biological studies of that species may actually refer to this species. This is a forgotten species, recently re-discovered, and is presently the subject of study as part of the *H. leviuscula* complex (Eernisse and Strathmann, 2008).

*Henricia multisepia* Fisher, 1910, the Spiny Henricia, is a medium size star with long, slender rays to about 15 cm (Figure 9c). The plates of the aboral surface are small and closely set, bearing 40-60+ minute glassy spines; the adambulacral plates have 35-50 spines. The aboral surface is pale lavender or pink, fading to white on outer portion of rays. The center of the disc has a small red spot. It occurs in the Gulf of Alaska and Aleutian Islands, west to the Kurile Islands, at depths of 15 to 150 m on rocky substrates. Nothing is known of the biology and natural history of this species. The profusely spiny (fuzzy appearing) plates of the aboral surface, and adambulacral plates as well as the distinctive color of *H. multisepia* will easily distinguish it from all other *Henricia* species.

*Henricia oculata* (Pennant, 1777), the Bloody Henry, is a relatively large star with moderately slender rays (Figure 9d). This species is pale orange to lavender mottled with red. It occurs from the Arctic circum-boreal, Bering Sea and Aleutian Islands and northwestern Gulf of Alaska, near Kodiak Island. Nothing is known of the biology or natural history of this species. This species closely resembles *H. rhytisma* Clark and Jewett, 2010, but differs in having much more slender rays, fewer abactinal thorns (15-20 compared to 25-35 in *H. rhytisma*), and fewer adambulacral spines (4-6 compared to 8-10).

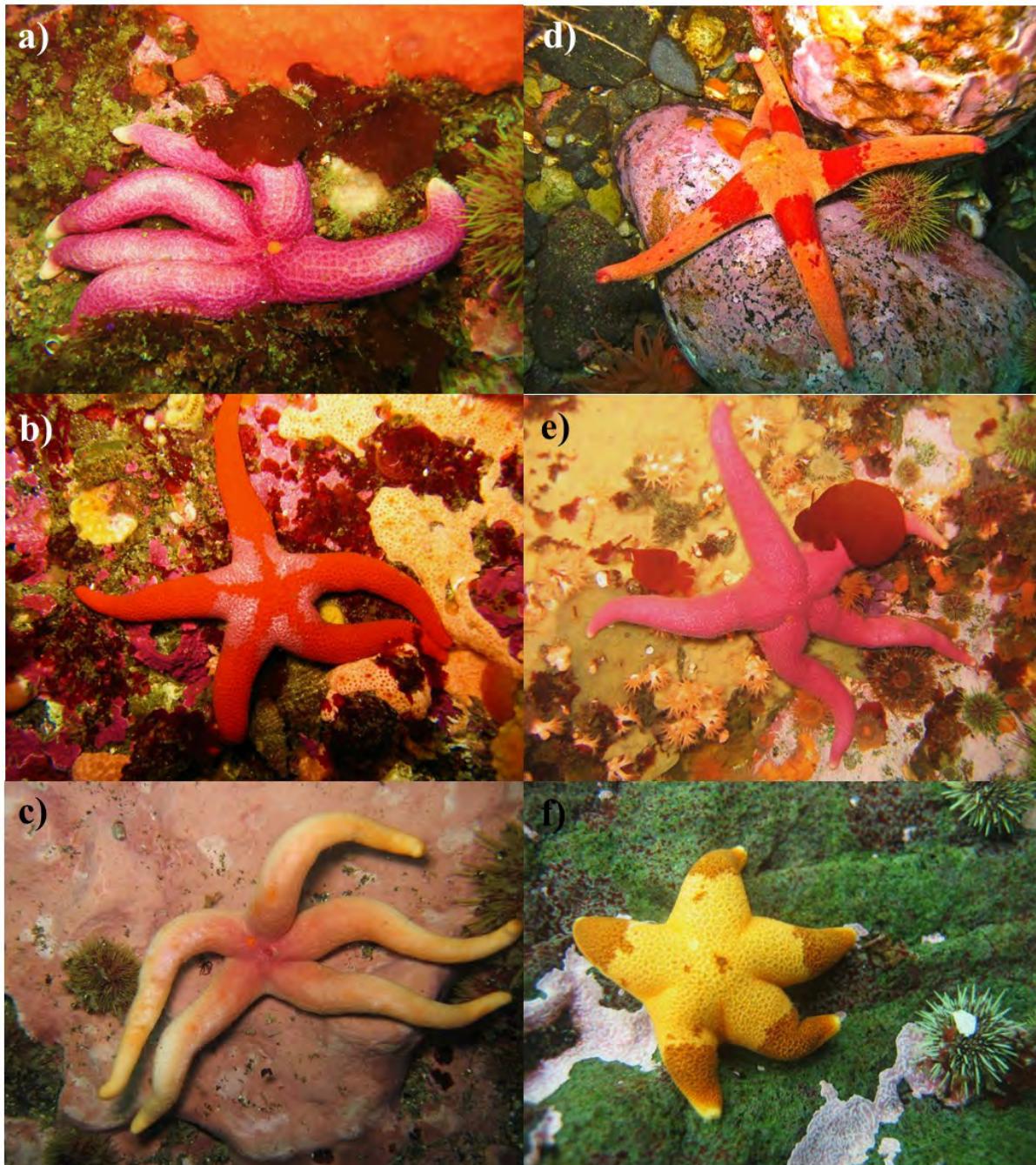


Figure 9. a) *Henricia asthenactis* Fisher, 1910, the Ridged Henricia, b) *H. sp. A*, the Armpit Blood star, c) *H. multispina* Fisher, 1910, the Spiny Henricia, d) *H. oculata* (Pennant, 1777), the Bloody Henry, e) *H. sanguinolenta* (Müller, 1776), the Northern Blood Star or Fat Blood Star, f) *H. tumida* Verrill, 1909, the Fat Henricia.

*Henricia sanguinolenta* (Müller, 1776), the Northern Blood Star or Fat Blood Star, is a moderately large star with relatively long and rather slender rays up to 10 cm long (Figure 9e). The creases in the “armpits” give it a puffy appearance. It is usually solid deep red, orange or purple. It occurs in the Arctic circum-boreal, south to the Aleutians on rocky bottoms from at least 10-200 m. It is seemingly rare in the Aleutians, but it has been collected in the Andreanof Islands in the central Aleutians. It feeds on plankton and is frequently seen on sponges, but seemingly does not eat them.

*Henricia tumida* Verrill, 1909, the Fat Henricia, is a small stout star with rays relatively short and thick to about 3 cm long (Figure 9f). It generally has a swollen or distended (tumid) appearance. The color is highly variable, from uniform or mottled with brown, gray-white, tan, red, orange, yellow or purple. It occurs in the Bering Sea and Aleutian Islands east to Kodiak Island, Gulf of Alaska on rocky substrates, intertidal to about 80 m. We found this species throughout the Aleutian Islands. This small variable species feeds on sponges, and is abundant on encrusting sponges in shallow water. *H. tumida* is one of several species of *Henricia* known to brood its young by arching its disc. With its small size, usually short thick rays and highly variable color, *H. tumida* is unlikely to be confused with other species of *Henricia*.

***Asterias amurensis* (Lütkin, 1871) - North Pacific Flatbottom Star  
(Figure 10)**

*Asterias amurensis* is a large, broad, fairly rigid, five-rayed star. The rays are moderately long to 18.5 cm and broad at the base, quickly tapering to slender tips. The live color is purple, ocher or orange, with white, spinose ridges. It is distributed mainly from the northern Gulf of Alaska to the northern Chukchi Sea, although uncommon in the nearshore Aleutian Islands. Most have been documented from trawl or dredge catches in the eastern Aleutians (north side of Unimak Is. - Lauth, 2011; Unalaska Is. - Fisher, 1928; Scheffer, 1959). Vicknair (1997) listed *A. Rathbuni* among the stars from Attu Island in the western Aleutians, although he later determined it was *A. microdiscus* (pers. comm., 2010). In the northern hemisphere it also occurs off eastern Japan (Hatanaka and Kosaka, 1958) and eastern Russia (D'yakonov, 1950). *Asterias amurensis* is the most abundant sea star in the Bering and Chukchi Seas of Alaska, particularly on sandy substrates at depths < 40 m (e.g., Jewett and Feder, 1981; Feder et al., 2005; Lauth, 2011). One reason it is scarce in the nearshore Aleutians may be because the substrate there is predominately hard. Although we did not find any *A. amurensis* or *A. microdiscus*, we believe they are members of the nearshore Aleutian sea star community. *Asterias amurensis* is an opportunistic predator, feeding on various invertebrates, particularly bivalves. In Norton Sound of the northern Bering Sea, we observed this species mass feeding on the Arctic armored cucumber, *Psolus fabricii*. *Asterias* is a broadcast spawner (Kasyanov et al., 1998). Because of its broad tolerance for temperature (0-25° C; Kim, 1968; Novikova, 1978) and salinity (18.7-41.0 ppt; Morrice, 1995), and because it grows rapidly (females mature ~ 12 months at ~ 10 cm diameter; Kim, 1968), is capable of spawning twice annually (April/June and August/September; Kasyanov et al., 1998), has high fecundity (10-25 million eggs; Turner, 1992), and is a voracious generalist predator (myriad of epifauna and demerel fish eggs), *A. amurensis* is listed among the top “100 World’s Worst” invaders by the International Union for Conservation of Nature, Invasive Species Specialist Group ([http://www.issg.org/worst100\\_species.html](http://www.issg.org/worst100_species.html); accessed 7/13/12). For example, it was accidentally introduced in Tasmania, resulting in considerable harm to benthic biota (Ross et al., 2003).



Figure10. *Asterias amurensis* (Lütken, 1871), North Pacific Flatbottom Star

***Evasterias* Verrill 1914**

**(Figures 11a, b, c)**

We encountered three species of *Evasterias* in the nearshore Aleutian Islands, *E. echinosoma* Fisher, 1926, *E. retifera* D'yakonov, 1950, and *E. troschelii* (Stimpson, 1862). This genus is a broadcast spawner with planktotrophic or free-swimming larvae (Miller, 2001).

*Evasterias echinosoma* is known as the Giant Star (Figure 11a). It is one of the largest sea stars not only in Alaska, but also in the world, reaching a full meter across, and more than 5 kg in weight. It is semi-rigid, spinose, five-rayed star. The color of adults is uniformly maroon aborally, cream orally, but small juveniles may be mottled with cream white spines. *Evasterias echinosoma* is wide spread in the North Pacific region, from the northern Sea of Japan, throughout the Okhotsk, Bering and Chukchi Seas, and along the Aleutian Islands, at depths of 5-105 m on mud, sand and pebble substrates. We only found this species in the central Aleutians on the north side of Adak Island in the Andreanof Islands. *Evasterias echinosoma* preys on a wide variety of mollusks and echinoderms.

*Evasterias retifera*, the Blue-spined Star, is a large, rather robust five-rayed star (Figure 11b). The rays are moderately long (to 20 cm) and stout (Figure 11b). Their color is red to red-orange with blue spines aborally. It occurs in the western Aleutian Islands to Kamchatka and the Kurile Islands, intertidal to at least 20 m on rocky substrates. We only found this species west of Buldir Pass, in the Near Islands (Attu). Vicknair (1997) observed that *E. retifera* dominated the sea star biomass around Attu Island before the arrival of sea otters (pre1983). *Evasterias retifera* declined once the sea otters were reestablished (by 1994) and today the *E. retifera* population is small, although few sea otters inhabit the Near Islands. Sea otters occasionally consume this sea star. Around Attu large *E. retifera* mainly feed on the horse mussel, *Modiolus modiolus*; smaller ones feed on the rock jingle *Pododesmus macrochisma* and the barnacle *Semibalanus cariosus*. *Evasterias retifera* can only be confused with *E. troschelii* where the two species occur together, in the Near Island group, but can usually be distinguished by the distinctive blue coloration in *E. retifera*.

*Evasterias troschelii*, the Mottled Star or True Star, is a large star with five long and slender rays to 30 cm (Figure 11c). The aboral coloration may be uniform or mottled with green, blue, brown, pink or orange, the spines are white or very pale blue, and the oral surface much paler. *Evasterias troschelii* occurs throughout the Aleutian Islands to central California, intertidal to 75 m, on a variety of substrates, including wharf pilings. It is especially abundant in sheltered waters. We found this species throughout the Aleutians. *Evasterias troschelii* feeds on tunicates and bivalves, and is particularly fond of the rock jingle, *Pododesmus macrochisma*. King crabs and sea otters occasionally consume *E. troschelii*. *Evasterias troschelii* is unlikely to be confused with any other Aleutian sea star with the exception of *E. retifera*, from which it may be distinguished by longer, more slender rays and variable coloration.

***Leptasterias* Verrill, 1866**

**(Figures 12a, b, c, d)**

Fisher's (1930) and D'yakonov's (1950) monographs on *Leptasterias* sea stars attest to the taxonomic difficulty of this genus, as does Lambert (2000). Fisher described three subgenera and 18 species and subspecies from the North Pacific and adjacent waters. Twenty years later D'yakonov listed five subgenera and 29 species and subspecies from North Pacific waters. With the exception of the subgenera *Hexasterias*, which has six rays, the remaining subgenera have five rays. We found 10 species of *Leptasterias* in the Aleutians, six of which were six-rayed species (Table 1). Herein are four examples, two five-rayed and two six-rayed species. It is assumed that the following species brood eggs and embryos, as do other members of this genus.

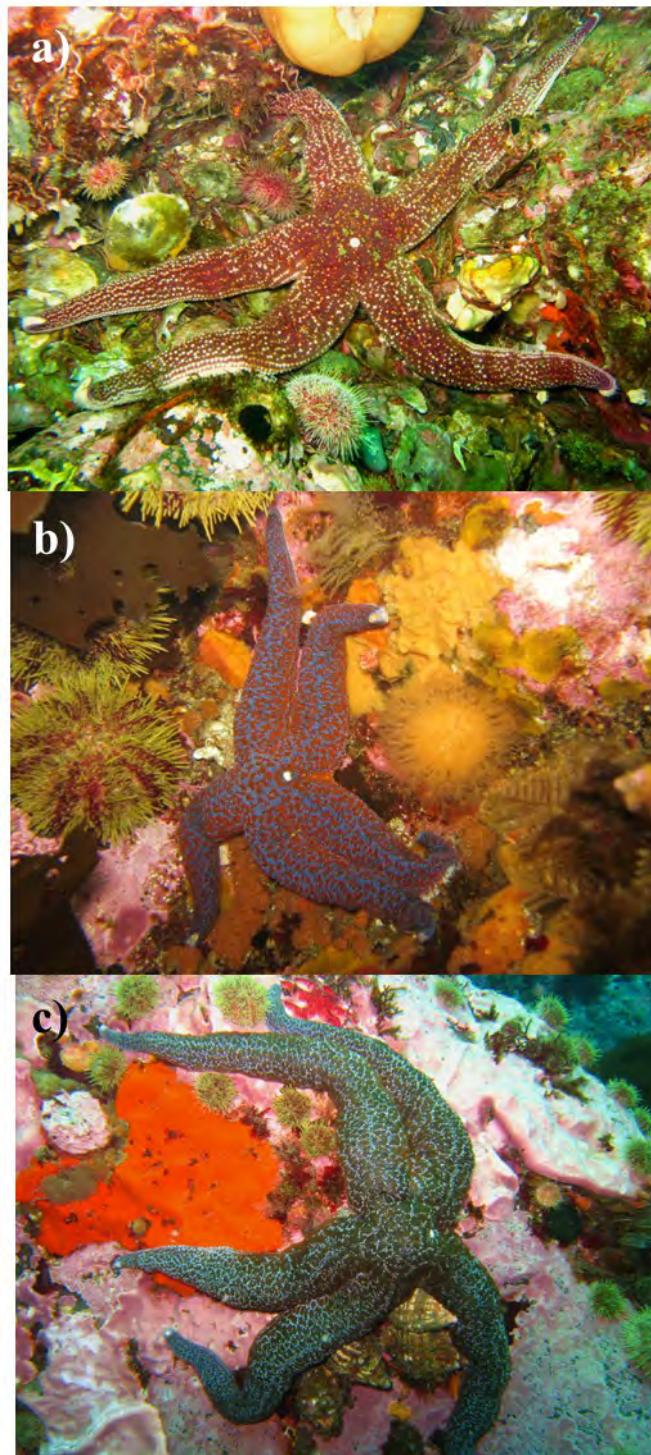


Figure 11. a) *Evasterias echinosoma* Fisher, 1926, Giant Star, b) *E. retifera* D'yakonov, 1950c, Blue-spined Star, c) and *E. troschelii* (Stimpson, 1862), Mottled Star or True Star.

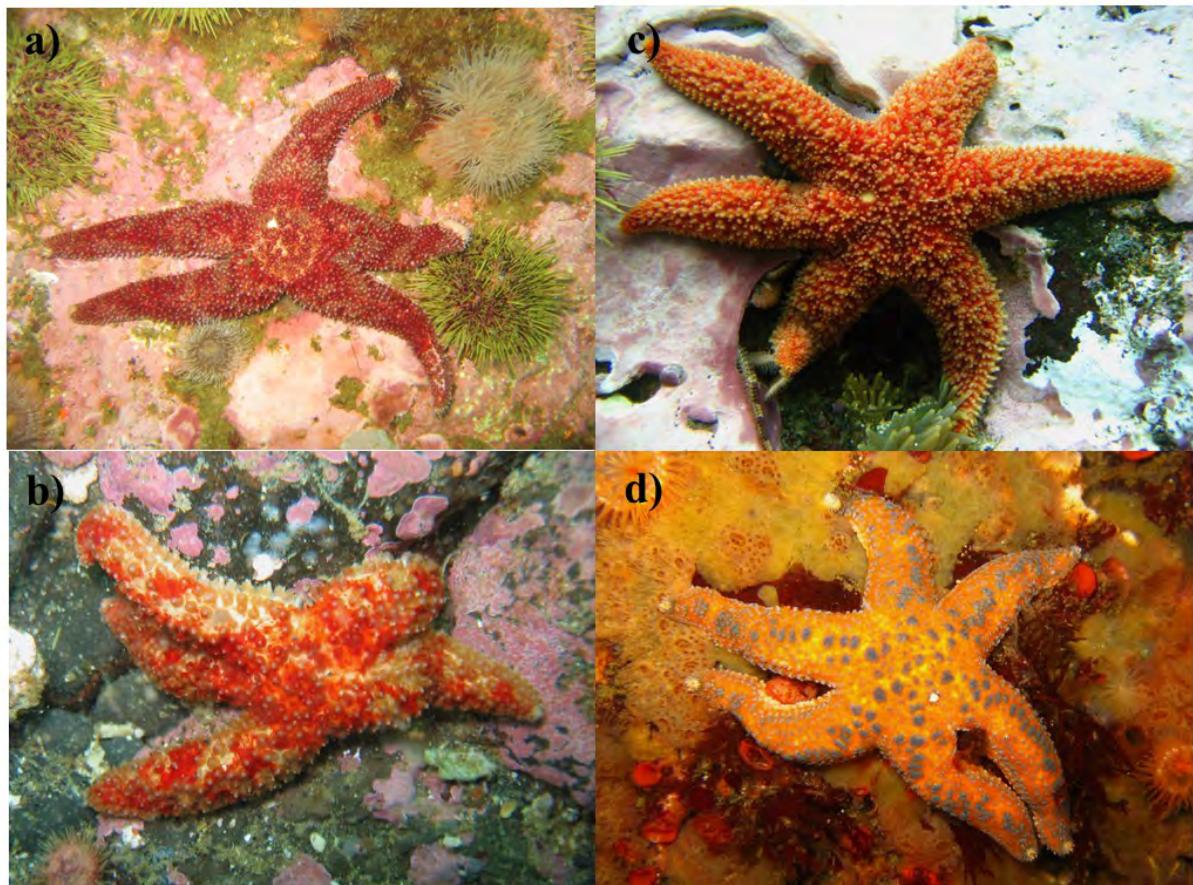


Figure 12. a) *Leptasterias cf. ochotensis* (Brandt, 1850), Okhotsk Star, b) *Leptasterias* sp. A, c) *Leptasterias alaskensis* (Verrill, 1909), Alaskan Six-rayed Star, d) *Leptasterias dispar* Verrill, 1914, Aleutian Knobby Six-rayed Star.

*Leptasterias* cf. *ochotensis* (Brandt, 1850), the Okhotsk Star, is a small five-rayed star with prominent white spines and moderately thick and short rays to 5 cm long (Figure 12a). The aboral surface appears fleshy, with irregularly spaced, thick white spines, which are inflated and blunt or flattened at the tips. The color is variably mottled, white with pink, reddish or brown. It occurs from the Sea of Okhotsk to the Aleutian Islands to southeastern Alaska, intertidal to 130 m on a variety of substrates. Little is known of the biology and natural history of this species. It prefers sheltered bays that warm up in the summer. This small species may be distinguished from similar appearing species by the thick, blunt spines and mottled color pattern.

*Leptasterias* sp. A, is a moderately large, fleshy five-rayed star with moderately long rays to about 5.5 cm (Figure 12b). The rays are sharply constricted at base. The aboral surface appears fleshy, with thick wreaths of pedicellariae surrounding spines to near the tip. It is reddish mottled with cream or brown. It is endemic to the Aleutian Islands, where it occurs at depths of 15-120 m on a variety of rocky bottoms. Nothing else is known of the biology and natural history of this species. This thick, fleshy species may be distinguished from similar stars by the rays sharply constricted at base, thick wreaths of pedicellariae surrounding the thick, blunt spines near the tips, and the dark, mottled coloration. The taxonomic description of this star is currently underway.

*Leptasterias alaskensis* (Verrill, 1909), the Alaskan Six-rayed Star, is a medium size six-rayed star with moderately long rays to 8.4 cm (Figure 12c). The aboral surface has scattered large, bivalved pedicellariae. The aboral coloration is reddish, brown, violet, orange or dark, green-black, with gray-green, cream, or pale orange spines. It is distributed from the western Gulf of Alaska (east to Cook Inlet), to the western Aleutian Islands, intertidal to about 20 m, on rocky substrates. We found this species throughout the Aleutian Islands, except the Near Islands. *Leptasterias alaskensis* may be distinguished from the many other species of *Leptasterias* in the Aleutians by the large, bivalved pedicellariae on the oral and aboral surface.

*Leptasterias dispar* Verrill, 1914, the Aleutian Knobby Six-rayed Star, is a medium size, six-rayed, rough textured star with moderately long rays to 8.0 cm (Figure 12d). The apical ridge plates on the aboral surface of the rays bear large, blunt spines, usually in clusters, in an irregular series. It is highly variable in color and may be uniform, striped, mottled with red, orange, purple, yellow, pink, brown, gray, green, tan or blue. It occurs in the Kurile, Commander, Aleutian and Pribilof Islands, and the western Gulf of Alaska, east to Kodiak Island, on rocky substrates at depths of 1-20 m. Little is known of the biology and natural history of this species. *Leptasterias dispar* was previously considered a subspecies or form of *L. camtschatica* (Brandt, 1835), but it is now known to be distinct. It may be distinguished from all other Aleutian *Leptasterias* spp. by its distinctively rough aboral surface and myriad of color variations. This is the most abundant of the smaller, shallow subtidal stars in the Aleutians.

#### *Pycnopodia helianthoides* (Brandt, 1835) - Sunflower Star (Figure 13)

*Pycnopodia helianthoides* is the only representative in the genus *Pycnopodia*. This huge, multi-rayed (15-24) sea star is one of the largest and fastest sea stars in the world, reaching more than 1 meter in diameter and 8 kg in weight. It occurs from the eastern Aleutian Islands to California, intertidal to 120 m on a wide variety of substrates. We found this species mainly east of Amukta Pass, but also at Adak Island (Kuluk Bay), which is a range extension. This star is a scavenger and a voracious predator, feeding on wide variety of prey, including (but not limited too) sea urchins, bivalves, helmet and hermit crabs, other seastars and just about anything else it can catch. *Pycnopodia* has been observed excavating pits 50 cm in diameter and up to 15 cm deep to feed on cockles and other



Figure 13. *Pycnopodia helianthoides* (Brandt, 1835), Sunflower Star.

bivalves. It also enters crab and shrimp pots for an easy feast. *Pycnopodia* feeds on clams by everting its cardiac stomach and digesting its preys externally, whereas it will swallow and digest urchins internally, and then discharge whole tests after digestion (Mauzey et al., 1968). *Pycnopodia* is a broadcast spawner with planktotrophic larvae (Miller, 2001). It begins life with 5-6 rays, and overtime, new pairs of rays bud out successively (Verrill, 1909). The much smaller *Solaster dawsoni* will attempt to prey on this species, resulting in *Pycnopodia* “dropping” a ray (Autotomy) and fleeing. *Pycnopodia* will usually outrun its slower predator (Van Veldhuizen and Oakes, 1981). *Pycnopodia* is sensitive to the scent of injured conspecifics and will flee (Lawrence, 1991). Compared to most sea stars, *Pycnopodia* is mostly decalcified and feels very fleshy and soft.

## Discussion

The great diversification of sea star species in the Aleutian Archipelago should be expected in such an extensive region (2500 km east to west). The central Aleutian Islands, the Andreanof and Rat Island groups, defined by Samalga and Buldir passes contain a very rich and diverse fauna that includes several apparently endemic species of asteroids (Table 2; Clark and Jewett, 2010; 2011a; 2011b). Numerous endemic species of mollusks and other invertebrates also occur here (Dr. James H. McLean, pers. comm., 2007; Clark, 2006), and this may represent a distinct faunistic pocket, or subprovince. Valentine (1966) estimated the percentage of endemic mollusks in the Aleutian province at 24%, and from our surveys it appears the endemic asteroid fauna may be as high or higher. The aforementioned species list (Table 1) is representative, but by no means complete. Our five dive surveys in the nearshore Aleutian Archipelago have yielded 53 sea star species, 19 of which are relatively new to science, but poorly understood ecologically. More extensive sampling via scuba is needed to explore for additional species and further our knowledge of the asteroid ecology in this remote region.

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## An Investigation of Behavioral Differences in Captive Sevengill Sharks and Implications for Dive Safety Management

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### Abstract

The Oregon Coast Aquarium (OCAq) in Newport, OR hosts nine captive broadnose sevengill sharks, *Notorynchus cepedianus*, in its largest exhibit, Open Sea. Most in-water husbandry activities are carried out by volunteer divers trained in the hazards of aquarium diving and captive animal care. In 2009 the 800,000 gallon fsw exhibit underwent a 3°F increase in average water temperature to accommodate plans for the introduction of a species of ocean sunfish. Between 2007 and 2011 the total increase in temperature was 7°F. Sevengill shark behavior was recorded throughout this temperature increase and a change in general behavior was noted. As a result of the observed shift in shark swimming patterns, changes to diver protocol were incorporated. These included training and testing the proficiency of divers to accurately identify individual sevengills, knowledge of habits unique to individual sevengill sharks, and post-dive shark behavior documentation as mandatory requirements in the OCAq volunteer diving program.

Keywords: dive safety management, diving with captive sharks, *Notorynchus cepedianus*, risk management, sevengill shark behavior

### Introduction

The risk of diving with captive sharks in aquaria has led to the development of numerous safety practices implemented by dive programs around the globe (Hodges and Frierson, 2008). Ideally research and husbandry diving tasks are designed to consider the welfare of all animals as well as the safety of divers (Smith et al., 2004). Risk management models are common within the scientific diving community and can be important tools in ensuring the achievement of these goals (Richardson, 2004). This paper explores a specific case study at the Oregon Coast Aquarium where changes in captive sevengill shark behavior were noted, and as a result, adjustments in dive safety protocol were made.

It is believed that the observed shift in sevengill shark swimming patterns was primarily due to an average water temperature increase that was implemented to facilitate the planned introduction of ocean sunfish into the OCAq Open Sea exhibit. Temperature has been known to directly effect metabolic rates among sharks but its relationship with other activities such as digestion, resting, and swimming behavior is less known (Boisclair and Tang, 1993; Schmidt-Nielsen, 1997). Tullis and Baille (2005) demonstrated that when *Chiloscyllium plagiosum*, whitespotted bamboo sharks, originated from thermally stable environments they struggled to metabolically compensate from environmentally altered temperatures. Shutting behavior is a recognized example of variation in shark swimming patterns as organisms move across thermal gradients in order to optimize physiological processes (Casterlin and Reynolds, 1979; Hopkins and Cech, 1994; Sims et al., 2006; Di Santo and Bennett, 2011). Wild populations of *N. cepedianus* enhance their physiological performance by using temperature as a cue for selecting and avoiding particular habitats with shifting

prey distributions (Heupel and Simpfendorfer, 2008). Temperature variability is also commonly associated with coastal migrations among sharks and can help signal reproductive behavior (Springer, 1967; Heupel and Hueter, 2001; Sims et al., 2003; Skomal et al., 2004; Bonfil et al., 2005; Hussey et al., 2009; Knip et al., 2010).

Of the five shark species within the Open Sea exhibit at the OCAq, *N. cepedianus* are the most dominant, and though not recognized as a particularly aggressive species, pose the highest potential safety risk for divers, primarily due to their size, width of the mouth and morphology of dentition. Sevengill sharks are commonly identified by their seven paired gill openings, broad head, dorsal spot patterns, and large anal fin (Peron, 1807; Barnett et al., 2012). *N. cepedianus* are high order marine predators found in shallow coastal waters, estuaries, bays of temperate seas ranging from 48-68 °F and are associated with areas of high biological productivity and upwelling (Ebert, 1991; 2003; Barnett et al., 2010). They primarily feed on sharks, especially of the genus *Mustelus*, batoids, teleosts, cephalopods, and marine mammals (Ebert, 1991; Braccini, 2008; Barnett et al., 2010). Sevengills are exposed to high fishing pressure due to their coastal zone habitat and are especially vulnerable to longline fisheries in South Africa (Compagno et al., 2005; DaSilva and Burgener, 2007). In North America sevengill sharks can be found from Baja, California to southeast Alaska with important nursery and birthing grounds existing in Humboldt and San Francisco Bays (Ebert, 2003). While there are several publications of *N. cepedianus* ecology from South Africa, Tasmania, southern Australia and Argentina, little is known about their behavior and movement patterns within their North American range (Ebert 1989, Lucifora et al., 2005; Braccini, 2008; Barnett et al., 2010; Williams et al., 2012).

## Methods

The Oregon Coast Aquarium is located in Newport, OR, USA (44° 37'N x 124° 2'W). The OCAq's Open Sea exhibit is representative of the epi-pelagic habitat, and is therefore intentionally void of any decoration. A 70 ft long underwater viewing tunnel bisects the exhibit. Open Sea holds 800,000 gallons of seawater and reaches 26 feet of depth. It hosts nine *N. cepedianus*; eight males and one female. There are also bat rays, *Myliobatis californica*, leopard sharks, *Triakis semifasciata*, spiny dogfish, *Squalus suckleyi* (Ebert et al., 2010), Pacific salmon *Oncorhynchus*, Pacific mackerel *Scomber*, California anchovies, *Engraulis mordax*, a soupfin shark *Galeorhinus galeus*, and a brown smooth-hound *Mustelus henlei* within the exhibit.

Reproductive behaviors have been observed seasonally among the sevengill sharks, inter and intra species aggression has occurred occasionally, and shark-diver interactions have been infrequent, though tracked carefully.

In winter 2007, winter 2009, and spring 2011, ethograms were conducted on all *N. cepedianus* to catalogue behaviors and swimming patterns of individual sharks (n=14, 9, and 21).

These ethograms were conducted over a twenty minute time period; position was marked on the exhibit map data sheet every twenty seconds along with direction (clockwise, counterclockwise) and general swimming patterns. Location in the water column was noted and categorized as Zone A, B, or C with A representing the upper third of the water column, B representing mid-water and C representing the lower third or benthos. Also documented was the behavioral choice of *N. cepedianus* to swim over the top of the viewing tunnel arch or to swim under it during each circuit of the swim pattern cycle. Temperature data was gathered from original OCAq aquarist logs from 2007-2011. No raw data exists from fall 2008-summer 2009; instead temperatures for this time period were estimated by averaging seasonal values from the previous and future years.

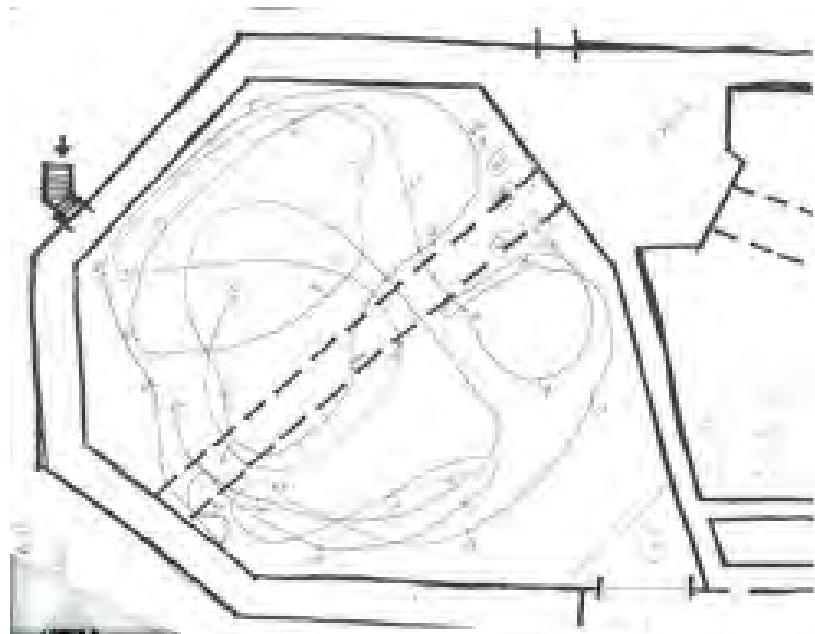


Figure 1. Raw ethogram data from a solitary sampling event

## Results

Temperature within the Open Sea exhibit underwent a 3°F increase between 2007, 57°F, and 2009, 60°F, (Figure 2). In general the water temperature has steadily increased annually with maximums recorded in September and minimums recorded in January (Figure 2). *N. cepedianus* have displayed insignificant changes in their distribution within Zone A; they have shown trends of decreasing their time spent in Zone B and increasing their time in Zone C, an approximate 10% transfer (Figure 3). The swimming behaviors of *N. cepedianus* exhibit a trend towards remaining below the Open Sea tunnel, increasing from 24% in 2007 to 53% and 32% in 2009 and 2011 respectively (standard error= 1.9, 1.1, and 1.5%) (Figure 4).

### **Limitations**

This study was limited by several factors, the most notable of which is the inconsistency of the temperature data provided by the aquarists. From January 2007 through summer 2008 temperature data consisted of one to two data points per month, whereas between fall 2009 through winter 2011 temperature data was collected an average of twenty-three times per month. Between fall 2008 through summer 2009 the only available temperature data comprised of a water system connected to the Open Sea and two other exhibits. These data were not used as it did not properly reflect temperatures experienced by organisms within Open Sea and averages are instead displayed in Figure 2.

The ethograms were initially designed to be a detailed mapping of sevengill swimming behavior over a twenty-minute time period. As such the ethograms are better suited to compare changes within a single shark's behavior rather than accurately representing changes within a population. The small sample size of two to three ethograms per shark per year could be improved by conducting significantly more ethograms. The data could also be more regulated by conducting studies every season, especially during temperature peaks.

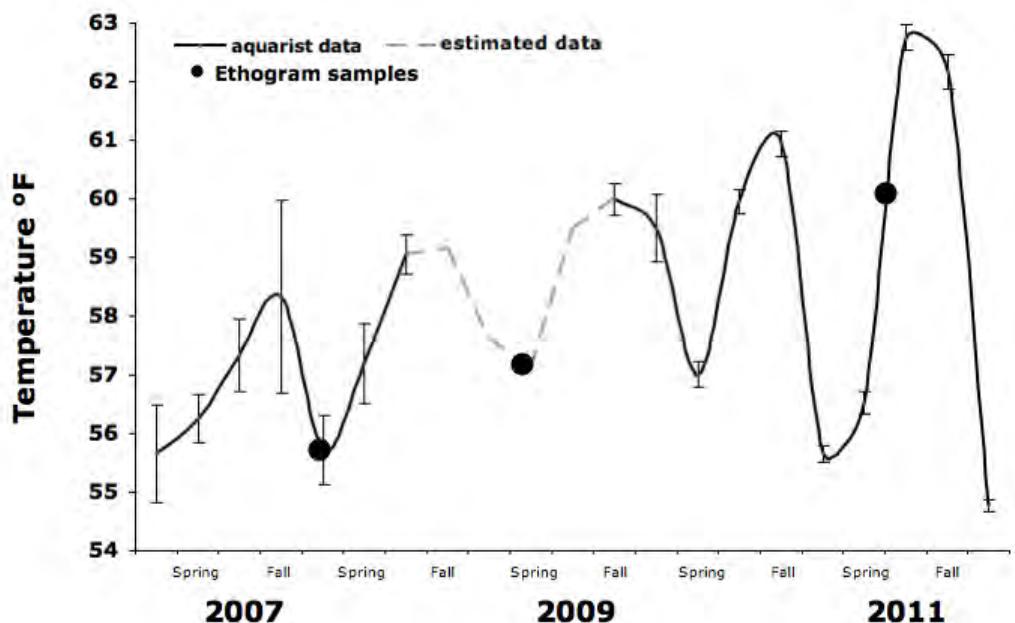


Figure 2. Seasonal temperature averages within the OCAq Open Sea exhibit

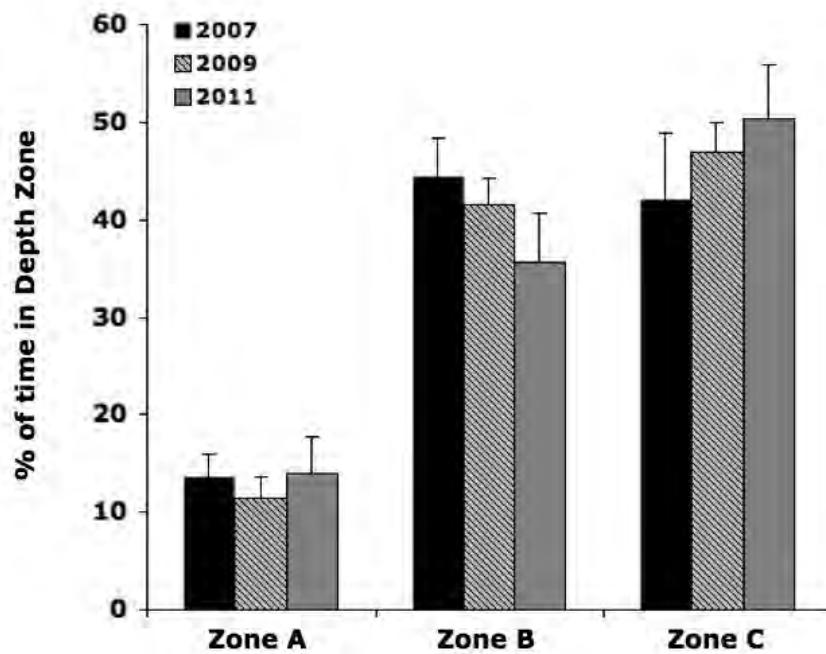


Figure 3. Zone distribution of captive *N. cepedianus* within the OCAq Open Sea exhibit during 2007, 2009, and 2011 ethograms.

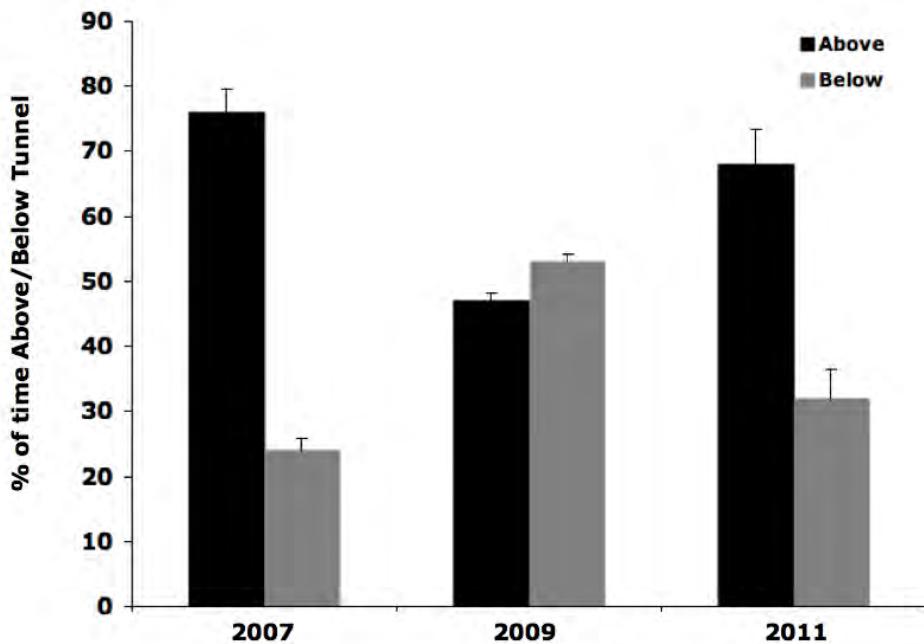


Figure 4. Percentage of encounters captive *N. cepedianus* spent swimming above or below the OC Aq Open Sea exhibit tunnel during 2007, 2009, and 2011 ethograms.

## Discussion

The Aquarium's plan to add ocean sunfish into the Open Sea exhibit necessitated a water temperature change to facilitate acclimation of the bony fishes (Figure 2). Ethogram data show a trend in *N. cepedianus* behavior toward spending an increasing amount of time in the benthos of Zone C and making less of an effort to swim above the viewing tunnel since 2007 (Figures 3 and 4). This tendency is thought to primarily correspond with the 2009 temperature increase in Open Sea.

The captive sevengills could be mimicking behaviors of the shortfin Mako, *Isurus oxyrinchus*, which swim towards deeper, colder water when stressed, particularly after being captured and tagged (Holts and Bedfore, 1993; Klimley et al., 2002). It is thought that vertical displacement in juvenile white sharks is triggered by thermal tolerance disruption in eastern Pacific waters, possibly relating to *N. cepedianus* (Weng et al., 2007; Speed et al., 2010). Variable water column distribution is present in sevengill sharks at night when oscillating swimming patterns are utilized for foraging. During the day sevengill sharks remain nearer to the substrate and exhibit long resting periods (Barnett et al., 2010). It is possible that temperature is none or one of several explanations for the swimming changes noted in *N. cepedianus* within the Open Sea exhibit but the continued and potential increased presence of sevengills in the benthic region of Zone C is concerning from a dive safety perspective. Working divers spend the majority of their time in Zone C of the exhibit retrieving/stowing vacuum hoses and clearing the bottom of uneaten food debris from scheduled feedings. Based on the foundation of data evidenced by these ethograms, there is an inevitable increase in shark and diver interactions.

### **Future Directions**

Previously, shark diving safety protocol included a classroom session and observation exercise in the observation tunnel during volunteer diver training, a step by step introduction to diving in the Open Sea exhibit, and the use of a safety “stick” diver wherein the stick is used primarily as a visual and physical barrier between the divers and the sharks. This system is widely used in captive shark diving and might be considered the standard of care (Hodges and Frierson, 2008). Previous protocols also included the requirement of the safety “stick” diver to be proficient identifying individual sevengill sharks. Additionally, divers were required to record shark behaviors in a log following the dive for purposes of ongoing monitoring and observing trends in behaviors that effect diver safety.

The results of this study have prompted some changes in the safety protocol for diving with captive sharks at the OCAq. Prior to diving, dive teams observe the sharks from the tunnel of Open Sea to get a general sense of the behavior of the sharks and practice identifying individual sevengills. It is expected that during this session lead divers will discuss swimming patterns and identification features unique to specific *N. cepedianus* and that all team members will become proficient in identifying the individual animals. A volunteer diver developed a web-based online identification examination using flashcard photos that display a physical profile of each Sevengill, and point out color, freckle/spot patterns, scars, and other identifying marks. During the exam, the flashcards are displayed and the user is prompted to select the correct shark from a randomly generated list of possible sharks. Volunteer divers are now required to go to the website and complete the flashcard examination and print their results, which is filed on the diver’s record. Divers are encouraged to use the tool until mastery (100% recognition) is achieved. The protocol of logging shark behaviors post dive has also been improved, with the use of a standardized form and ranking system. All divers are now encouraged to become familiar with these tools and use them, rather than restricting it to the lead divers. It is the belief of the DSO that volunteers should be as aware as possible of any potential risk and that by better understanding the behavioral ecology within Open Sea, a stronger and safer dive program within the OCAq will result. The primary focus has been to develop a culture of safety among the divers through participation and full involvement in all aspects of the dive, including making observations, planning, briefings, and post dive discussions and assessments of shark behavior.

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## Burrow and Current Production by the Mantis Shrimp, *Squilla empusa*

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### Abstract

The mantis shrimp *Squilla empusa* forms extended burrows in the silty mud. We investigated burrowing in *S. empusa* *in situ* using SCUBA, and animals were collected for further laboratory studies. Burrowing in the field was studied primarily by making repeated daily visits to individually marked burrows and recording changes in the number, diameter, and structure of burrow openings. Burrows varied considerably in their length, width, number of openings, and the amount and timing of reconstruction, with some changes occurring on a daily basis. We analyzed burrowing activity by releasing captive animals back into their native habitat and filming the resulting burrow excavation. Animals were also filmed moving sediment in the laboratory. Both in the laboratory and in the field, *S. empusa* employ two methods of moving sediment: pleopod fanning, which directs stirred-up sediment posteriorly, and carrying sediment forward in a “basket” made of their maxillipeds. The pleopod fanning motion is also instrumental in generating large currents within the burrow once the construction is complete. These currents were studied in detail using field particle image velocimetry. The resulting current profiles make it possible to distinguish between burrows with one opening and burrows with multiple openings.

Keywords: fanning, maxilliped, particle image velocimetry, pleopod, sediment

### Introduction

The mantis shrimp *Squilla empusa* form extended burrows in silty substrates along the Atlantic Coast south from Cape Cod to the Gulf of Mexico (Pollock, 1998). The animals rely on these burrows for protection from predators, as a base for their own hunting, and for reproduction. This temperate species is known to have vertical burrows in the winter, and U-shaped burrows in the summer (Myer, 1979). However, mantis shrimp lore has long held that burrows are costly to create and stridently defended, and that no changes are made to the burrow over long periods of time except for the yearly changes noted by Myers (1979). However, recent studies of *S. empusa* burrows in Great Harbor have shown that these animals engage in frequent burrow remodeling, altering the number or type of opening between successive dives on the same day. To better understand this behavior, field and laboratory studies were undertaken to understand the extent of burrow remodeling, and to investigate the burrowing process. Early studies of animals in the laboratory revealed that *S. empusa* fan their pleopods vigorously, presumably to facilitate ventilation. Field observations indicated that this activity created currents vigorous enough to stir up sediment into a visible plume. These currents, not yet described in the literature, became the focus of this project.

## Methods

### **Burrow identification and measurement**

Two to five hundred foot transects were laid out in Great Harbor, near Woods Hole, MA each summer for a total of twelve transects over a four year period. During this period, a total of 94 burrows were marked with survey flags or with numbered floating whiffle balls. Sixteen burrows were measured once each in 2009, 32 burrows were measured and monitored over 26 dives over a six week period in 2010, 35 burrows were measured and monitored 21 times in 16 days in 2011, and 11 burrows were measured 3 times each over seven weeks in 2012. Squid bait was used to lure the mantis shrimp out of its burrow and ascertain the size and sex (when possible) of the inhabitant. Fluorescein dye was injected into burrows to determine which openings belonged to a particular burrow. The number of openings, opening diameter, distance between openings, and distance between burrows was measured. Burrow diameter was measured to the nearest mm, and distance between openings and between burrows was measured to the nearest cm.

### **Observation of burrowing activity in the laboratory and in the field**

Nine wild caught *S. empusa* that were returned to Great Harbor burrowed in the substrate immediately following release. The burrowing activity was filmed using a 30 Hz JVC Pixsio video camera. Burrowing was also investigated in the laboratory, using a Fastec Imaging Troubleshoter operating at 125 Hz. Because filming using the natural sediment led to murky water and poor filming, aquarium gravel and sand were used to facilitate analysis of burrowing movements in the laboratory, although *S. empusa* were not able to form complete burrows with the artificial sediment. Both field and laboratory videos were digitized using Image J software, freely available from NIH.

### **Current measurement using dye and field particle image velocimetry**

Currents produced by animals in their burrows were measured by slowly injecting fluorescein dye and filming the motion of any dye that emerged from a burrow opening using a 30 Hz JVC Pixsio video camera. Forty burrows were characterized in this manner. The movement of the dye front was analyzed using Image J. To measure velocity in greater detail, divers used a 250 mW 532 nm laser-generated light sheet and a 30 Hz video camera as per Dabiri et al. (2010) to obtain videos of particulate matter moving within the plane of the lightsheet. These videos were processed using DaVis software. This analysis generated finely scaled current profiles perpendicular to the openings of four burrows.

## Results

### **Burrow opening measurements**

Over the course of each summer, burrows changed seasonally, daily and even on hourly timeframes. At the start of the summer (typically the first couple of weeks in June), almost all burrows had a single opening, which was often plugged during daytime dives. By the end of June, about 80% of the burrow openings were cleared (unplugged), and about 75% of these burrows were U-shaped, with two openings. Over the course of the 2009-2012 summers, 94 burrows were measured (Figure 1).

Burrow openings ranged from 10-75 mm in diameter. Overall, 47% percent of *S. empusa* burrows had two openings, and 36% had one opening, although the relative percentages changed dramatically as the summer progressed. When burrows had multiple openings, the mean  $\pm$  sd between openings was  $59 \pm 29$  cm ( $n = 44$ ), and the mean distance between burrows was  $2.13 \pm 0.95$  m ( $n = 94$ ). Thus, dynamic changes include removing a plug ( $n = 92$ ) and excavating a second opening ( $n = 42$ ), often within 24 hours of a previous examination of the same burrow. In addition, the repeated measurements of the same burrows undertaken in 2011 showed that the diameter of burrow openings

usually changed on a daily basis, as the inhabitants increased or decreased the opening by a few mm to cm or sealed off an opening completely. Within a given pair of dives, some animals enlarged burrow openings while others narrowed them; we saw several examples of changes in the opposite direction within the same burrow. Burrow openings that were enlarged showed a 16% mean increase in burrow opening diameter in the three hours between morning and afternoon dives ( $n = 16$ ), and a 57.2% mean increase over a 24-hour period ( $n = 11$ ). Burrow openings that were filled in showed a 20.1% mean decrease in burrow opening diameter between morning and afternoon dives ( $n = 17$ ), and a 22.1% mean decrease over a 24-hour period ( $n = 13$ ). Less commonly observed were large mounds and cones built around one opening, often constructed within three hours ( $n = 2$ ). Two mid-October dives indicated that the burrows had single openings that were partially obstructed, with a thin crust extending from the periphery and covering up to 70% of the surface area of the opening ( $n = 18$ ).

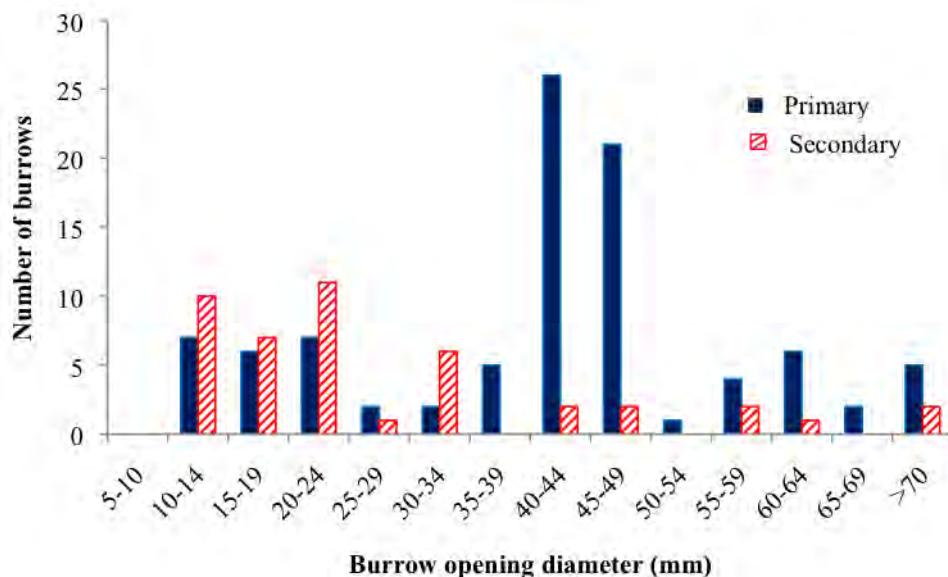


Figure 1. *S. empusa* burrow opening diameters

### Burrowing activity

Burrowing activity observed when nine previously captured animals were returned to the field indicated that *S. empusa* can form small but functional burrows in the field within 30-45 minutes. Continued analysis of burrowing in the field and in the lab has shown that *S. empusa* employ two different methods for moving sediment. The animals typically start by vigorously fanning their pleopods, which suspends and pushes sediment behind their telson. The posterior end of the growing depression ultimately becomes the primary burrow opening. Most individuals are able to create a depression big enough to fit their body within 1-2 minutes, but this method of moving sediment is not sustainable. After several bouts of this exercise, the animals turn around and engage in a new method of substrate removal using their maxillipeds to carry lumps of sediment forward and out of the burrow. This second burrowing method only moves about one fifth as much sediment per unit time as pleopod fanning, but animals can maintain this excavation approach for much longer. *S. empusa* continue burrow construction with their maxillipeds until their body can be completely enclosed by the growing burrow. This quick burrowing method is facilitated by the dorsoventral flattening of the body, which enables tight turns. Preliminary scanning electron microscopy studies suggest extremely

setose pleopods and maxillipeds, which may help them to move and/or carry large amounts of sediment.

### **Burrow currents**

The pleopod fanning motion that is used to move sediment is also used to create substantial currents in the burrow. Since the pleopods move fluid posteriorly, the direction of the fluid flow through the burrow depends on the location of the mantis shrimp relative to the burrow opening of interest. Animals typically make currents that bring water into the burrow opening when they are positioned head-up by the burrow opening. In contrast, when the animal is upside-down near an opening, the current sends water out of that burrow opening. The latter position is believed to be defensive.

Fluorescein dye and PIV data indicate that the animals can produce currents of up to 6 cm/s. The PIV measurements also made it possible to resolve the time course of fluid ejection from the burrow. Often, the current started with a large, fast, constantly flowing expulsion of fluid, followed by a slower, oscillatory period. The mean current out of the burrow during this period was  $2.7 \pm 0.3$  cm/s.

In the two hours of PIV video, the mantis shrimp were shown creating these currents  $35\% \pm 14\%$  of the time. However, there is a great deal of individual variation in the relative amount of time individuals spend generating incurrents (from 5% to 24%) and excurrents (7% to 41%).

Lastly, PIV profiles make it possible to distinguish between burrows with one opening and burrows with two openings. The former typically had water flowing into one side of a burrow opening and out the same opening, while the latter experienced flow into one end of the burrow and out the other end of the burrow.

## **Discussion**

Mantis shrimp burrowing activity, at least in *S. empusa*, appears to be more dynamic than previously thought. Most burrows acquire a seasonal second opening, and the diameters of the burrow openings change on a daily basis. The actual burrow excavation mechanisms that give rise to these changes, pleopod fanning and the use of maxilliped baskets to carry sediment, are fast and efficient. The fact that *S. empusa* can build new burrows quickly may explain their lower level of aggression relative to other mantis shrimp species (Caldwell and Dingle, 1976). The constant remodeling could have important effects on other inhabitants of the substrate. These effects could include damage to their shelters, changes in ventilation and oxygenation and other biogeochemical aspects of the sediment, and exposure to predation.

Pleopod fanning seems at first like an inefficient and inaccurate means of moving sediment. However, recent studies show that pleopod movements provide jet propulsion-like motion during mantis shrimp escape responses (Campos et al., 2012). These observations suggest that the water currents produced by pleopod fanning that move sediment during burrowing could be more directed and thus more efficient than previously considered. A less vigorous version of pleopod fanning creates strong currents within the burrows. Putative functions for these currents include both ventilation and transport of chemical signals. These possibilities will be the subjects of future investigations.

*S. empusa* burrows are similar to *S. mantis* burrows in that they both typically have two openings with one usually larger than the other. However, the openings are closer together in *S. empusa* than in *S. mantis* (Atkinson, 1997). The methods of moving sediment also appear to differ between the two species. *S. mantis* appear to use more head and maxilliped probing and less pleopod fanning to make

the initial depression. During later stages, larger animals back out to deposit the sediment held by maxillipeds or push it beneath their body rather than somersaulting and exiting forward like *S. empusa*. Furthermore, *S. mantis* appear to spend more time grooming with its first maxillipeds. In *S. empusa*, the first maxillipeds are most often used to tamp down and consolidate the bolus of sediment held within the basket formed by maxillipeds 2-5. Perhaps as a consequence of these differences, *S. mantis* takes several hours to burrow down 20 cm, while *S. empusa* can dig this deep in less than an hour.

In conclusion, *S. empusa* may be unusual in the rapidity with which they first construct and later remodel their burrows. Their building efficiency may affect both their own behavior by minimizing the pressure for aggressive defense of their burrows. The frequent construction may also affect the surrounding sediment and other animals living in the sediment.

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## Experimental Marine Ecology Along the Open Coastline of the Western Antarctic Peninsula

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### Abstract

Although every region where science diving occurs has unique challenges, one of the most formidable diving regions is Antarctica, from McMurdo Sound to the western Antarctic Peninsula. Along the open coastline of the western Antarctic Peninsula challenges differ from areas of Antarctica with year round ice cover. They can range from encounters with megafauna to the extreme environmental characteristics of the continent. Common science diving protocols and techniques need to be adapted in order to deal with these challenges and perform ecological field experiments. This presentation discusses these protocols and techniques in reference to the work done by the University of Alabama at Birmingham and the University of South Florida. The ecological work is multi-disciplinary and includes chemical ecology, drug discovery, algal physiology, and climate change.

Keywords: western Antarctic Peninsula, dry suit, climate change, marine ecology, SCUBA

### Antarctica

The Antarctic marine ecosystem is a combination of unique biology and extreme environmental factors. The separation of Antarctica from surrounding land masses and formation of the Southern Ocean, including creation of the Antarctic Circumpolar Current (ACC), effectively isolated the continent from other marine habitats in the late Cretaceous. Isolation of the biological community from previously sympatric communities led to high incidences of endemism and losses of many marine phyla (Dell, 1972). Yet, Southern Ocean deep water upwelling provides waters with high nutrient content sustaining many biologically rich marine communities. These include pelagic seas which host abundances of krill, a keystone species in the Antarctic food web (May et al., 1979), subtidal benthic communities like those in the Ross Sea, which are largely dominated by invertebrates (Dayton, 1994), and benthic communities dominated by macroalgal canopies along the western Antarctic Peninsula (Wiencke and Amsler, 2012). Antarctica is designated as an area most likely to be impacted by global climate change, especially the Antarctic Peninsula (Clark et al., 2007). Examining these unique ecosystems provides an opportunity to study ecological processes (Amsler et al., 2001) and their response to a rapidly changing environment.

Fifty nations actively work in Antarctica in ordinance with the Antarctic Treaty. Most stations dot the coastlines (Figure 1), and are facilitated by vessels which some also use for research. Diving programs vary between country and station, and generally are tailored to the highest degree of safety for the type of science and specific environmental conditions to which the divers are exposed. The three Antarctic dive platforms outlined in the Office of Polar Programs' diving manual include

McMurdo Station, Palmer Station, and Research Vessels along the peninsula. This paper will discuss the work and conditions at USAP Palmer Station along the western Antarctic Peninsula.

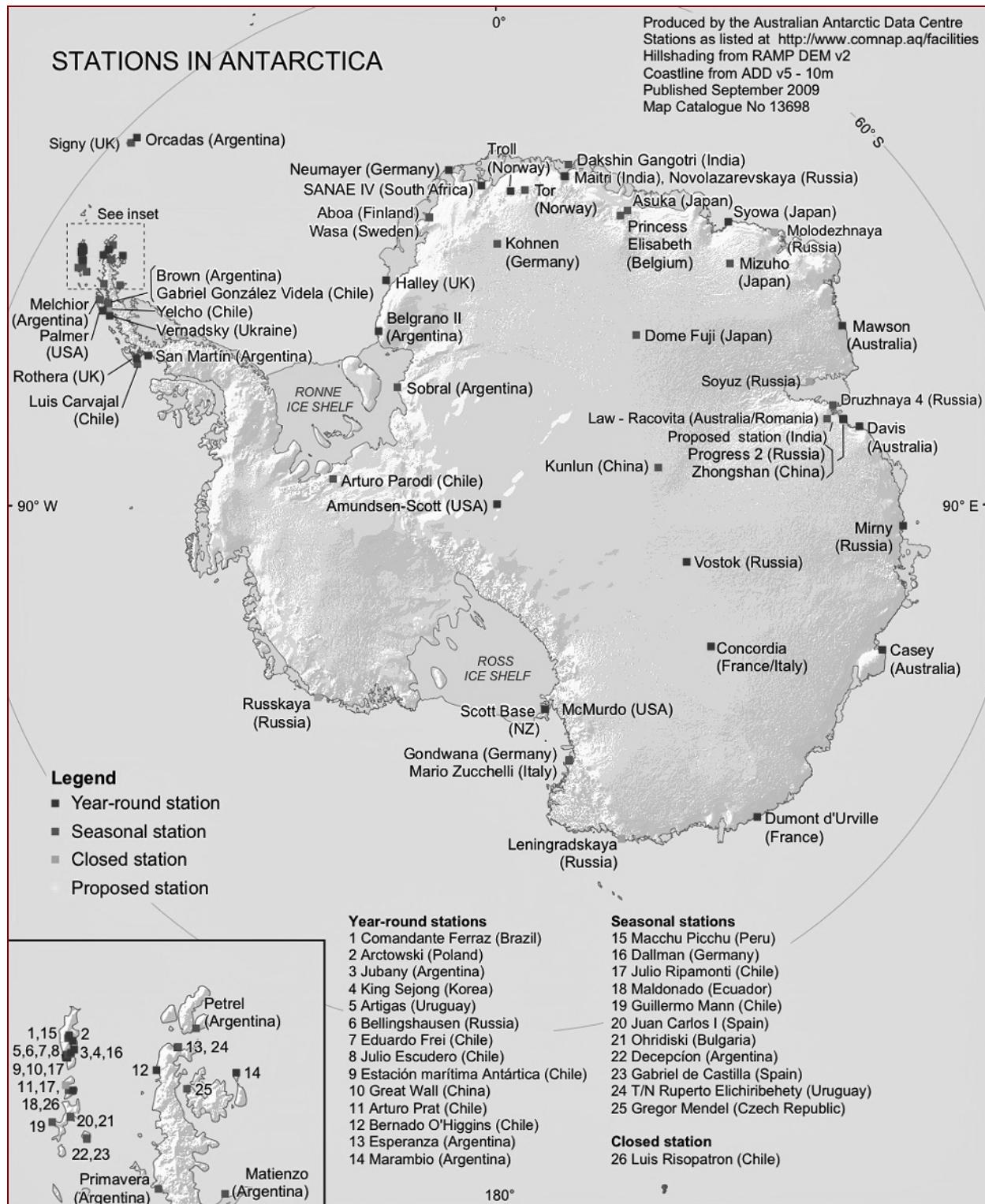


Figure 1. Map of Antarctic Continent with stations (image from <http://www.scar.org/information/>).

## Diving along the western Antarctic Peninsula

Conditions along the Antarctic Peninsula are tumultuous and can change rapidly. The western Antarctic Peninsula has varied sea ice cover, reaching maximum mean density in mid-August and minimum mean density in mid-March (Stammerjohn et al., 2008). Open coastline conditions allow the use of Zodiacs as a diving platform and as transportation to and from dive sites. However, these coastlines are steep and are subject to surge, pack ice, wind, swell, dim light conditions, and are accessible to top predators (Figure 2).



Figure 2. Leopard seal (photo credit Bill Baker).

These conditions require live tending and at least two dive tenders on board the Zodiacs at all times. Lines are rigged to the Zodiacs for gear retrieval and a diver recall horn is always on board in the event that the weather changes or a leopard seal is observed in the vicinity (Figure 3).

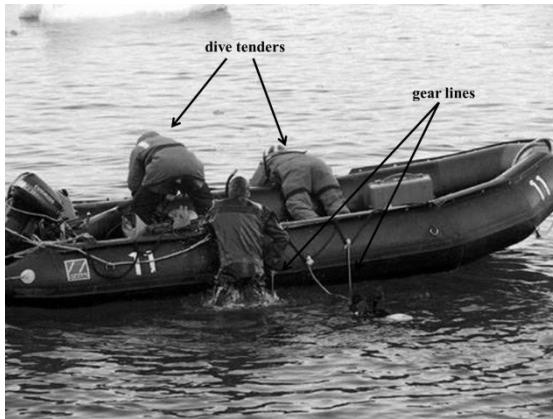


Figure 3. Dive boat setup with tenders (photo credit Deneb Karentz).

Visibility along the peninsula can range from 30m in the late Austral winter through early summer to 1-5m in the summer and early fall because of phytoplankton blooms and glacial flour. Water temperatures are low, with maximum fluctuations between -1.5°C and 2°C during the Summer. Weather and leopard seals are a primary concern in safety, as well as the type of science planned for the dive. Therefore extensive measures are taken when surveying a dive site. After a site is deemed safe a ten minute or longer leopard seal survey is done within a 1km radius of the dive site.

The remoteness of the study area increases the danger of diving. In the case of a dive accident, protocol for treatment first includes retrieval of the diver(s). Since divers are not tethered, there is no anchor or descent line, and underwater breathing is self-contained, this would become difficult if the diver was non-responsive. When a diver(s) are retrieved from an accident site, his or her condition is assessed (ABCs), oxygen therapy and/or treatment for hypothermia is initiated, and the dive group immediately returns to the station. Although the doctor on station is briefed in diving medicine, that is not his or her professional specialty and there is no chamber access. Therefore any extended treatment, specifically recompression, requires immediate transport to BAS Rothera Station or Argentine base Jubany (Figure 1) via vessel or Twin Otter, or immediate transport by vessel to recompression in South America. The OPP DSO is immediately contacted and accident management is carried out using dive logs and diver, dive buddy, and dive tender debriefs.

Dry suits are used by most divers in this area and cold water gear includes two regulators (the primary is equipped with a Zeagle isolator valve in case of free flows), a standard weight harness with easily dumped weight pockets, a vest BC, and back-lit dive computer (Figure 4).



Figure 4. Diver in dry suit with a tender, gearing up for a dive off of a Zodiac  
(photo credit Charles Amsler).

## **Ecological experiments**

Diving facilitates ecosystem studies otherwise impossible along the western Antarctic Peninsula. Field experiments, specialized collections, photography, and exploratory dives are just an example of this dive work. Specific areas of research are detailed below with brief descriptions of corresponding dive activities.

### ***Chemical Ecology***

The study of chemical ecology examines how biologically produced chemicals (primary and secondary metabolites) are involved in ecosystem interactions including those between organisms, and those between organisms and their environment. In Antarctica, studies to date have described the role of chemical defenses in trophic interactions (Amsler et al., 2001), defense against predation in common invertebrate and algal species (Amsler, 2001; Mahon et al., 2002; Mahon et al., 2003; Amsler et al., 2005), biofouling (Amsler et al., 2000), and community-wide interactions involving biological chemistry (or secondary metabolites). The interaction between the large mesograzers cohort and the chemically defended macroalgal canopy has been described as a mutualism, where the mesograzers gain refuge from predation within the chemically defended macroalgae and benefit macroalgae by grazing down potentially harmful epiphytic algae (Amsler et al., 2009; Zamzow et al., 2010; Aumack et al., 2011). Other current studies include examination of the role reactive oxygen species have in anti-predator defenses (McDowell, personal communication) and of how cell wall constituents of coralline algae may affect invertebrate recruitment to Antarctic reefs (Schoenrock, in progress). These projects require a variety of diving skill sets, including underwater identification and collection for extraction and manipulation in lab, night diving, and deployment of substrates to weight down long-term field experiments. This sort of technical diving is done with extreme care and consideration of the environmental conditions (Figure 5).



Figure 5. Dive tenders lowering concrete substrates to divers off Zodiacs at Norsel Point, Amsler Island 2010 (photo credit Maggie Amsler).

### **Drug Discovery**

It is commonly predicted that incidences of chemical defenses in organisms will decrease from low to high latitudes globally (Bakus and Green 1974). Antarctica is the exception to this rule; many marine organisms, both invertebrates and algae, have been found to elaborate secondary metabolites within their tissues (Amsler et al., 2000). Whether this has evolved as a defensive mechanism or is product of the evolutionary isolation of the continent remains in question. Still, drug discovery capitalizes on natural biological products, and compounds from many marine organisms common to the western Antarctic Peninsula are medically interesting. Collections for these studies require dives of up to 150 feet for specific organisms and can be long (up to 40 minutes). Dives are always planned within no decompression limits.

### **Algal Physiology**

The study of algal physiology is broad, spanning from the various forms of metabolism within the algae to plant (thallus) morphology. Experiments examining the various physiological aspects of

algae along the western Antarctic Peninsula include an examination of phlorotannin production of dominant macroalgae (Fairhead et al., 2005) and an investigation into the impact of filamentous algal endophytes on growth, reproduction, and survival of various endemic and cosmopolitan algae (Schoenrock, in progress). Field work for these experiments includes field collections from multiple depths, use of a pulse amplitude modulated fluorometer (Walz, Germany) to analyze photosynthetic characteristics of individuals, community sampling using quadrats, and deployment of substrates for transplant experiments.

### **Climate Change**

The western Antarctic Peninsula has been cited as an area of the world that is very susceptible to global climate change. In 2012, a study at Palmer Station investigated the response of two calcified marine invertebrates, and both calcified and non-calcified crustose algal species, to current and predicted levels of water temperature and acidity. Diving collections provided organisms of the appropriate size and species for an in-lab experiment.

### **Conclusion**

Although broad in spectrum, all of the research conducted along the western Antarctic Peninsula provides information on marine benthic community interactions and individual species distributions as well as how they persist in this particularly harsh environment. Although science diving in the Antarctic can present physical and environmental challenges to research, the ability to safely and thoroughly conduct studies in this area provides an ecological baseline for future research. Further, new methods for conducting *in situ* experiments in this environment are always being sought and this paper will hopefully inspire discussion and new projects.

### **Acknowledgements**

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## Closed-Circuit Diving Techniques for Wild Sea Otter Capture

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### Abstract

Sea otters (*Enhydra lutris*) are both a keystone and sentinel species in temperate coastal ecosystems of western North America, and provide researchers with a “window” into the health of the nearshore environment. In order to accurately monitor these populations, it is necessary for researchers to capture wild sea otters to collect morphometric data, tissue samples, and to attach or implant markers for long-term tracking studies. As a result, a collaboration of the US Geological Survey, California Department of Fish & Game, and University of California, Santa Cruz, has developed an innovative approach to capturing wild sea otters using divers. The techniques have evolved over several decades and currently utilize state-of-the-art equipment including closed-circuit oxygen rebreathers, highly modified diver propulsion vehicles, and custom designed “Wilson Traps” to catch sea otters. Stress or chance of injury to the animal is minimized using the current design. The design is ideal for re-capture of sea otters in order to retrieve archival instruments (i.e. implanted time-depth recorders) and conduct longitudinal studies related to health and disease or pathogen exposure. The described diving techniques have greatly advanced the field of sea otter research, providing greater understanding of sea otters and the capability to closely monitor this federally protected species throughout its range.

Keywords: animal health, diving, nearshore ecology, oxygen rebreathers, sea otter

### Introduction

Sea otters (*Enhydra lutris*) are an important predator in nearshore ecosystems of the North Pacific. Unlike all other marine mammals, sea otters do not have a thick insulating layer of blubber, and instead, possess the thickest fur of any animal (Kenyon, 1969). This unique fur coat allows otters to survive in cold Pacific waters, an environment well outside their zone of thermal neutrality (Morrison et al., 1974). This fur coat made sea otters a prized commodity in the 1700’s to Russian fur traders. The sea otter hunt continued until the passage of the International Fur Seal Treaty in 1911. By the early 1900’s only 13 remnant sea otter colonies existed in the Pacific. A mere 30-50 otters survived in California, where current numbers have rebounded to approximately 2,800 individuals, and they remain listed as a federally threatened species. Historically, sea otters populated the entire west coast of North America, from Baja California all the way around the Pacific Rim to Russia and Japan. Today, three subspecies exist in fragmented populations. *Enhydra lutris nereis* occurs only in Central California, while *E. l. kenyoni* is found in Alaskan waters, British Columbia, and Washington, and *E. l. lutris* in Russian waters.

As a keystone species in kelp forest and other nearshore communities, the presence or absence of otters can greatly affect the dynamics of an entire ecosystem (Estes and Palmisano, 1974). They are also considered a sentinel species, making them critical indicators of the health of our coastal environments and resources (Jessup et al., 2004).

In order to monitor the health and status of sea otter populations, and by extension, the health of nearshore ecosystems, researchers must be able to effectively and efficiently capture sea otters. Catching these animals not only allows scientists to assess health and individual body condition, but information on diet and feeding habits, exposure to disease, toxins, or other stressors, can be gained from sampling tissues, whiskers, and blood. Additionally, captured otters can be implanted with archival instruments like time-depth recorders (TDRs) or VHF radio transmitters allowing for long-term monitoring and tracking studies that provide scientists with a wealth of behavioral and bio-geographic data.

### ***History***

A variety of sea otter capture methods have been utilized over the past several decades. Dip netting of otters from a fast boat has been effective at catching rehab animals, juveniles in open water, or distressed animals such as those in the 1989 Exxon-Valdez oil spill in Prince William Sound, Alaska. Tangle nets, which are similar to gill nets, are very effective at catching a large number of otters, but are indiscriminate, risk injury or drowning to the animals, and also tend to catch non-target species such as seals, sea lions, small cetaceans, or marine birds. In most circumstances, these two methods have been replaced by the capture of individual animals using diver-operated traps.

The capture of sea otters using divers was pioneered by biologists from the California Department of Fish & Game (CDFG) and was later adopted by the U.S. Fish & Wildlife Service and U.S. Geological Survey. The basic concept utilized an aluminum framed basket lined with netting to entrap an otter when a purse line was pulled. CDFG biologists Ken Wilson and Jack Ames developed the design for this trap, which today is known as the Wilson trap (Ames et al., 1986). In the early days, the trap was attached to the end of a long pole (typically a broomstick) and manually pushed through the water by a pair of divers. These divers utilized conventional SCUBA to swim this awkward trap through the dense kelp forest and occasionally had to “walk” the trap across the bottom. Once an otter was located, the two divers would simultaneously steer and push the trap up under the resting otter. This method proved to be effective (80-90 otters were caught this way) but inefficient as it required a tremendous amount of effort (Sanders and Wendell, 1991). The divers or their bubbles were easily spotted or smelled by the otters, resulting in many failed capture attempts.

A number of great improvements were made to the original design, the first of which was to replace the broomstick with a diver propulsion vehicle (scooter) to push the trap and pull the diver through the water. Not only did the scooter technique make moving the trap much easier, but it allowed for both divers to carry a trap and scooter, potentially doubling the catch on every dive. The use of scooters also allowed divers to travel faster and cover much greater distances, which meant that dives could be started further away, reducing the chances of the boat spooking the otters. Scooters were a great improvement over the push pole technique; however, the exhaust bubbles from using conventional SCUBA still regularly alerted otters to the presences of divers below them. In 1988, sea otter capture divers sought to solve the bubble problem by using closed-circuit oxygen rebreathers. The effectiveness and efficiency of otter captures increased dramatically when rebreathers were used in combination with the scooters and Wilson traps.

The diving techniques for capturing sea otters are constantly evolving and being honed. In recent years, divers have further increased their success by wearing a handheld marine radio in a custom built pocket on their hood. The radio is packed in a vacuum-sealed bag to keep it dry. The addition of

a radio allows the diver to receive directions and critical information from a boat driver or shore spotter when the diver is at the surface. The divers can only receive transmissions and not respond, but there is little need for a response. The addition of the “radio heads” allows the boat/spotter crew to keep the diver abreast of changes in the status of the target animals and give them new headings or course changes. This information is often critical to a successful capture dive.

The most recent equipment addition is the use of radio telemetry to locate divers. Though telemetry has been used to locate otters for decades, we have only recently realized that this could be a useful tool for signaling that a capture diver is at the surface. In poor sea conditions (large swell, intense sun glare), or dense *Nereocystis luetkeana* kelp beds, it becomes very difficult for the boat crew to spot a diver’s head at the surface. When the diver is at the surface, they are waiting for course correction information and target status information from the boat crew. By wearing a small radio transmitter on the hood or mask strap, a boat equipped with a radio receiver and antenna will immediately be alerted that a diver is at the surface. The crew can then give information to the diver even if they can’t see him/her. Wearing a radio transmitter isn’t always necessary, but it can be extremely helpful in less than ideal weather conditions. Capture divers have also recently started using custom made hoods that are solid black, feature a sewn neoprene radio pocket over the ear, and have a fluorescent yellow panel on the back of the head. Since divers are almost always facing the otter, the yellow panel on the back of the head faces the boat, which greatly improves the boat crew’s ability to spot a diver at the surface and provide directions.

## Methods

### ***The Dive Team***

In California there are a total of six sea otter captures divers: three from the U.S. Geological Survey, two from the California Department of Fish & Game, and one from the University of California Santa Cruz. In Alaska, the U.S. Geological Survey has a total of three sea otter capture divers. Great efforts have been made to standardize training and equipment configurations in order to operate as a cohesive unit. Only divers that had a great deal of experience on open-circuit SCUBA, and demonstrated exceptional skill in the water, were selected to receive training as a sea otter capture diver. All divers received advanced rebreather training in the classroom, pool, and ocean, and exceeded the training requirements set forth by their respective institutions and AAUS.

### ***Equipment***

Capturing sea otters is a clandestine operation. If an otter is alerted to the presence of a diver, they will quickly depart, often disturbing other otters in the vicinity and making their capture impossible. Therefore, sea otter capture divers have abandoned the use of traditional SCUBA equipment in favor of closed-circuit oxygen rebreathers. The “bubble-less” nature of closed-circuit rebreathers allows the divers to position themselves directly underneath otters without being detected, even getting within inches of them if desired. The ability to remain undetected while swimming below the otters allows the dive team to carefully assess the group and selectively capture individual target otters if necessary. Since sea otters rest at the surface, typical dive profiles for capture dives are very shallow (<7m, and typically in the 2-3m range). Sea otter capture divers have no need for any complicated gas mixing, so the team uses simple 100% oxygen rebreathers, which minimizes nitrogen-related risks. Utilizing pure oxygen does bring up other potential problems (mainly oxygen toxicity), but keeping careful track of depth and total oxygen time helps avoid these issues. Embolism is always a concern when breathing compressed gasses, but capture divers are careful to exhale during ascents to minimize such risks. Sanders and Wendell (1991) outlined the risks and precautions associated with using closed-circuit oxygen rebreathers.

Unlike most recreational oxygen rebreathers, the military grade units used by sea otter capture divers are fully closed circuit rebreathers and do not release gas on ascent. In 2009 most of the capture team replaced their older Draeger LAR V or COBRA rebreathers with the Aqualung FROGS (Full Range Oxygen Gas System) rebreather. This compact oxygen rebreather is only available to the government or military and has been in use by the French Navy since 2002. The FROGS rebreather features multiple water traps, diver adjustable breathing resistance, a bypass system that allows the diver to breathe even with a second stage failure or flooded unit, easy maintenance, and tool-free assembly and disassembly. The FROGS unit is also very sleek, streamline, and one of the most compact rebreather units on the market. This unit was originally designed to be chest mounted, but when mated with the Aqualung Combat Swimmer Assault Vest (CSAV) or backplate buoyancy compensator, can be worn on the back. The CSAV functions as a buoyancy compensator and has its own gas supply (two 1.5 ft<sup>3</sup> cylinders) if desired, as well as fully ditch-able weight integration.

A few researchers are still diving Carleton COBRAs (Closed Circuit Oxygen Breathing Apparatus), an older but reliable closed circuit oxygen rebreather. The COBRA rebreather was based on an even older design, the CCR-25, originally manufactured by Biomarine Inc. This is a back mounted unit and even today is considered to be one of the easiest breathing and most comfortable oxygen rebreathers that our dive team has used.

Each member of the dive team uses either Oceanic Mako or Tekna scooters that have been modified for otter captures. The nose cone of the scooter has been fitted with a custom machined metal post where the Wilson trap can be attached to the scooter. Since the original design of the scooter was intended simply to pull a diver through the water and not to push and steer a heavy trap, there was some skepticism as to how well the scooter would perform this advanced duty. We were surprised to learn that the Makos and Teknas performed well, even at factory settings. Adding a trap to the front greatly reduced speed and maneuverability, but the scooters still handled the additional load. In recent years, we have made more custom modifications to these scooters including: high power motors, clutch upgrades, and battery upgrades to provide the divers with more speed and power. We also use prop guards on the scooter shroud to keep the propeller free from entanglement when navigating a dense kelp forest.

Every diver on the capture team now wears custom DUI Combat Diver drysuits, which are modified CLX suits only made available to the military and government. The combat diver suit features multiple cordura and kevlar overlays that make the suit extremely robust and durable. The added durability is a necessity for capture work as divers often get off on wash rocks or beaches and sometimes need to hike to scout for animals to avoid spooking them. Some divers have moved the suit inflation valve from the chest to the upper thigh. This location is beneficial when wearing a chest mount rebreather, but also allows the diver to wear a small inflation cylinder on the thigh, solving cylinder attachment and hose routing problems. The drysuits, as well as the rebreathers, scooters, and traps, are all black with no bright colors or reflective material. This helps the divers go undetected both underwater and at the surface. Pockets and accessories are customized for each individual diver, though several have a bellows pocket on the right thigh, and an inflation bottle pocket on the left thigh. U.S. Geological Survey divers are using Aqualung D.S.I.S. (Drysuit Inflation System) cylinders that provide 5ft<sup>3</sup> of gas for offsetting drysuit squeeze, or as a redundant source of providing positive buoyancy.

Sea otter capture divers use a gauge console that is trap-mounted so that it is in the direct line of site when the diver is navigating to the target otter. The console consists of a compass and depth gauge, which are monitored continuously to ensure that proper headings and depth restrictions are maintained. Many divers also wear dive computers, some of which (Suunto Vyper 2 or Vytec) are capable of logging total O<sub>2</sub> saturation for continuous diving. The previously mentioned “radio head”

hoods worn by capture divers are additionally customized by including a single fluorescent yellow panel on the back of the otherwise black hood, which helps the boat crew spot a diver at the surface. For safety purposes, divers carry surface signaling devices, whistles or air horns, and a cutting tool.

Capture diving is done from a variety of vessels, but the boats are carefully selected and modified for stealth and functionality. The vessels are usually fiberglass boats in the 16-20ft range but frequently inflatables and RIBs are used as well. Regardless of the boat type, it must have a low profile, preferably be a muted color (i.e. navy gray), reflective surfaces must be taped over, and the motor should be a four-stroke outboard (lower smell and noise signature than two stroke motors). Virtually silent electric trolling motors can even be used when extreme stealth is required. Each of these requirements aid in the ability to covertly move into a position to begin the dive.

### ***Sea Otter Capture Techniques***

In order to catch a sea otter, researchers must first formulate a plan and locate target animals. In areas where otters are very skittish, we often employ the use of shore spotters, who can locate animals from great distances away by reaching an elevated observation point and utilizing high powered spotting scopes that are capable of magnifying 80x. The approximate location of the target otters are relayed to a boat crew. With the targets' location known, the boat is kept a good distance away (often 1 km or more) until the divers can visually locate the target animals using binoculars. Once a visual is obtained, the boat silently and slowly closes the distance to the otters. The targets are always approached from downwind, and whenever possible, an approach is made that places the shoreline, rocks, or some natural feature behind the boat, making the outline of the boat less likely to stand out than if the otters were approached from offshore with a clean horizon. The minimum acceptable distance to the otters depends on their level or alertness. In Monterey, California, where otters are conditioned to constant boat activity, the boat might be able to get within 300m of the target animals. However, in remote locations like Big Sur, California, or certain areas of Alaska, 500 or 600m might be the minimum distance before the otters spook. In extreme cases, a minimum distance of 800m to 1km might be required.

Once an appropriate distance is reached, the motor is shut down and the boat is secured if possible. If the boat is in a kelp bed, tying the bow line to kelp is the preferred method for securing the boat since it is silent and can be undone quickly by the boat tender. When no surface kelp is present, the anchor may be deployed, which is more likely to spook the otters and may also result in the boating taking longer to get to the divers if a problem were to occur. In some cases, such as in the narrow fjords of Alaska, the bottom is too deep to anchor and the team must make live boat drops over open water. This is a situation where a very skilled boat operator is critical to the success of the mission.

With the boat secured, the targets are observed using binoculars. The team attempts to assess the activity level of the group, and the relative positions of target and non-target animals within the group. It is important that the target and surrounding otters be resting, with their heads above the surface, so they are unlikely to hear or see approaching divers. The dive is declared a "go" once it is decided that the targets are resting or in a state of inactivity. At this point, a buddy team of two divers gear up and "go on oxygen." This involves donning the rebreather, fully purging the breathing loop of CO<sub>2</sub>, and beginning to breathe oxygen. The buddy team always consists of a "lead diver," that navigates to the target otter(s), and a "follow/trailing diver." Both divers in the buddy team are equipped with Wilson traps so that a double capture can be made if the opportunity presents itself. The lead diver takes a compass bearing from the boat to the target otter and quietly enters the water. The dive team meets beneath the boat and begins to move in the direction of the target by swimming the proper heading. Ideally, the trailing diver falls into formation alongside, and slightly behind the lead diver, which allows the lead diver to see their buddy in their peripheral vision while maintaining focus on the trap mounted compass. In poor visibility, the two divers will be nearly shoulder to

shoulder. The underwater kelp forest represents a maze of tangled obstacles which means course deviations and corrections are constantly being made as needed. The depth of the dive depends on thickness of the kelp canopy. As a rule, because the dives are on 100% oxygen, divers never descend below 7m (20ft). In practice, the dive depth usually ranges between 2-3m. Throughout the dive, the lead diver will periodically surface to confirm that they are on the correct course. While at the surface, the diver can receive instructions (via the radio in their hood) on the status of the target(s) and course correction information from the boat crew. The number of “head checks” will vary based on the distance to the otters and the activity level of the target animals. During surface checks, the trailing diver follows the lead diver towards the surface, but hangs just below the surface. Head checks are a critical time when the otters might spot the diver, so one head at the surface is stealthier than two. The lead diver spends only enough time at the surface to get information from the boat crew, or to visually locate the targets.

Depending on visibility, the final head check may be made anywhere from 10 to 30m away from the targets. After the final head check, the dive team begins to make preparations for a capture by “shaking out” any trapped bubbles, securing loose gear, adjusting the speed on their scooters, and spreading out to increase the chances of spotting the otters from below. Once the otters are located, the divers move into position below them, identify which ones they are targeting, orient their traps and scooters vertically, and then ascend quickly, while exhaling, using the scooters to power upwards in the water column. Synchrony between the two divers is critical for timing a double capture. During the ascent, the divers are exhaling the entire way. The depth from which the final ascent starts varies depending on the speed needed to break through the kelp canopy. When otters rest in open water, the ascent might start with the trap rim only 1 of 2ft below the otter. The rim of the trap breaks the surface and envelopes the otter. The immediate flight response of a sea otter is to dive, which actually aides in getting the otter deep into the net of the Wilson trap. A drawstring cord is quickly cinched and tied off to a cleat on the trap. With the otter(s) secured, divers attain positive buoyancy by inflating their drysuits and/or buoyancy compensators. The trap is easily held at the surface with the otter inside. In cases where a particularly large or strong animal wants to dive, the divers can combat this by activating the scooter and keeping the otter at the surface. If the trap and otter is still too heavy, there is a buoyancy balloon with a CO<sub>2</sub> canister mounted on either the trap or the scooter that can be activated to provide additional buoyant force. A hand signal is given to the boat crew to pick up the divers and captured otters.

The otters are transferred from the Wilson traps to specially designed sea otter transport boxes on the capture boat, and then either brought ashore to a mobile veterinary lab or to a large vessel that serves as a mobile vet lab. Under the direction of the chief veterinarian, anesthesia and the sampling and instrumenting process can then begin.

## Discussion

The California Department of Fish & Game, U.S. Geological Survey, and U.S. Fish & Wildlife Service have been using divers to catch otters for nearly 30 years. Over this time period, the equipment and techniques have continually evolved to take advantage of new technology that has greatly improved our effectiveness and efficiency. The techniques described here allow researchers to selectively target individual animals while also minimizing the risk of injury to both the sea otters and the divers. The selective nature of this capture technique is most beneficial when trying to re-capture an animal in order to retrieve previously implanted instruments. Time-depth recorders could hold a full year’s worth of dive data, but is only useful if that specific animal can be recaptured and the TDR retrieved. Selective recapture also allows us to replace VHF transmitters once their batteries die, so that a study animal can continue to be monitored. Though the methods described here are highly

specialized for sea otter capture, portions of these diving techniques might be adopted for the covert capture of other marine animals (i.e. marine birds) that remain at the surface for a significant amount of time.

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