Cold Water Diving for Science

Stephen C. Jewett, Editor

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Preface

Stephen C. Jewett

These proceedings contain 22 extended abstracts of papers presented before Cold Water Diving for Science, the 21st Annual Scientific Diving Symposium sponsored by the American Academy of Underwater Sciences. The symposium was held September 19-23, 2001, at the Alaska SeaLife Center in Seward, Alaska. The first part of the program, a technical forum on cold water diving, enabled several invited experts in the field to share their knowledge and experience, to result in another AAUS scientific diving resource document Cold Water Diving for Science: Tips, Techniques and Training, a post-symposium publication. The second part of the program, these proceedings, included a variety of interdisciplinary presentations, most relevant to cold water diving.

This is the third AAUS proceedings to focus on cold water diving for science. The first was *Coldwater Diving for Science 1987* (Michael A. Lang, Editor), held at the University of Washington. It resulted in *Special Session on Coldwater Diving* (Michael A. Lang and Charles T. Mitchell, editors) as well as the regular proceedings. The second proceedings was the *AAUS Polar Diving Workshop* (Michael A. Lang and James R. Stewart, editors), held at Scripps Institution of Oceanography in May 1991. The rationale for revisiting cold water diving for science is to update the scientific diving community on recent advances made in gear, techniques, and training necessary to conduct research in such an extreme environment.

The symposium was hosted by the Alaska SeaLife Center; Prince William Sound Science Center; Alaska Underwater Science Foundation; and the University of Alaska Fairbanks School of Fisheries and Ocean Sciences, Scientific Diving Program, and West Coast and Polar Regions Undersea Research Center. The steering committee consisted of Robert Hicks (chair), Tom Kline, Val Hodges, and Stephen Jewett. Thanks to the following for making these proceedings possible: the authors for contributing manuscripts; Sue Mitchell for copy editing and layout; Tatiana Piatanova for designing the cover; John N. Heine for cover photo (McMurdo Station, Antarctica); Sue Keller for proofreading; and University of Alaska Sea Grant for publishing.

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German Activity in Cold Water Scientific Diving

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The goal of this presentation is to give a brief overview of German activity in cold water scientific diving. First, we will outline the requirements for scientific diving under German legislation. Second, two locations where much of the cold water diving is performed will be described, Kongsfjord in Spitsbergen (Arctic) and Potter Cove at King George Island (Antarctic). Some examples of scientific projects will be presented.

Research Diving in Germany

Diving for science in Germany goes back to the 1960s, when there were no regulations or defined requirements. After two deadly accidents in 1969, guidelines for scientific diving, modified from the "Guidelines to avoid dive accidents" applied to commercial divers, were implemented by the civil engineering trade association (Fachausschuss Tiefbau der BGZ 1988). They define the type and characteristics of the gear, training requirements, protocols on dives and planning, and provide the legal background. Only after passing an exam taken with the technical committee of the civil engineering trade association are divers authorized to conduct any official research diving with German universities, research institutes, or any governmental organization. For every project, a contract is made between the contracting institute and the research diver hired to do the work. Since 1970, eight facilities (seven research institutes and one private company) have obtained legal permission to provide the training. Typically, these facilities offer one course per year for up to twelve candidates each, most of whom are students and technicians in biology, geology, paleontology, and archeology. Up to now (April 1, 2001), 936 divers have been certified as scientific divers.

As prerequisites, candidates are required to have a thorough dive physical, current first aid certification including CPR, and a recent lifeguard certification. The training comprises 240 hours in total which are typically split into two parts of three to four weeks each. Five sections are covered: (1) safety instructions (12 hours), (2) dive medicine (16 hours, lectures and hands-on training), (3) gear instructions (24 hours), (4) dive duty (138 hours), and (5) dives (20 hours pool, 20 hours open water up to 10 m, 10 hours open water up to 30 m).

Some of the most obvious differences between diving in Germany and the United States are that a German dive group consists of one diver in the water who is, via a tether, directed and monitored by a dive tender onboard/on land while a standby diver and a dive operation leader are on site. Diving is performed with a full face mask and in dry suits, therefore a buoyancy control device is not compulsory with a neoprene dry suit.

Similar to the United States, German scientific divers usually perform only non-decompression dives.

Diving in the Arctic

The base for most of the German research diving activity in the Arctic is the Koldewey Station (established in 1991), Kongsfjord, Spitsbergen, which is run by the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven (www.awi-bremerhaven.de). The station is situated at 78.9° N, 11.9° E within an international research base at Ny-Ålesund, administrated by Norway. It offers accommodation for up to eight guests; additional accommodation can be rented with the Norwegian Polar Institute.

Atmospheric research was the main aim when Koldewey Station was established, but marine biological activities have become another major focus in recent years (www.awi-bremerhaven.de/Polar/koldewey.html). The station itself houses a chemistry lab and office facilities, whereas a marine biology wet lab is rented for the summer months from the Norwegian Polar Institute. New international marine laboratory facilities are currently planned. In terms of dive equipment, the Koldewey Station provides two inflatable boats. A portable compressor (200 and 300 bar) is rented from the Norwegian Polar Institute; dive gear and an emergency oxygen unit are brought by the scientific dive group. At present, the closest decompression chamber is in Tromsø (northern Norway), but a treatment decompression chamber will be purchased in the near future (shared among all stations in the research community).

The Kongsfjord is an 8 km wide and 26 km long fjord with a maximum depth of 400 m. The range of the semidiurnal tides is between 1.5 and 2 m with weak currents, allowing dive activities at any time. The shores comprise steep rocky bottom, in parts densely populated by a rich macroalgal community, as well as weakly declining slopes with predominantly soft glacial sediments. The input of terrestrial sediments and freshwater by glacier runoffs can reduce visibility from 20 m down to 1 m from July to September. Ice cover and glacier calving can preclude diving in the inner fjord until mid-June. The mean annual water temperature is just above 0° C but can rise to 6° C at the surface and 3.6° C at 20 m depth in summer. Over the last years, diving has taken place from early May through September at depths of 4 to 30 m. Most sites can be reached in 15-40 min boat rides. Due to the regular occurrence of polar bears, a gun is always required when a person is leaving the station.

Diving in the Antarctic

In January 1994, the Instituto Antártico Argentino and the Alfred Wegener Institute for Polar and Marine Research established the Dallmann Laboratory at the Argentine Jubany Station on King George Island (62° 14′S, 58° 40′W), situated at Potter Cove. The Dallmann Lab is open from October through March (Jubany Station is staffed all year round) and offers space for twelve people (www.awi-bremerhaven.de/Polar/dallmann.html). It is equipped with four laboratories, workshops, storage space, aquarium container, and diving equipment (including a compressor and a one-person transportation decompression chamber). Several inflatable boats and a larger fiberglass boat are available for dive operations. Often, joint Argentine-German diving operations are carried out under the agreement that the stricter rules from either the German scientific or the Argentine professional diving regulations concerning depth and dive time are applied.

Potter Cove covers about 6 km^2 and is up to 90 m deep in the outer and 50 m in the inner cove. The outer shores of Potter Cove consist of rocky bottom with dense macroalgal cover. The southeast coast is characterized by a broad rocky intertidal platform connecting to a weakly declining sublittoral. The inner cove is predominately soft bottom composed of the sediment load provided by bordering glaciers and glacial creeks. Sometimes this freshwater inflow creates a surface layer of reduced salinity loaded with sediments, which significantly reduces light penetration into the water column below (where visibility can still be 20 m). Temperature ranges from –0.9° C to 1.4° C. The cove is usually ice-covered from May to October.

Recent and Ongoing Projects Performed by German Scientific Divers

Kongsfjord

- UV-effects on marine macroalgae, morphological, physiological and biochemical adaptation (e.g. Hanelt et al. 2001, and ongoing)
- Macrofauna associated with macroalgae (e.g. Lippert et al. in press)
- Plant-animal interaction between marine macroalgae and invertebrates, with emphasis on antifeeding strategies (Hagen, Wessels; ongoing)
- Animal-animal interaction between marine invertebrates, chemical ecology (Lippert, ongoing)

Potter Cove

- Macroalgal communities (e.g., Klöser et al. 1994)
- Interactions between macroalgae and herbivores (e.g., Iken 1999)
- Energy budgets of benthic suspension feeding animals of the Potter Cove (e.g., Kowalke 2000)
- The function of macroalgal derived MAAs in invertebrate protection against UV and antioxidative stress (Abele, Obermüller; ongoing)

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An Experiment of Simulated Predation: Can River Otters Become Food Limited in a Marine System?

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Introduction

River otters *(Lontra canadensis)* inhabiting marine environments feed primarily on intertidal and demersal fishes in the nearshore system (Larsen 1984, Bowyer et al. 1994). Investigations were conducted from 1995 to 1998 in Prince William Sound, Alaska, to determine whether river otters and three other top predators inhabiting the nearshore environment continued to be negatively influenced by chronic effects from the 1989 *Exxon Valdez* oil spill. That ecosystem study (Nearshore Vertebrate Predator [NVP] project) addressed the questions: Have these species recovered? If not, is it oil, or is it food? (Holland-Bartels 1999). In that study, densities of intertidal and demersal fishes that are commonly consumed by river otters were compared between oiled and nonoiled sites and between random sites and latrines used by river otters (Holland-Bartels 1999).

In this companion study, a manipulative experiment was conducted to ask the question: Can river otters affect their prey base (i.e., can river otters become food limited in a marine system)? Previous studies investigating predator-prey interactions of Eurasian otters *(Lutra lutra)* and fishes (Koop and Gibson 1991; Kruuk et al. 1988) conducted experiments removing fishes *(Pholis gunnellus, Zoarces viviparus,* and *Ciliata mustela)* from study plots by collecting fishes from under rocks and vegetation at low tide, when only a few centimeters of water remained. Both studies noted that removed fishes were replaced within two tidal cycles by new fishes, concluding that predators likely could not deplete an area of those species of fishes. Those studies were limited to assessing only fishes that seek refuge under rocks and vegetation as the tide recedes and therefore did not evaluate potential effects of predation on all types of fishes consumed by otters.

Methods

We used scuba equipment to conduct a fish removal experiment in Herring Bay (oiled site) from late July to mid-August 1997, to test the hypothesis that otter predation influences local abundance of fishes. Three removal and three control sites with similar aspects and intertidal substrate characteristics were selected for the experiment. Prior to removal experiments, demersal fishes were counted at each site along two transects separated by 20 m, running perpendicular to shore. Transects extended a distance of 30 m or to a depth of 15 m, whichever occurred first. Each site was permanently marked with 6 mm nylon rope delineating the centrally located 30 m transects (i.e., a 20 m wide by 30 m long area) and a buffer zone on either side of the transects (15 m wide by 30 m long).

At each transect, fish in the water column were counted over a 2 m wide swath along the bottom and a second diver moved aside vegetation and counted benthic fishes in a 1 m wide swath. All fishes were identified to family and classified into three size categories (<8 cm, 8-15 cm, >15 cm). Following preremoval assessment of fish abundance at all sites, intense localized predation was simulated at removal sites by divers attempting to spear and remove all fishes. Four divers conducted fish removals at each removal site on three consecutive days. Two divers were assigned to the central 30 by 20 m area and a single diver to each of the outer areas. Each diver conducted a systematic search of the area attempting to spear any fish >8 cm in length that was encountered. Spearing episodes lasted 25-68 minutes. Immediately upon surfacing, divers recorded the number of fish seen but not successfully speared (i.e. number of fish missed) by fish family and size category (8-15 cm and >15 cm). Fish speared during the removal experiments were preserved in 10% buffered formalin for P4501A1 analysis.

Censuses of central areas were conducted to assess post-removal influences of simulated predation because the number of fishes encountered on preremoval transects was few compared with the number of fishes removed. Two days after the fish removals were completed, a census was done on the central 30 by 20 m area of each removal and control site, counting all demersal and pelagic fishes encountered. Censuses were repeated at each site two weeks later. Census dives involved a systematic search of the entire area and required 53-82 minutes to complete, depending on the amount of vegetation.

Fish removal data were analyzed using paired sample *t*-tests and GLM repeated measures analyses employing SAS software. Models were based on type (removal or control) because there were insufficient degrees of freedom to run models by site. Paired *t*-tests conducted on preremoval transects detected no difference between control and removal sites in fish abundance ($F = 16.69$, $P = 0.07$) thus sites were appropriate for comparison of post-removal abundance of fishes. Significantly more fishes (>8 cm) were missed than were removed ($F = 7.18$, $P = 0.04$), with greater numbers of fishes missed and removed on each subsequent day of the experiment (Figure 1). Divers likely acquired a better search image for fishes as the experiment progressed, and fishes likely became more cautious when divers were present as a result of previous experience.

A GLM repeated-measures analysis of post-removal censuses detected no difference between removal and control sites in number of fishes >8 cm present at each census ($F = 0.06$, $P = 0.~824$). There was, however, a difference in fish abundance between sampling events ($F = 248.44$, $P = 0.04$), with a greater number of fishes present in the first post-removal census compared with the second census (Figure 2). By fish family (>8 cm), only sculpin differed significantly between removal and control sites (greater at control sites; $F = 289.0$, $P = 0.037$), whereas cod (greater in rep #1; $F = 497.03$, $P = 0.028$) and Pricklebacks *(Stichaeidae)* (greater in rep #2; $F = 99999.9$, $P < 0.001$) differed significantly between census repetitions (Figure 2).

Most differences in fish abundance occurred between sampling events rather than between control and removal sites, indicating a seasonal fluctuation in fish abundance that likely was not related to the removal experiment. The change in abundance for all fishes >8 cm between post-removal sampling periods (Figure 2) was driven primarily by cod, which were not targeted for removal. Preliminary food habit data obtained in 1996 from 25 samples of otter feces collected from latrine sites in Jackpot and Herring bays indicated that cod were not an important prey item for river otters at those sites (Holland-Bartels 1997). Pricklebacks also varied in abundance between post-removal censuses (Figure 2) and were present in greater numbers at removal sites compared to control sites.

Only sculpin occurred in lower numbers at removal sites compared with control sites during post-removal sampling, indicating that these relatively sedate fishes, which are commonly consumed by river otters (Larsen 1984, Holland-Bartels 1997), may be affected by predation. Nonetheless, when abundance of all fishes was considered, there was no difference

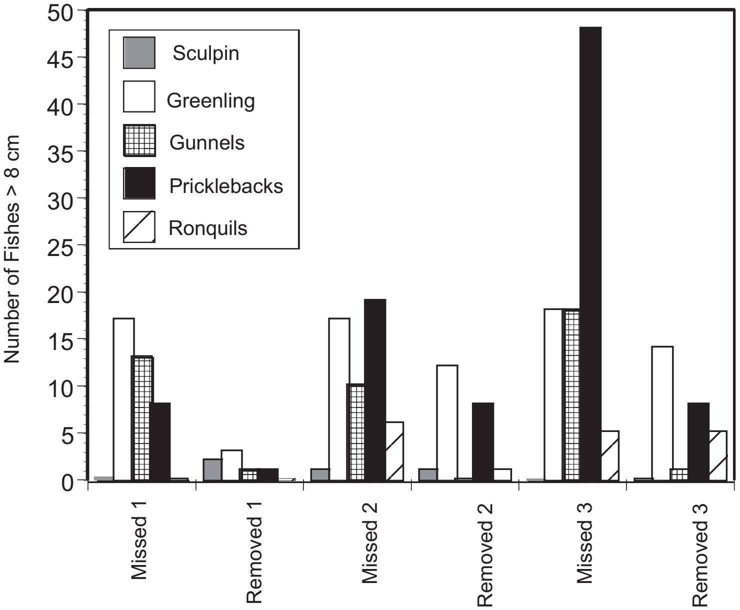

Figure 1. Total number of fishes >8 cm missed and removed at fish removal sites (n = 3) on three successive days of spearing by divers.

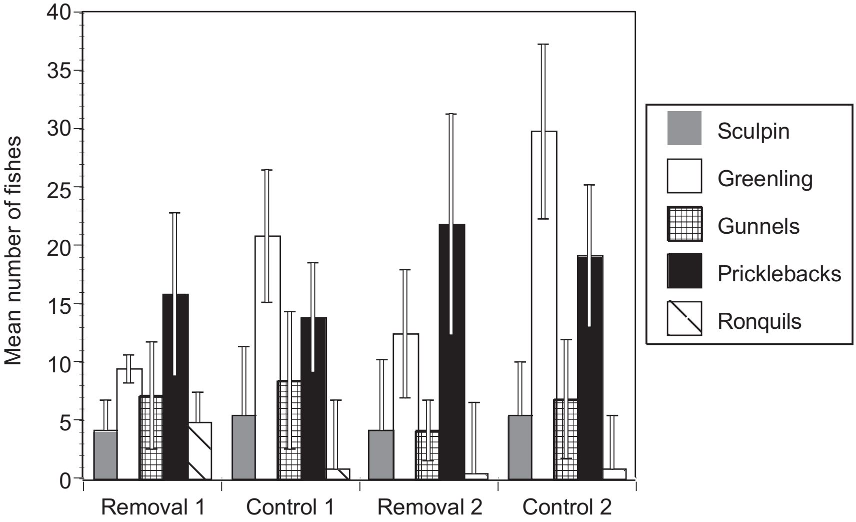

Figure 2. Mean number of fishes occurring at removal and control sites two days (removal and control 1) and two weeks (removal and control 2) after removal of fishes was conducted.

between removal and control sites in post-removal abundance of fishes >8 cm, indicating that the removal of fishes at those sites did not affect the subsequent number of most fish species that were present. Our conclusions agree with those of previous otter-fish studies (Koop and Gibson 1991; Kruuk et al. 1988). Because of the mobility of most demersal fishes, prey removed by predators are quickly replaced and depletion of a site is unlikely when fishes occur at densities similar to those noted during this study.

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Survey Design and Methods for Determining Oil Spill Damage to Pacific Herring *(Clupea pallasi)* Embryos

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On March 24, 1989, the oil tanker *Exxon Valdez* struck Bligh Reef and spilled 42 million liters of Prudhoe Bay crude oil into Prince William Sound (PWS), Alaska. Approximately 40 to 45% was beached in the sound (Wolfe et al. 1995) and about 634 linear km of shoreline was contaminated by oil (Gundlach et al. 1990). This was the largest spill to date in U.S. coastal waters, and it coincided with the spawning period of Pacific herring *(Clupea pallasi)* in the sound. The length of oiled shoreline overlapped about half of the length of shoreline on which herring spawning was recorded (Brown et al. 1996). This coincidence suggested that the spill may have injured the local Pacific herring stock. Previous research has demonstrated that the eggs of herring and other marine fish can be injured by exposure to hydrocarbons, either by direct exposure to oil-contaminated water (Lindén 1978, Rice 1985, Rice et al. 1987a) or by exposure of adult female herring to oil prior to spawning (Struhsaker 1977, Rice et al. 1987b).

Pacific herring spawn intertidally and subtidally in PWS, generally by mid-April. Embryos incubate in natal areas for approximately 24 days (Brown et al. 1996). Natural mortality until hatch is high; egg loss due to wave action and predation can be up to 90% (Palsson 1984, Haegele 1993, Rooper 1996). Egg mortality of remaining attached eggs is dependent on air exposure (desiccation), water circulation, egg density (asphyxia and fungal infections) (Palsson 1984, Hay 1985, Biggs and Baker 1993), and possibly on the type of kelp substrate (plant toxins from red kelps; (Rajasilta et al. 1989). Egg loss contributes far more to the total embryonic mortality rate than mortality of remaining attached eggs (Rooper et al. 1996).

Egg loss and survival of remaining attached herring eggs was measured *in situ* using scuba at 10 oiled and 10 control sites in PWS. The objective was to estimate the change in mortality rate over baseline due to oil exposure. Randomly selected transects (in each region) were adopted that met the following three criteria: (1) spawn had to contain only two to three egg layers to minimize mortality from asphyxiation and to aid in accurate counts of egg numbers; (2) eggs had to be distributed over a wide range of depths (+1.52 m to –9.14 m) to test for effects of depth; and (3) mussels *(Mytilus)* had to be present near transects so as to use the hydrocarbon concentrations in mussel tissue as an index of oil exposure of herring eggs (Short and Harris 1996, Brown et al. 1996). Transects were established perpendicular to shore following a compass course set by divers. Sampling stations were set at depths of 1.52 m, 0.30 m, 0.00 m, –1.52 m, –4.57 m, and –9.14 m relative to mean lower low water (MLLW). Depths were located with a diver's depth gauge and were corrected for tide stage. Each transect was sampled every four days, which resulted in three to six scuba dives along each transect between the time of spawning and the time of hatching, assuming a 24 day incubation period at an average water temperature of 7° C (Alderdice and Velsen 1971).

For measurements of egg loss, a 5 × 2 grid of 0.1 m^2 quadrats was anchored at each of the six depth locations for the entire incubation period. Because wave energy was extreme in some locations, stainless steel mountaineering pitons were used to anchor frames into rock and 1 m rebar for soft substrates. During each visit, egg abundance was estimated in each grid cell at each depth. Kelp species used as spawning substrate was also recorded for each grid. Diver calibration algorithms, established by Alaska Department of Fish and Game (ADF&G) (Willette et al. 1998), were used to correct bias and estimate error in counts. An exponential decay model was formulated to determine egg loss as a function of site- or transect-location effects, depth, time (from spawning), and random error. In logarithmic form, the model comprised a linear analysis of covariance (ANCOVA) with two-factor effects (transect and depth) and one covariate (number of days after spawning).

For measurements of egg mortality (of attached eggs), three samples of herring spawn were collected at each depth on each dive. Samples of eggs were placed in prelabeled mesh bags and kept moist in a cooler until they could be counted. All counts of live and dead eggs were made with a binocular microscope within four hours of collection. Live eggs were clear and the embryo was visible in late-stage eggs, moribund eggs were tinged with white, and dead eggs were completely white and opaque. Moribund eggs were classified as dead. Counting ceased after three replicates of 100 eggs each had been tallied from each station, day, and depth. A nested mixed-model analysis of covariance (ANCOVA) was used to test for significant differences in *in situ* survival of herring eggs between oiled and nonoiled areas while accounting for the number of days since spawning, depth, and the duration of spawning (days) as an indicator of egg density.

The use of scuba was essential for this project. Although the dives were relatively shallow (maximum of 18 m [60 ft]), cold water, poor visibility, and wave action resulted in challenging conditions. The proximity and contact with sea lions also represented a threat; the sea lions were drawn to the region to feed on adult herring spawners. The dives often required long trips in open skiffs and extended exposure to the elements. Divers were all required to have annual medicals and follow procedure as established by the ADF&G Dive Board (similar to policy created by NOAA). All divers participating in the project had experience with spawn deposition surveys (Willette et al. 1998) for at least three previous years. That level of experience was required because diver calibration curves were established and stabilized over that time period. Error introduced from diver bias was potentially large and precision improved with experience; therefore, the best way to minimize error was to require that level of experience. Results of the study are summarized in Brown et al. (1996).

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Diving Techniques Used for Deploying an Underwater Camera Array during a Sonar Operation in the Chandalar River, Alaska

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Introduction

Accurate salmon escapement counts on Yukon River tributaries are important for assessing management guidelines for annual harvest as well as for monitoring long-term population trends. Visual methods for estimating fish abundance and documenting habitat type via underwater cameras or divers are common in other areas of the country and in Canada. These techniques have yet to be applied to cold water environments in Alaska's Interior, where traditional sampling methods for migrating salmon include weirs, counting towers, mark-recapture programs, ground surveys, and hydroacoustics.

In situ observations of salmonids in their natural habitat via underwater video can provide insight to the behavior and general ecology of these species (e.g., Hankin and Reeves 1988, Baltz et al. 1991). Such research can provide data used by managers to better understand and manage this valuable resource. For example, Enzenhofer et al. (1998) found that estimates of sockeye and pink salmon in the Frasier River using underwater and surface video were comparable to sonar counts at low fish densities, and that as fish densities increased, visual counts produced more accurate estimates than sonar. The techniques discussed in this study may be further developed and applied to other areas in Alaska to improve existing salmon escapement programs.

Purpose

The purpose of this preliminary study was to determine if an underwater camera array could be deployed adjacent to the ensonified zone of a split-beam sonar system during the upstream migration of adult fall chum salmon, *Oncorhynchus keta,* in the Chandalar River. The cameras were used to view fish as they passed through sections of the ensonified zone. We then confirmed targets of migrating salmon on the sonar screen using recorded video images. Guided by audible signals from personnel onshore, divers acted as real-time targets to confirm target signatures from sonar with video images. We also evaluated the system's effectiveness at identifying additional fish species.

Our objectives were: (1) to use video to check species composition; (2) to document lotic habitat and bathymetry of study site; and (3) to qualitatively evaluate underwater video as a tool to accomplish these tasks in a timely manner.

Study Area

The Chandalar River is a fifth-order tributary of the Yukon River. Draining roughly 21,000 km^2, the Chandalar flows 460 km from its headwaters in the Brooks Range to its confluence with the Yukon, located 1,630 km upriver from the Yukon River mouth in the Bering Sea. The study site was located 22 km upstream from the Yukon River confluence. Water visibility is highly variable, depending on rainfall. Precipitation ranges from 15 to 33 cm annually, with the majority falling between May and September. The river is typically ice-free from early June through late September. Water velocities are generally less than 0.75 m/s. Site locations were operational from August 8 through September 26.

River Profile and Split-Beam Sonar

Determining a site-specific river profile is essential before initiating sonar operations. Transducer beam selection and bottom anomalies that may allow fish to go undetected were determined from accurate river profiles and confirmed by scuba divers.

Transect markers were spaced along each bank at 15 m intervals. Transects were run perpendicular to river flow from each marker to the thalweg, keeping boat speed constant. Buoys were placed at known distances from shore and used as reference points when performing transects. Charts were redrawn, adjusting horizontal distances from buoy location data. These bathymetric maps were used to select the best beam fit and transducer deployment site for each bank (Figure 1).

A split-beam hydroacoustic system was used to enumerate upstream migrating fall chum salmon in the Chandalar River. Specific component descriptions and operations are detailed in HTI operational manuals (HTI 1994a, 1994b).

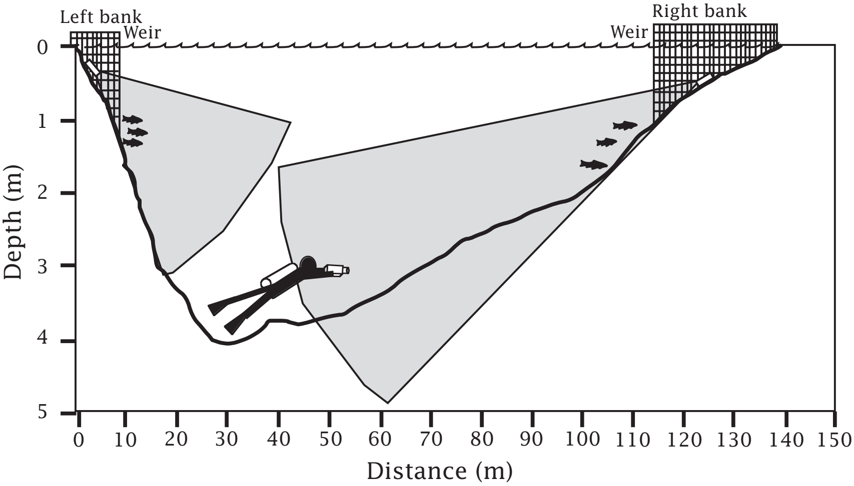

Figure 1. Chandalar River profile

Scuba and Underwater Video

Four underwater video cameras were deployed along the downstream edge of the ensonified zone produced by an elliptical-beam transducer. The array consisted of four 12 VDC underwater cameras with 0.01-lux sensitivity, a 3.6 mm lens, and 30 meters of cable. A 24-hour real time/48-hour time lapse VCR recorded the images. The cameras were mounted on an aluminum frame and secured in place by settling the frames down into the substrate to a depth of 0.6-1.5 m. Cameras were oriented perpendicular to river flow and aimed such that the field of view covered the downstream portion of the acoustic beam.

Divers were directed to position the cameras by shore personnel using audible signals. They moved across the bottom substrate in the current using a creeper. Targets were anchored on the river bottom and used to precisely aim the cameras. This was critical because most fish traveled close to the bottom. A small rise in vertical aim could allow fish to pass under the camera undetected. Placement is also important for the simultaneous comparison of acoustic target with video image (e.g. Enzenhofer et al. 1998). Visibility at the site tended to be low (~2 m), so a final check on the aiming was performed using the divers as reference targets on the sonar real-time display.

Conclusions

Several factors affected the performance of our video array, including low visibility and high water. During periods of extremely low visibility (<1 m), performance of the video dropped off, while divers were unable to enter the river at high water. Limitations of this setup were that we were unable to cover the entire sonar beam, only the front edge, and that video focused on the river bottom, while sonar encompassed more of the water column. Our system was useful during times of low fish passage rates but became less effective at higher fish densities due to low visibility in the Chandalar River. Based on this preliminary study, we determined that performance could be improved in future studies by increasing vertical and horizontal area covered by the video. In summary, although our underwater video array has some limitations, it can be used as a complementary tool to perform quality control for the sonar count.

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Investigation of the Overwintering of the Annual Macroalga *Nereocystis luetkeana* in Kachemak Bay, Alaska

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Introduction

Kelp forest communities are critical to the entire marine ecosystem because of their high primary and secondary productivity and their source as food and refuge to a wide variety of organisms. *Nereocystis luetkeana* is the major surface-canopy-forming kelp in Kachemak Bay and most of Alaska and British Columbia. This brown macrophyte is considered an annual because it produces only one stipe during its lifetime and cannot regrow tissue once the upper stipe is destroyed (Nicholson 1970). However, because specimens that mature late in the season may survive until the next spring, *Nereocystis* may be regarded as a "facultative biennial" (Foreman 1970). Among the several factors known to affect the dynamics of kelp communities, winter storms play a major role in the destruction of *Nereocystis* beds since they cause large numbers of specimens to become entangled and pull loose from their holdfast. With reduced numbers, remaining individuals then become more susceptible to sea urchin grazing (Dayton et al. 1992). Other physical factors that can affect kelp growth and survival include temperature, salinity, light attenuation, and scour (e.g., Dayton 1985).

The circumstances under which the annual *Nereocystis* survives through the winter are still unclear. The initial purpose of this study was to determine whether or not overwintering *Nereocystis* was present in

Kachemak Bay, Alaska. As *Nereocystis* was observed in March 2001 only at some of the sites that exhibited kelp beds in summer 2000, we focused our attention on possible explanations for the partial presence of overwintering *Nereocystis* within Kachemak Bay. Our ultimate objective was to measure the abundance of the principal herbivore, the green sea urchin *Strongylocentrotus droebachiensis,* and to characterize the hydrographic environment (temperature, salinity, light irradiance, and abrasion) at Gull Island, where kelp was observed, and at Archimandritof Shoals, where overwintering kelp was absent.

Methods

The study was conducted in March 2001 at Archimandritof Shoals and Gull Island within Kachemak Bay. These sites were chosen because kelp was observed at both locations in August 2000 (Figure 1). The presence or absence of overwintering *Nereocystis* was recorded during a visual survey conducted at low tide from a boat. Because young *Nereocystis* sporophytes appear on the seafloor in late spring in Alaska and usually don't reach the surface until early summer, any individual seen at the surface in mid-March can be assumed to be a survivor from the previous summer.

The densities of green sea urchins were estimated by counting the number of specimens found within five random 0.25 m^2 quadrats along three different transects at both sites. The three transects were laid at a depth of 6 m and all originated from a central buoy line. The direction and starting distance of each transect were determined by random compass bearings and distances from the centerline. The quadrats were laid at random distances along the right side of the transect tape. The final urchin densities were expressed as the number of individuals per square meter at each site.

Temperature and salinity readings were obtained using a portable meter (Yellow Springs Instruments). The probe was lowered from the side of the boat, and readings were taken every meter to a depth of 6 m.

Measurements of PAR (photosynthetically active radiations) were made using a spherical underwater quantum sensor (LI-COR, LI-193 SB). The light conditions at each site were characterized by calculating the fraction of quantum irradiance absorbed per meter of water, expressed both as the percentage of quantum lost through the water column and by the extinction coefficient (η). The extinction coefficient was calculated with the following formula: $\eta = [(\ln \text{quantum at the surface}) - (\ln \text{quantum at depth})] / \text{depth}$.

The abrasion factor due to water motion and suspended particles was quantitatively estimated by measuring the weight loss of clod cards submerged for two days at each site. Our procedure was based on that used by Konar (2000). Clod cards were made out of a mixture of plaster of Paris, water, and latex paint (8:3:1 ratio by volume) molded in ice cube trays. Each clod card was glued to a small sheet of plexiglass, cured in seawater

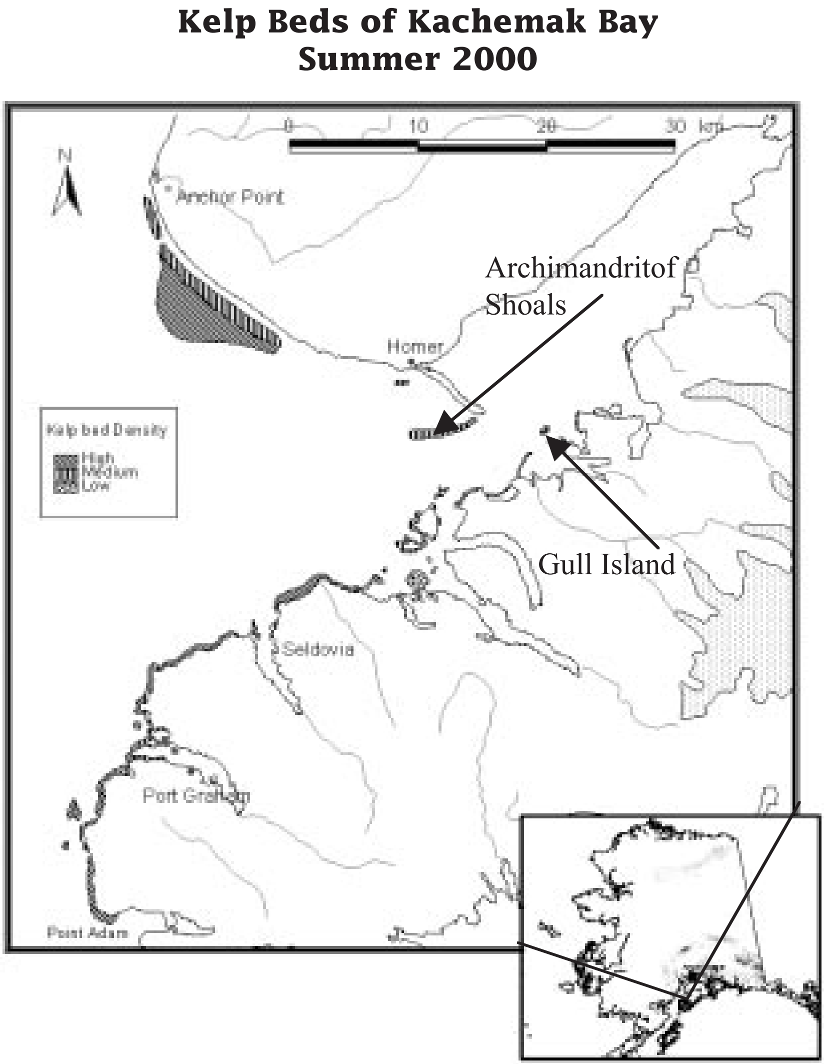

Figure 1. *Map of the Nereocystis kelp beds from aerial surveys in Kachemak Bay in August 2000 and of the two sites studied in March 2001.*

Table 1. Summary statistics for the different factors measured at Archimandritof Shoals and Gull Island, Kachemak Bay, Alaska.

	Shoals		Gull Island		
Factors	Mean	SD	Mean	SD	*t*-test
Nereocystis (# stipes)	1	–	30+	–	–
Strongylocentrotus density (per m^2) (n = 15)	57.1	27.3	0.3	1.0	1.3×10^{-6}
Temperature (Celsius degrees) (n = 6)	4.9	0.1	4.6	0.5	0.179
Salinity (ppt) (n = 6)	28.1	0.5	26.8	0.8	0.005
Extinction coefficient (η) (n = 1)	0.34	–	0.26	–	–
Light attenuation (%) (n = 1)	87.3	–	78.4	–	–
Abrasion (weight loss [g]) (n = 5 or 7)	2.0	0.4	1.6	0.1	0.059

overnight, and dried. At each site, seven clod cards were horizontally positioned on the seafloor and weighed down with rebar. After 48 hours, the clod cards were collected, gently rinsed with freshwater, and dried until a constant weight was recorded. The dry weight of each clod card was recorded before and after the submersion in the field. In order to control for the dissolution of the clod cards due to submersion in still, clear water, a set of seven controls was left in a tank of seawater for the same duration as for the *in situ* experiment. Weight loss caused by damage during handling and transport was also monitored by taking a set of clod cards in the field, down to the seafloor, and back to the laboratory. The mean weight lost due to dissolution or transport and handling damage was subtracted from the weight lost by the clod cards submerged at each site. The difference between the original weight and the final weight of each clod card from each site gives a relative estimate of the abrasion factor due to both water motion and suspended particles in the water column.

The different factors were compared between our two study sites by performing a student's *t*-test for a two-tailed distribution and samples of unequal variance.

Results

The results are summarized in Table 1. The visual surface observation from the boat revealed that overwintering *Nereocystis* was present at Gull Island but absent at the Shoals. A substantial number of individuals (30 +) were visible at Gull Island, whereas only one stipe was seen at the Shoals.

Urchin densities differed significantly between the two sites ($P = 1.3 \times 10^{-6}$). The density of *Strongylocentrotus droebachiensis* was 57.1 urchins/m^2 at the Shoals but only 0.3 urchin/m^2 at Gull Island.

The water temperature was similar at the two sites (4.9 and 4.6° C at the Shoals and Gull Island, respectively; $P = 0.179$) whereas the salinity was significantly greater at the Shoals than at Gull Island (28.1 and 26.8, respectively; $P = 0.005$).

The light conditions seemed different between both sites; however, due to time and weather constraints, light measurements were performed only once at each site and no statistics were calculated for this variable. The extinction coefficient was greater at the Shoals than at Gull Island (0.344 versus 0.256). At the Shoals 87.3% of the light that penetrated the surface was absorbed by the time it reached a depth of 6 m. In contrast, only 78.4% of the light was absorbed at the same depth at Gull Island.

The mean weight loss of the clod cards differed between the Shoals and Gull Island (2.0 and 1.6 g respectively; $P = 0.059$). No weight was lost due to dissolution but an average of 1.5 g was lost due to damage during transportation and handling and was subtracted from the weight loss of each clod card. Some of the clod cards were discarded since they came unglued from the plexiglass sheets. The final number of clod cards considered at each site was $n = 5$ at the Shoals and $n = 7$ at Gull Island.

Discussion

Overwintering beds of the annual kelp *Nereocystis luetkeana* are present in Kachemak Bay, Alaska. However, not all kelp beds established in summer 2000 survived the winter. The results of our study reveal that our two sites, Archimandritof Shoals and Gull Island, are significantly different with respect to grazing pressure, turbidity (light attenuation and scour), and salinity. The most dramatic disparity between the Shoals and Gull Island is the density of the green sea urchin, *Strongylocentrotus droebachiensis.* The high grazer abundance found at the Shoals is thought to be the major contributing factor in the disappearance of the *Nereocystis* at this site. Dayton et al. (1992) propose that the amount of kelp drift available to urchins decreases when kelp beds are thinned out by storms. The urchins are then forced to leave the crevices where they hide from predators in order to graze on remaining standing kelp stipes. High abundance of urchins can easily convert a weakened kelp bed into an urchin barren.

In addition, our hydrographic measurements suggest that the Shoals are characterized by higher light attenuation and greater abrasion than Gull Island. Those two physical factors are correlated to turbidity, which is known to be detrimental to kelp growth and survival (e.g., Dayton 1985). In contrast, because lower salinity, which could potentially have adverse effects on kelp (e.g., Dayton 1985), was found at Gull Island, and because similar temperatures were recorded at both sites, salinity and temperature are not believed to be determining factors for the absence of overwintering kelp at this site.

To conclude, because the difference in grazing pressure between our two study sites is so overwhelming, the role of turbidity (light attenuation and abrasion) in the presence/absence of overwintering *Nereocystis* appears only marginal in our study and cannot be confirmed at this time.

Measurement replication as well as greater numbers of transects and study sites are necessary to confirm our preliminary findings and establish a stronger correlation between these factors and kelp survivorship over the winter. It would be interesting to follow the evolution of the kelp bed at the Shoals in order to determine whether the occurrence of urchins at that site is an occasional anomaly and will prevent the kelp bed from establishing itself again in summer 2001 or whether this event is a recurring seasonal trend. In the latter case we would expect kelp to be present at the Shoals in the summer but to disappear again over next winter.

The present work is a preliminary study for a project that will investigate the role of various factors in the spatial distribution of kelp beds throughout Kachemak Bay. The overall dynamics of kelp forest communities is created by a complex interaction between large-scale oceanographic and physical processes, such as storms, hydrographic anomalies and climatic regime shifts, and local-scale biological processes such as predation and inter- and intra-competition (e.g., Foster and Schiel 1985). An advanced knowledge of how different factors affect the survival of annual kelp over the winter will further our understanding and improve the efficiency of management and protection of this coastal resource.

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West Florida Continental Shelf Diving and the ECOHAB-ONR-COMPS Monitoring Array

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This overview describes the accomplishments of the University of South Florida's Ocean Circulation Group (OCG) in the Gulf of Mexico using a variety of oceanographic and meteorological instrumentation and how critical diving is in this research. Heavily deployed in the Pacific Ocean as part of the Tropical Ocean Global Atmosphere project with National Oceanic and Atmospheric Administration (NOAA), OCG also began conducting science locally, on the west Florida continental shelf (WFS) just west of the USF campus. In cooperation with the U.S. Geological Service Center for Coastal Geology, an element of the West-Central Florida Coastal Studies Project, the West-Central Florida Shelf Hydrography and Circulation study was initiated in 1993. The goal was to provide an improved description and understanding of the relevant physical processes that control the shelf circulation and hydrography. This is the prerequisite to understanding the physical oceanographic impacts upon coastal oceans. AAUS divers play an important role in the collection of these data and the entire ECOHAB-ONR-COMPS monitoring array.

Understanding the circulation on the west Florida shelf is important for a variety of reasons. Knowledge of currents and sea level is necessary to monitor coastal erosion. This information can also be used for recreational and commercial navigation and for search and rescue operations. Similarly, prediction of the movements and dispersal of hazardous material spills is critically dependent on knowing the currents and how they respond to tides and winds. The interactions between the coastal waters and the offshore loop current in the Gulf of Mexico affect the distribution of biological and chemical properties that ultimately affect fisheries and red tides. Compared with other continental shelf regions, little is known about the west Florida shelf circulation.

The Ocean Circulation Group manages the *in situ* physical oceanographic measurements and modeling on the shelf. Funding comes from a variety of sources such as USGS, Minerals Management Service, NOAA, Office of Naval Research (ONR), the State of Florida, the Department of Environmental Protection, National Science Foundation, and others. After a series of projects on the WFS, the monitoring array has evolved into 13 moorings, six surface sites, and seven subsurface sites. All use acoustic Doppler current profilers (ADCPs) for water column measurements. Temperature and salinity recorders are spaced on the moorings as well as the bottom mounts. Four of the surface moorings measure surface meteorological parameters and telemeter data in real time. The most complete system provides surface meteorological sampling, water column currents, temperature, and salinity at six depths, all telemetered in near real time via the NOAA-GOES (Geostationary Operational Environmental Satellite) data collection system. Ongoing are an Ecology of Harmful Algal Blooms (ECOHAB) regional field study to advance our understanding and forecasting ability for red tides; ONR-supported *in situ* measurements and modeling; and a State of Florida–supported Coastal Ocean Monitoring Prediction System (COMPS) to provide real-time data for emergency management use.

A Comparison of Tethered Research Diving in Lake Hoare, Taylor Valley, Antarctica, Using a Surface-Supplied Air Source and Scuba

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Introduction

The McMurdo Dry Valleys are one of the coldest and driest deserts on Earth, yet almost paradoxically, large perennially ice-covered lakes persist. The dry valley ecosystem and these lakes are the focus of the National Science Foundation–funded McMurdo Dry Valleys Long Term Ecological Research (LTER) site. Our research diving program is in support of mainly benthic experiments for the LTER. All operations are conducted from a permanent field camp in Taylor Valley, Antarctica, which is approximately 130 km by helicopter from the main U.S. logistical base in Antarctica, McMurdo Station. During the summer research season (October to February), the sun is up 24 hours a day, temperatures range from –20° C to +5° C, and winds are usually moderate (up to 5 m/s).

This paper summarizes the methods and experiences of a limnology research team that conducted approximately 50 dives into a perennially ice-covered lake in Taylor Valley, Southern Victoria Land, Antarctica, during two Antarctic summers. During the 1998-1999 season we were diving in January using scuba. During the 2000-2001 season we were diving in December and used a surface-supply system.

Gaining Access

Before diving can commence, a hole must be made in the 4-6 m ice cover at the research site. The hole needs to be large enough for a fully suited diver to easily clear the hole, so that in an emergency he/she can be pulled back to the surface. We also ensure that there are no jagged edges in the hole where the line could get caught in an emergency. Through much experimentation in the past, we have found that the following procedure works best for making holes. We use a gas-powered auger to create a hole within about 0.5 m of the bottom of the 4 to 6 m ice cover. A "hot finger," created by pumping hot ethylene glycol through copper tubing wound around a 1.5 meter shaft, is lowered into the incomplete hole to melt the remaining ice and allow lake water to fill the hole. The "hot finger" creates a column of warm water that sits in the hole and melts the ice walls and expands the hole to a suitable size in one to three days. This procedure works best when the air temperatures are below 0° C. When temperatures are above 0° C, cold meltwater runoff on the ice surface flows into the hole, and because it is more dense than the warmed water in the hole, the heat energy is swept away and melting times are dramatically extended. For this reason, even if we are diving in January, we try to have holes made in October/November and kept open until our arrival.

Under Ice Diving

A hearty pioneer of dry valley diving stated "there is no way that one can adequately train and prepare for Antarctic research diving" (Simmons 1991, p. 31). AAUS guidelines now require Antarctic divers to have dry suit certifications, and there is some discussion for requiring a specified number of dry suit dives to be completed during the year preceding research in the Antarctic. In our experience, conventional ice diving techniques taught by reputable dive training organizations convey very little information that is useful in the dry valleys. Taken as a primer, such courses can introduce the diver to the considerations imposed by regulating body temperature in a cold environment, working in an overhead environment in reduced visibility, and working without being able to see the only exit to the surface.

Excellent dry suit skills are essential for work in this environment to avoid disturbing the fragile benthic community, which is the focus of our studies. Disturbance from diving is a major issue of concern among the science community (e.g. Kepner et al. 2000). Simmons (1991) reported in most cases his dive team "did not use fins, but relied on canvas boots and ankle weights." All of our divers used fins and some used ankle weights. Fin pivots using either one or two fins, and breath control, created the least impact while divers were working on the bottom. Controlled inflation of the dry suit was used to rise off the bottom, and divers would only move around laterally once a suitable distance from the bottom had been attained.

With one exception, all dives were planned to deploy a single diver. Continuing communications with the diver in the water is important. Electronic communications between the diver and the surface, as the AAUS requires, are far superior and allow the team to monitor diver safety, assist in problem solving, and log research data and observations communicated by the diver (AAUS 2001).

Problems of working in cold environments are not unique to the Antarctic. Modern dry suits coupled with suitable underwear provide good thermal protection for the body. The best thermal protection for the head seems to be provided by a bandmask For the research diver, preserving hand strength and dexterity in the 0° C to +2° C water is important. Gloves provide insulation but decrease sensation, strength, and dexterity. A balance is difficult, but a good dry glove system is essential.

The role of the fully suited backup diver may be the most difficult because he has the least thermal protection of any other member of the dive team. However, under the conditions in Taylor Valley, putting two divers in the water simultaneously is difficult and while conducting tethered diving a standby diver is a requirement (see AAUS 2001, section 9.45). Somers (1991) reported that “in more than 20 years of doing it [tethered diving], we have never had to deploy a standby.” During the approximately 50 dives we completed during these two seasons, we did not have any situation arise in which we even considered placing a rescue diver in the water. The key, in our minds, is to prepare a large hole for simple egress in an emergency and avoid multiple lines in the hole.

During approximately 50 dives, we experienced only one freeze-up in the dry suit inflator valve. None of the research divers chose to use a BCD (bouyancy compensation device) as part of the dive gear. This eliminated the need to vent two air sources and the possibility of a freeze-up in the venting valve. However, regulator free-flow events can have disastrous consequences and strict adherence to the rule is recommended. We experienced free-flow events without consequence, only because we stayed within our safety margins. Even with these precautions, strong consideration should be given to a completely redundant air supply when using scuba.

Comparison of Scuba and Surface-Supplied Air Systems

Scuba is simple, relatively portable, does not require extra training, and is low cost. The rule of thirds was used to manage air consumption. However, this requirement decreases dive times and requires more dives. Although free-flow events were low (<5%), they can have disastrous consequences and strict adherence to the rule is recommended. We experienced free-flow events without consequence, because we stayed within our safety margins. Even with these precautions, strong consideration should be given to a completely redundant air supply when using scuba.

Our move to a surface-supplied system in 2000-2001 was motivated by the risk of scuba free-flow events and was an unqualified success. We used an Amron console with a multihose umbilical which carried compressed air from two K cylinders, communications, and a pneumofathometer. The advantages of this system were: (1) "unlimited" air supply with reduced risk from free-flow (we returned to the surface in a free-flow event since experience from prior users advised that icings from prolonged free-flow could block air pathways), (2) the floating umbilical reduces the chance of it contacting the fragile benthic community, (3) a small bailout bottle means increased freedom of movement, (4) the system is apparently warmer, and (5) our dive times were 2-3 times longer, and we were able to comfortably move farther away from the hole. With regard to point 4, it has been reported that "surface-supplied air is warmer than the air from a scuba cylinder (Antarctic Support Associates 1998). We wondered whether the increase in warmth may be attributed to the increased insulation provided by the bandmask and some initial heating of the air as it contacts the face.

Disadvantages of surface-supply are: (1) less portability on the surface, (2) additional training needed, and (3) greater expense. Portability for us was not a great issue since we had to move our hole-melting equipment by helicopter anyway. The additional training was minimal and we feel the cost was far outweighed by our amplified productivity. In fact, we often found that our dive times were limited by the comfort of the people on the surface, rather than by anything to do with the diver. For this reason, in the future we will investigate better ways of providing shelter on the ice surface.

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Transplanting Giant Kelp *(Macrocystis pyrifera)* onto Artificial Reefs: The San Clemente Reef Mitigation Project

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Southern California Edison Co. (SCE) is required to build a 300 hectare (150 acre) artificial reef for the purpose of mitigating the impacts of the San Onofre Nuclear Generating Station on nearby kelp bed communities. One of the primary mitigation requirements is that the reef supports a stable population of moderate to high density of giant kelp *(Macrocystis pyrifera).* As an initial step in reef development, SCE constructed an experimental reef in fall 1999 to test several reef designs that are being considered for the larger mitigation effort (Deysher et al. 1998, in press). The experimental reef consists of 56 modules, each measuring approximately 40 × 40 m, which were placed on a sandy bottom at depths of 12 to 15 m off San Clemente, CA. Half the modules were constructed of quarry rock, the other half were constructed of waste concrete, and all were low relief (less than 1 m). In summer 2000, we transplanted juvenile giant kelp *(M. pyrifera)* onto 14 of these modules (seven quarry-rock and seven concrete) to test transplanting as a potential means of enhancing and maintaining moderate to high densities of kelp. In this paper we describe the diving techniques used in anchoring these plants onto concrete or rocks.

The kelp used in transplanting were initially reared in the laboratory using methods described in Foster et al. (1985) and then transplanted onto the reefs. Divers collected sporophylls (spore-bearing blades) from the base of adult kelp and brought these back to the laboratory. There, we released spores from the blades and inoculated 0.6 cm diameter ×10 cm long nylon lines with the spore solution. The lines were cultured in the laboratory for about three to five weeks until a dense culture of small kelp plants (about 1 mm to 5 mm in height) was visible. The lines were then taken to reef sites and anchored onto rocks or concrete.

The anchoring systems used to attach cultured lines to the rocks were put out in fall 1999 and winter 2000, shortly after the reef modules were installed. These were made of rectangular plastic plates measuring 10 cm ×2.5 cm ×0.7 cm. Two plastic cable ties were strung through holes in the plastic so that lines with small kelp plants could be attached to the plate. The plates were attached to the rocks or concrete as follows. First, one diver drilled holes in the rocks using a pneumatic drill run off of a compressor on the boat. A second diver followed and attached the plastic plates. A commercially available stainless steel anchor bolt with a nylon expansion sleeve was placed through a hole drilled into the plate and the bolt was hammered into the hole in the rock or concrete. Plastic tags were placed on the plates so that they could be more easily located when we were ready to transplant the kelp. A total of 60 anchors were placed on each reef module. The modules were placed along two permanent lead core transect lines stretched the length of the reef module and spaced about 15 m apart. Anchors were placed about 1 m on either side of the transect line at about 2.5 m intervals along the line.

Laboratory cultures were initiated in spring 2000, and transplanting was begun in June of that year. We took the lines with small plants from the laboratory culture, and divers placed one line on each of the anchors. Prior to entering the water, divers transferred lines onto small wooden racks (approximately 30 cm ×4 cm ×1 cm). Each rack had a strip of Velcro™ attached and was fitted with a short piece of fishing line and a small fishing weight. The nylon lines with plants attached were secured to Velcro™. This provided divers with a holder that could be placed on the bottom to free both hands for transplanting. The racks kept the lines with plants attached from being swept away by surge or being abraded by contact with the bottom, yet made pieces of line easy for divers to remove during the transplanting process.

On average, each diver was able to transplant 15 plants on a single dive of approximately 40 minutes. Conditions during the transplanting were often less than optimal, with visibility less than 2 m and moderate to strong surge. This made the process of locating anchors somewhat difficult at times, even though the anchors were tagged and laid out along transect lines. Once divers located anchors, they were able to quickly place the line with small kelp onto holders and then cinch down the cable ties.

The transplanting effort was completed in July 2000. A survey of the reefs in September and October 2000 indicated that approximately 90% of the lines that were put out had surviving plants on them, and most had at least one plant that was 40 cm or larger. By November of that year, many of the transplants were nearly a meter tall and had holdfasts (root-like structures) that had grown over the anchor plates and were attached to the rock or concrete. Surveys are continuing in order to track the growth and survival of these plants.

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El Niño 1997-1998: Scale-Dependent Patterns of Disturbance and Recovery on Giant Kelp Forests of the Northeast Pacific

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El Niños are large-scale, climatic anomalies that originate in the tropical Pacific and affect oceanographic and atmospheric conditions globally. Along the west coast of North America, where El Niños are characterized by abnormally warm water, low nutrient availability, and intense winter storm activity, they can have severe consequences to nearshore marine communities, especially subtidal kelp forests. Unlike most large-scale disturbances, however, El Niños may take a year or more to develop at mid- to high latitudes, making their impending arrival in the northern Pacific Ocean predictable months ahead of time. Here, I report the effects of the 1997-1998 El Niño on forests of giant kelp *(Macrocystis pyrifera)* in the northeast Pacific Ocean. I describe these impacts at five spatial scales spanning six orders of magnitude throughout giant kelp's geographic range in the Northern Hemisphere. I show that these impacts were strongly scale dependent and that the nature of this dependency differed between the disturbance itself and recovery from it. I then assess the relative importance of various factors associated with El Niño and factors separate from it in driving the observed patterns of giant kelp mortality and recovery.

Prior to the development of the El Niño, most of the total range-wide variability in giant kelp density (86%) was accounted for at the smallest spatial scale examined (among *transects*). This was not surprising given that such small-scale processes have previously been proposed as the most important factors structuring giant kelp communities in southern California during non–El Niño years. In contrast, very little of the total range-wide variability in giant kelp density (<3%) was accounted for at the largest scale examined (among *regions*), suggesting processes acting at very large scales were not as important in structuring these communities.

Following the El Niño (June 1998), however, differences among *regions* accounted for considerably more of the total variability (37% vs. 3%), than did differences among *areas* (19% vs. 5%). In contrast, differences among *transects* (44% vs. 86%), and differences among *locations* (0% vs. 6%) explained less of the total variability. Differences among *sites* remained unchanged (0%). More important, while variability among *regions* (independent of all other spatial scales) increased during this period (i.e., *regions* became more dissimilar), variability at each of the other spatial scales either decreased or did not change. Together, this identified *region* was the scale at which giant kelp populations were most affected during El Niño; prior to the El Niño, giant kelp densities were not significantly different among *regions* ($P = 0.217$) whereas differences were highly significant immediately following the El Niño (ANOVA: $P < 0.001$). Furthermore, among-*region* differences in adult mortality were striking; mortality was not significant in central California (~27%; $P > 0.99$), was significant in southern California (~88%; $P < 0.01$), and was highly significant in Baja California (>99%; $P < 0.01$).

The large among-*region* differences in adult mortality appeared to result from corresponding differences in El Niño-induced changes in ocean temperature (which is inversely related to nutrient concentration) and wave intensity. In central California, sea surface temperatures exceeded 16° C for only a brief (<2 week) period during El Niño and were not nutrient depleted. In contrast, sea surface temperatures exceeded 18° C for nearly a year (April 1997-March 1998) in both southern and Baja California and were highly nutrient depleted, suggesting giant kelp in these *regions* were nutrient starved during the El Niño. Consequently, when storm-driven waves impacted the west coast of North America between September 1997 and March 1998, the giant kelp in southern California and Baja California were presumably more easily removed than those in central California, and as a result, giant kelp survival was much lower than in central California. In sum, the combined effects of El Niño-induced changes in nutrient availability (i.e., ocean temperature) and wave intensity resulted in a near-to-complete loss of giant kelp populations throughout the southern two-thirds (approximately 1,000 km) of the species' range in the Northern Hemisphere, but only minor losses throughout the northern one-third of its range.

Following the El Niño, the west coast of North America was subjected to anomalously cold nutrient-rich ocean water during a strong La Niña event, enhancing giant kelp recovery. Recruitment was generally poor in central California, likely because seafloor light remained limited due to high adult survival. In contrast, recruitment in southern California was generally strong but variable at multiple spatial scales. Recruitment in Baja California was generally poor but also variable at multiple spatial scales, especially at the scale of *locations.* In sum, although the specific factors affecting recovery are not yet clearly understood, it is evident that the spatial patterns of giant kelp recovery following El Niño were very different from those of mortality during El Niño and thus controlled by factors operating at different spatial scales.

One year after El Niño, giant kelp populations had returned to pre–El Niño densities in central and southern California, but not in Baja California. This recovery once again redistributed the total range-wide variability in giant kelp density among the five spatial scales such that most (71%) was again accounted for at the smallest spatial scale examined *(transects)* while relatively little (9%) was accounted for at the largest scale examined *(regions).* This appeared to reflect a return to pre–El Niño conditions in that giant kelp density was largely under local control. A residual signal, however, was still evident at the *regional* scale (some populations at some *locations* in Baja California had still failed to recover even a year after the El Niño ended), demonstrating long-term, large-scale disturbance effects. Continued monitoring should further elucidate longer-term patterns of giant kelp recovery.

By studying El Niño's impacts on giant kelp populations at multiple spatial scales throughout the species' geographic range in the Northern Hemisphere, not only was I able to identify the scale at which El Niño-driven conditions affected these populations, but I also identified the scales at which these populations recovered. As a consequence, I was able to assess the nature and magnitude of El Niño's impacts on giant kelp populations, as well as evaluate the relative importance of various environmental factors, both associated with the El Niño and separate from it, in creating patterns of spatial variability in giant kelp populations. The principal impact of El Niño was to shift control of giant kelp abundance from processes acting at very small scales to processes acting at very large spatial scales. Recovery of giant kelp populations resulted in a shift back to local control within a year after the El Niño ended, although a residual large-scale signal was still evident. Studies done at only one or a few *locations, areas,* or *sites* would have easily failed to capture either the variation in, or the magnitude of, these impacts.

Red Sea Urchin Growth in Southeast Alaska

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Red sea urchin *(Strongylocentrotus franciscanus)* populations are assessed and studied in Southeast Alaska primarily through use of scuba. The Alaska Department of Fish and Game maintains an active dive program to monitor these and other invertebrate populations that are harvested by commercial divers. Development of guideline harvest levels, which are determined by the department, requires an understanding of key population parameters to allow for sustainable harvest. One of these important factors is red urchin growth rate. Using scuba we have been able to locate suitable sites and collect urchins for a PIT (passive integrated transponder) tag study to determine individual growth rates. The tagging procedure involves injecting an 11.5-mm PIT tag through the soft tissues surrounding the bony mouthparts that make up the Aristotle's lantern. A PIT tag scanner is then rapidly rotated about the urchin, which excites the tag circuitry by radio frequency induction and returns a unique code. Measurements of test diameter are recorded and the urchin is replaced by hand, using scuba, to a central point within the collection site. Since minimizing tagging and handling mortality is essential, divers must carefully handle urchins during the recovery and releasing phases. A typical day involves two or three divers collecting approximately 750 urchins during a period of two hours. Each urchin is hand picked, often with aid of a knife, and placed into a collection bag. After scanning and then PIT tagging about 250 urchins at the surface, divers replace the tagged urchins by descending with a seawater-filled plastic tote of urchins and gently returning them to their original location and position.

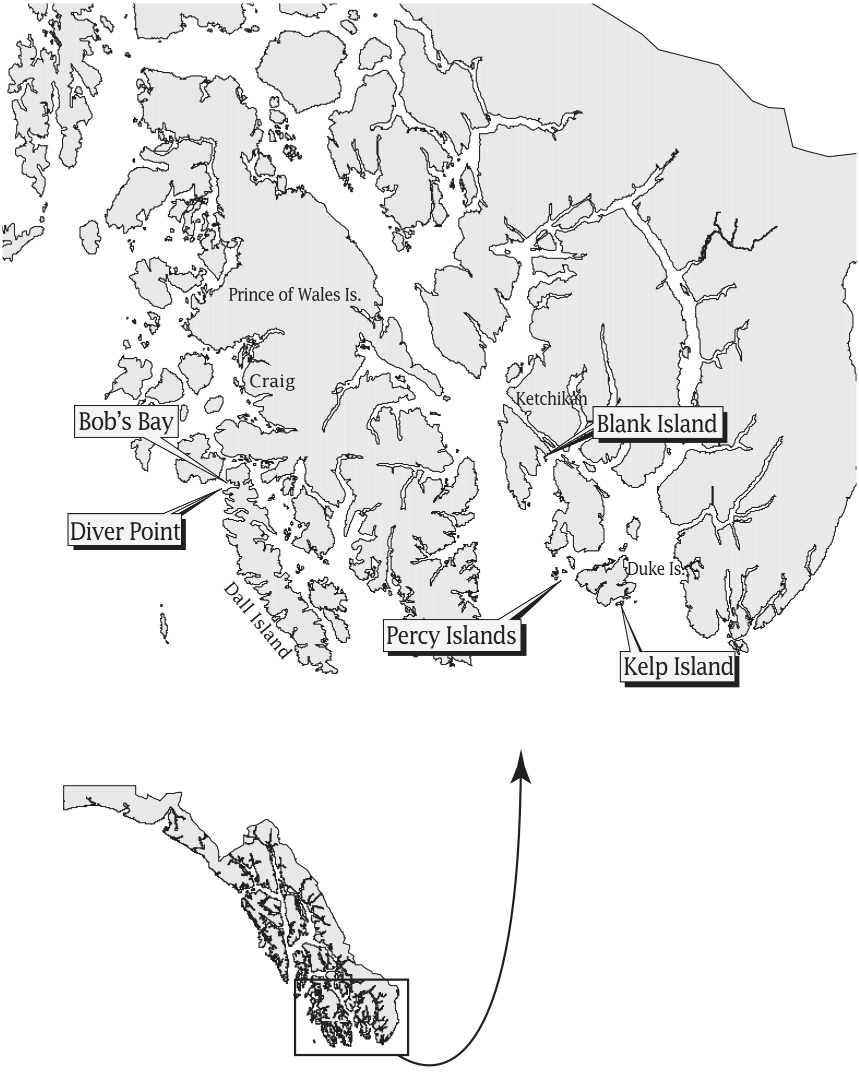

Figure 1. Map of Southeast Alaska showing red urchin PIT-tagging sites.

Five tagging sites have been selected in areas that represent a variety of habitats where red urchins support commercial harvest in southeast Alaska (Figure 1). Most tagging sites allow for diving in relatively protected waters; however, some sites present serious challenges and hazards to divers. The sites exposed to open water have very strong currents and

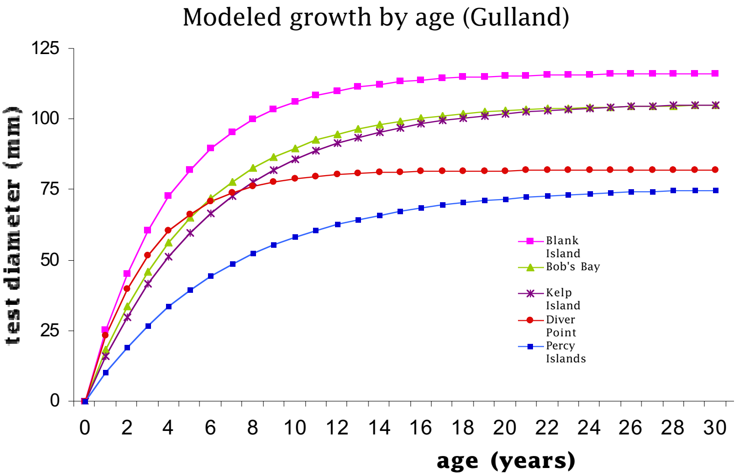

Figure 2. Red urchin growth using Gulland model at five sites in southeast Alaska.

ocean swell. Diving is conducted at depths between 3 and 9 m (10 and 30 feet), making collection very difficult and sometimes dangerous in these areas because of strong surge and presence of urchin spines. These exposed sites provide important data because they represent the most productive urchin populations, which contribute significantly to the commercial harvest.

During the years 1994-2000, a total of 4,146 red urchins were PIT-tagged and released at five locations. A total of 962 (23%) tags have been recaptured, including multiple recaptures. Red urchins are easy to tag, retain tags, and appear to recover well from tagging trauma, making them a good candidate for PIT tags for this type of study. Natural mortality is assumed to be minimal and fishing mortality is nonexistent; however, mortality from handling is unknown.

Comparison of several growth functions (e.g., Gulland, von Bertalanffy, Richards) indicates that typically red urchin growth is rapid during the first five years, slows between five and ten years, and gradually approaches an asymptote after ten years (Figure 2). Using Gulland's (1983) rearrangement of the von Bertalanffy model provides a difference equation, where the increment of growth from time t to time $t + 1$ is

$$\Delta D_t = (D_\infty - D_t)\,(1 - e^{-k})$$

where D_∞ is asymptotic test diameter, D_t is diameter at time t and k is the Brody growth parameter. The Bertalanffy model and variations are usually used for older age classes where the assumption of declining growth rate is valid and so these models do not adequately address growth in early

Table 1. Average annual growth in test diameter (millimeters) at five PIT-tagging sites in southeast Alaska.

Growth		Initial test diameter												
year	Tag site	10	20	30	40	50	60	70	80	90	100	110	120	130
1994-1995	Blank Island		19.9	18.1	12.6	12.6	10.8	7.7	6.9				4.9	3.9
1997-1998	Blank Island			21.2	21.6	19.6	11.8	8.5	7.5	6.9				
	Bob’s Bay			8.5	8.3	8.8	7.6	3.0						
1998-1999	Blank Island			15.2	13.7	12.2	9.3	6.8	5.5	1.8	4.5			
	Bob’s Bay			13.3	12.0	10.4	7.2	5.0	4.7	−1.0	4.1			
	Percy Islands			4.4	4.5	3.0	0.6	1.7	−1.1	−2.5				
1999-2000	Blank Island		11.6	15.2	7.7	9.6	6.3	4.3	2.9		−0.5			
	Bob’s Bay		9.5	8.1	11.2	12.1	7.9	6.3	4.6	2.3	−2.0			
	Percy Islands		13.2	8.1	8.1	6.9	3.9	3.0	0.5	1.3	1.6	2.0		
	Diver Point	14.0	18.0	13.0	12.0	6.9	3.1	2.3	0.0	1.0	−2.7			
	Kelp Island		10.5	10.8	9.3	11.2	8.2	3.6	2.2	1.5				

stages. Other models, for example Tanaka (1982), account for slow growth between larval and earliest years before rapid growth during juvenile years. This analysis is preliminary, and the final analysis will explore these models.

Generally, average growth rate is greatest among urchins in the 20-49 mm size range; however, growth rate usually peaks when urchins reach a diameter of 25-35 mm (Table 1). Growth patterns may differ dramatically among locations, with much slower growth occurring where urchins are exposed to strong currents and storm-induced wave action.

Mortality rate is a key component in the surplus production model used to determine urchin harvest levels in southeast Alaska and can be derived from estimates of growth rate. Preliminary analysis reveals a large variation of mortality rates among areas. Estimates of instantaneous rate of mortality produced by this study may potentially replace the value 0.16 currently used in the surplus production model. The current value was based on a small sample size and assumptions of growth rate using modes from size distribution data, rather than actual measurements of growth. This method, although practical, is subject to error in assumptions. Direct measurements of individual growth will provide a more realistic estimate of mortality and potential for annual yield.

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Scuba Techniques Used to Assess the Effects of the *Exxon Valdez* Oil Spill

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In March 1989, the T/V *Exxon Valdez* ran aground in Prince William Sound (PWS), Alaska, and spilled nearly 42 million liters of crude oil. About half of the oil became stranded on the shoreline, and an estimated 13% was deposited in subtidal sediments. Because the shallow subtidal regions of PWS are mosaics of habitats, from sheltered muddy bays dominated by eelgrass to exposed rocky points dominated by kelps, it was not feasible to assess the damage from the spill using standard shipboard sampling techniques. Instead, scuba techniques were implemented to assess damage and monitor recovery of subtidal communities. The *Exxon Valdez* Oil Spill (EVOS) Trustee Council sponsored two multi-year investigations that utilized research diving: (1) the effects of the spill on shallow subtidal communities (1989-95); and (2) mechanisms of impact and potential recovery of nearshore vertebrate predators following the spill (1995-99). The following is a synopsis of scuba techniques and methodologies used to assess and monitor the effects of the spill in the shallow (generally <20 m) subtidal regions of PWS (Table 1).

Table 1. Scuba sampling that occurred on two multi-year investigations relative to the *Exxon Valdez* oil spill.

Effects on Shallow Subtidal Communities (1989-1995)

Sample type	Scuba activity	Reference
Fishes	Counts by species and size groups in 1 ×30 m transects	Laur & Haldorson 1996; Dean et al. 2000a; Dean & Jewett, in press
Large epifauna	Counts by species in 1 ×30 m transects	Dean et al. 1996b; Dean & Jewett, in press
	Musculus mussels: experiments	Jewett et al. 1995
Infauna	Collect 0.1 m^2 quadrats to 10 cm deep via airlifts	Jewett et al. 1996; Jewett et al. 1999; Dean & Jewett, in press
Eelgrass	Count turions and flowering stalks in 0.25-m^2 quadrats	Jewett et al. 1997; Dean et al. 1998; Dean & Jewett, in press
Laminaria/Agarum	Percent cover in 0.25 m^2 quadrats	Dean et al. 1996a; Dean & Jewett, in press
	Determine growth	Jewett et al. 1995
Nereocystis	Count plants >2 m high in 4 ×30 m transects	Jewett et al. 1995
	Measure 20 stipe diameters 1 m off bottom in 4 ×30 m transects	

Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP) (1995-99)

Sample type	Scuba activity	Reference
Sea otter prey	Clams ≥ 20 mm: counts by species in 0.25 m^2 quadrats	Dean et al. in press; Fukuyama 2000 VanBlaricom et al. in press
	Crabs ≥ 50 mm CW: counts by species in 0.5 ×200 m transects	Dean et al. in press
	Sea urchins ≥ 15 mm diameter: counts in 0.5 ×200 m transects	Dean et al. 2000b; VanBlaricom et al. in press
Sea otter competitors	Collect data on density, diet, and activity of invertebrate predators	Gage 1998
River otter prey	Demersal fish counts by species and size groups in 1 ×30 m transects	Bowyer et al. in press
	Pelagic fish counts by species and size groups in 2 ×30 m transects	
Harlequin duck prey	Collect all small epifauna in 0.25 m^2 quadrats via airlifts	Esler et al. 2000
Pigeon guillemot prey	Count demersal fishes in 2 ×30 m transects	Golet et al. in press

Effects on Shallow Subtidal Communities (1989-1995)

Sampling Design and Methods

For most of our studies on the subtidal communities, we used a stratified random sampling design to determine the effects of the spill and monitor recovery. We measured population parameters (e.g., abundance, biomass, diversity, reproductive success) for the dominant plant, invertebrate, and fish species at both oiled and control sites. Five habitats were investigated in the Knight Island archipelago of western PWS: *Zostera marina* (eelgrass) beds, *Laminaria/Agarum* (brown algae) beds both in bays and on points, *Nereocystis* (brown alga) beds, and silled fjords. These habitats were defined with respect to dominant plants, physiography, and location within the sound to ensure that variance due to factors other than oil was minimized, thereby increasing the power to detect differences among oiled and control sites. *Zostera* dominates in areas of soft substrate that generally occur in back bays in the vicinity of mouths of streams. *Nereocystis* (bull kelp) dominates on points in more exposed areas with strong currents. While *Nereocystis* habitats are relatively rare in PWS, they represent habitats of special significance, with high diversities of algae, epifaunal invertebrates, and nondemersal fishes. Few (<6) silled fjords occur in the vicinity of Knight Island. Below the shallow zones of *Zostera* and *Laminaria/Agarum* in fjords, the substrate mainly consists of a dense layer of flocculent detritus over mud. The *Laminaria/Agarum* habitat is the most widely represented nearshore habitat in the sound.

Sites within habitats were initially chosen based on an overlay of oil information and habitat information on navigational charts. From those oiled areas for each habitat, a 200 m section of shoreline was selected for sampling. Control sites were selected that were indicated as not oiled in two earlier oil surveys. Controls were matched with selected oiled sites as closely as possible with regard to aspect, proximity to sources of freshwater input, slope, wave exposure, and water circulation.

The sampling effort within each habitat was stratified by depth. In the *Zostera* habitat, three strata were selected: 3-6 m, 6-20 m, and at the midpoint of the *Zostera* bed (generally <3 m) (Figure 1). In the *Laminaria/Agarum* habitats two strata were selected: 2-11 m and 11-20 m. The sampling stratum within the *Nereocystis* habitat was 2-8 m, the depth range for *Nereocystis.* Sampling in silled fjords occurred at 20 m depths. At each *Zostera* and *Laminaria/Agarum* site, we randomly established three 30 m transects within each depth stratum. Up to six transects per site were established in the *Nereocystis* habitat.

Fishes and large epifaunal invertebrates were counted along each 30 m transect. Two divers swam each transect and counted fishes and invertebrates by species within 1 m on either side of the transect line and within 3 m off the bottom. All observations were recorded on data sheets under water. Fishes mainly belonged to nine families. Large invertebrates were

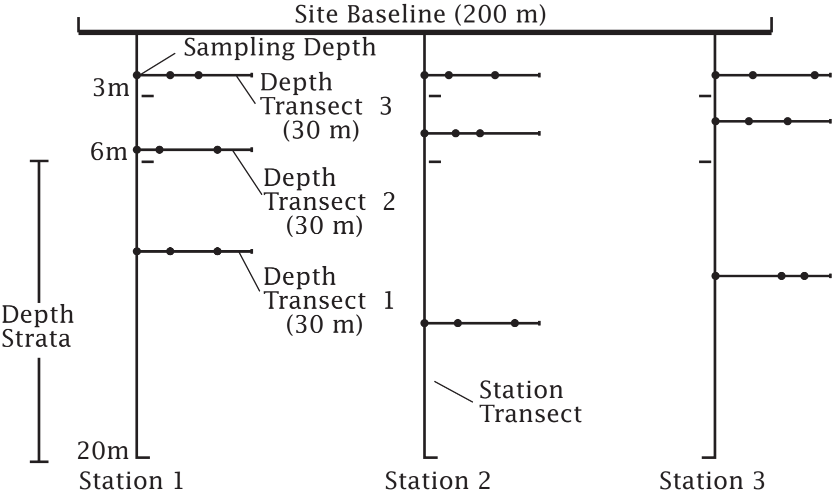

Figure 1. Hypothetical site layout for sampling in the eelgrass habitat.

mainly the helmet crab *(Telmessus cheiragonus)* and five species of sea stars.

Four 0.25 m^2 quadrats were randomly placed along each transect to assess *Zostera* or algae. *Zostera* turions (above-sediment portions of the plant arising from the rhizome, usually with four or five leaves attached) and flowering stalks were counted, with slight modifications in technique from year to year. The percent cover of understory algae, mainly *Laminaria/Agarum,* was determined for each quadrat. All algae greater than 10 cm in height were collected from the quadrats and returned to the boat where each individual was identified, weighed, and measured. *Nereocystis* density was determined by counting all plants greater than 2 m in height within a 4 m swath along transects. The size distribution of *Nereocystis* was determined by measuring the diameter of the stipe, at a distance 1 m above the bottom, for the first 20 plants observed along each transect. The relationship between stipe diameter and total wet weight was determined by weighing and measuring the stipe diameter of each plant from 20 to 40 plants collected from each site. The analysis of these data indicated that stipe diameter was an excellent predictor of weight.

Infaunal invertebrates in *Zostera* and *Laminaria/Agarum* habitats were collected from two 0.1 m^2 quadrats randomly placed along each 30 m transect. Samples were collected to 10 cm sediment depths by divers using a suction dredge. In the *Zostera* bed, eelgrass shoots were cut off above the sediment surface and removed prior to taking the suction dredge samples. The dredge sampler was fitted with a collection bag with a mesh size of 1 mm.

Divers also collected two sediment samples from each transect. One of the samples was used to determine sediment grain-size composition and the other to determine hydrocarbon concentrations.

Determining Growth Rates of Seive Kelp Agarum clathratum (Jewett et al. 1995)

The growth rate of *Agarum* was determined at two pairs of oiled and control sites in the summer of 1990. At a depth of 8 m at each site, 20 plants between 50 and 100 cm in height were selected. All plants were within two 2 ×30 m swaths and were separated by 1 to 2 m. Each plant was marked by driving a steel spike, with a numbered plastic tag attached, into the seafloor next to each plant. A small piece of plastic surveyors flashing was placed through a hole near the midrib at a height approximately 10 cm above the juncture of the holdfast and the blade. We then measured and recorded this distance. Surrounding plants within a radius of about 1 m were removed in order to eliminate potential competition. After a period of 41 to 57 days, the stations were revisited and the distance from the bottom of the blades to the tag was remeasured and recorded. The growth of each plant was calculated as the change in distance from the base of the blade to the tag over the 41 to 57 days. All measurements were standardized to the growth (in cm) per 30 days.

Experimental Studies with the Mussel Musculus (Jewett et al. 1995)

Experiments were conducted in Herring Bay in 1993 to examine the effects of *Musculus* spp. on *Zostera* and to examine the effects of predation on the distribution and abundance of *Musculus.* Studies in 1990 demonstrated that *Musculus* was more abundant at oiled sites, *Zostera* was more abundant at control sites, and that potential predators of *Musculus* were more abundant at control sites. We hypothesized that densities of *Musculus* were higher at oiled sites because abundances of predators (especially the crab *Telmessus* and the sea star *Dermasterias*) were lower there, and that higher densities of *Musculus* at oiled sites led to a reduction in *Zostera* density.

The first experiment was designed to test the hypothesis that *Musculus* inhibited the growth of *Zostera.* Ten 1 m^2 plots were established within the *Zostera* bed at Herring Bay, where densities of *Musculus* averaged about 40,000 m^2. The plots were placed about 2 m apart along two 20 m long lines laid within the *Zostera* bed. All *Musculus* were removed from 5 randomly selected plots. Divers gently rubbed the blades of the *Zostera* and then collected the mussels using an airlift. The remaining five plots served as unmanipulated controls.

The initial removal was conducted on 17 and 18 July 1993. Approximately two months later, we revisited the site and collected all of the *Zostera* blades within a 0.25 m^2 area within each plot. After collection, we counted the number of *Zostera* turions and the number of *Musculus* on the *Zostera.*

A second experiment was conducted to test the hypothesis that the abundance of *Musculus* could be locally limited by predation, especially predation from the crab, *Telmessus,* and from the sea star, *Dermasterias.* Two 30 m long transect lines were established within the *Zostera* bed at Herring Bay. A total of 10 1 m diameter plots were established at equal distances along each line. The plots were randomly assigned one of five treatments: predator exclusion (caged), *Dermasterias* inclusion (caged with a *Dermasterias* enclosed), *Telmessus* inclusion (caged with a *Telmessus* enclosed), cage control (a partial cage), and a control (no cage). The cages used were 1 m in diameter hoop nets that were approximately 1 m tall and were constructed with 2.5 cm mesh nylon netting. The bottom hoop of each cage was secured to the bottom using U-shaped steel reenforcement bar "staples." The net was maintained in an upright position by placing small fish-net floats on the upper two rings of the hoop net. The cage control consisted of a cage, but with one-half of the netting of the hoop cut out. The netting was removed such that there were two panels of netting separated by two areas where the netting was removed.

Telmessus and *Dermasterias* were collected by hand from the surrounding areas within Herring Bay and one animal each was placed in their respective cages. The *Telmessus* were approximately 8 cm in carapace width and the *Dermasterias* were about 15 cm from ray tip to ray tip. The animals were placed into cages on 18 July 1993. Approximately two months later, on 26 September 1993, the site was revisited and all *Zostera* within each cage were sampled by divers and placed into a small mesh bag under water. Care was taken to place the *Zostera* blades into the bags without dislodging any *Musculus* that may have been attached. The samples were preserved in formalin and later the number of *Zostera* blades and *Musculus* in each sample were counted.

Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP) (1995-1999)

Scuba was used to assess several factors potentially constraining the recovery of four nearshore vertebrate predators—sea otters, river otters, harlequin ducks, and pigeon guillemots—"injured" by the EVOS. Prey groups of these predators were examined from oiled and unoiled locations. The oiled area was along northern Knight Island, at Herring Bay, and Bay of Isles. The unoiled area was along the northwestern Montague Island. Within each study area, potential sampling sites were chosen by selecting a random starting point, then systematically dividing the shoreline into sequential intervals of 600 m length throughout the rest of the study area. Sampling segments were chosen at regular intervals, beginning at the random starting point. Sampling by divers occurred along 200 m shoreline segments within selected sites.

Sampling Sea Otter Prey (Dean et al. 2000b, Dean et al. in press, Fukuyama 2000, VanBlaricom et al. in press)

Three sea otter subtidal prey categories (clams, crabs, and sea urchin) were targeted in the NVP study. Emphasis was placed on prey sizes typically taken by otters, i.e., clams ≥20 mm, crabs ≥50 mm carapace width, and urchins ≥15 mm diameter. Clams were sampled within a randomly chosen subset of the 200 m segments selected for intertidal sampling. Two depth strata (10 and 20 m) were sampled at each site using a Venturi suction dredge. The dredge hose and nozzle were dropped in the appropriate depth stratum at each site and a 15 m transect tape was laid on the bottom substratum along the depth contour, beginning where the nozzle came to rest on the seafloor. A steel quadrat frame of 0.5 ×0.5 m was placed along the transect tape at a random starting point with the first 3 m of the tape. Three to five replicate quadrats 3 m apart were dredged, generally to about 0.5 m. All clams excavated by the dredge were collected and placed into mesh bags.

Crabs, mainly *Telmessus,* and sea urchins were sampled within two depth strata, 0-5 m and 5-10 m, since previous information indicated *Telmessus* and urchins were mainly found at these depths. The sampling depths at each site were randomly selected within each depth stratum. Transects were 0.5 m in width and 200 m in length, running parallel to shoreline. Divers swam along transects and collected all crabs and urchins. All crabs and the first 100 urchins encountered at each site were measured for length-frequency distributions.

Sampling Sea Otter Prey Competitors (Gage 1998)

Scuba sampling in this component of the NVP study was designed to test the hypothesis that high rates of clam consumption by predatory invertebrates were limiting the size of clam populations in oiled areas, and consequently, the local recovery of sea otters from EVOS. Subtidal sampling of invertebrate predators in summer and winter was conducted adjacent to randomly selected 200 m transects from oiled (Herring Bay and Bay of Isles) and unoiled (northwest Montague Island) areas. Depths sampled were 4, 7, and 10 m. A buoy line was dropped to locate the starting point at 4 m in depth. Divers laid out a transect tape perpendicular to shore, from 4 m to 10 m in depth. This line is referred to as the "mainline." A depth of 7 m was marked on the mainline as it was laid out. Divers determined 7 m and 10 m in depth using depth gauges. Transect lines were set out perpendicular to the mainline extending 10 m in either direction at 4, 7, and 10 m. Transects followed the depth contours. Invertebrate predators located within 1 m either side of the transect line were sampled. The sampled plots were 40 m^2 in area for each depth.

Divers recorded substrate type and temperature, and water samples were collected for salinity determination. Divers recorded observed activity and invertebrate predator species (snails, crabs, and sea stars) on underwater data sheets. Activity was categorized as digging, feeding, having an extended stomach (for sea stars), escaping (for crabs), inactive, or moving. Diets were recorded during sampling dives for all invertebrate predators that were observed actively feeding in the sampling plots. Additional diet determinations were made at the surface and in the laboratory. All specimens were measured at the surface.

Sampling River Otter Subtidal Prey (Bowyer et al. in press)

Nearshore demersal fishes were sampled at 30 latrine sites used by river otters for both Herring and Jackpot bays in July 1996-1997, as well as 30 random sites at each location in both years. Demersal fishes were counted along two transects oriented perpendicular to shore by two scuba divers. Transects extended 30 m, or in instances where the tidal zone was steep, until a depth of 15 m was reached. The two transects at each site were separated by 20 m and originated 10 m to either side of the center of a particular site. Fishes in the water column were counted over a 2 m wide swath. Demersal fishes were counted along a 1 m wide swath on each transect while gently moving aside algae and other vegetation. All fishes counted were classified into three size classes (<8 cm, 8-15 cm, >15 cm total length) and were identified to family.

Divers also conducted a fish removal experiment (see Blundell et al. 2001, this volume).

Sampling Harlequin Duck Prey (Esler et al. 2000)

Sampling for harlequin duck subtidal foods was conducted beside 23 200 m shoreline sites. Samples (0.25 m^2 quadrat) were obtained at three locations at each of two depths (0.5 to –0.5 m and –0.5 to –1.5 m MLLW) (mean lower low water) along each of the 200 m shoreline sites. At each quadrat, divers collected and bagged all algae or eelgrass and scraped all visible epifauna from the substrate and airlifted them into a mesh bag. Epifauna were later scraped from algae and eelgrass, combined with epifauna from substrate, sorted, and identified to seven prey types (limpets, chitons, lacunid snails, littorine snails, other snails, amphipods, and other crustaceans).

Sampling Pigeon Guillemot Prey (Golet et al. in press)

Dive transects were performed at guillemot foraging areas near the study colonies. Demersal fish population densities were established in 1996 and 1997. A total of 60 sites were surveyed (15 per area-year). Sites were systematically selected within a 4 km radius of major guillemot nesting areas. At each site, we counted demersal fishes along two transects running perpendicular to shore. Transects extended a distance of 30 m, or in cases where the shoreline was steep, until a depth of 15 m was attained. The two transects at each site were separated by 20 m and originated 10 m to either side of the center of the site. Demersal fishes were counted along a 1 m wide swath on each transect while moving aside algae and other vegetation. All fishes <15 cm were identified to family, and classified as one of two size classes (1-8 cm and 8-15 cm). For comparison purposes the average density (fish per 100 m^2) was calculated for each fish family in each area.

Research Diving Statistics

In the 10-year period (1989-1998) of research diving on the two multiyear EVOS projects, 26 divers made 4,315 dives for approximately 2,068 hours of bottom time. Only one diving incident occurred: a Type I DCS in 1991. This diver was treated on a Navy Table 6 and was cleared to resume diving following a two-week suspension of diving.

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Underwater Capture of Juvenile Steller Sea Lions with Scuba: A Narrated Video Presentation

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The western population of Steller sea lions *(Eumetopias jubatus)* in Alaska declined by approximately 85% over the past 30 years and is classified as "endangered" under the U.S. Endangered Species Act. Data collected during the 1980s strongly suggested that nutritional stress played a role in the declining population (Calkins et al. 1998, Pitcher et al. 1998). Studies conducted during the mid-1990s suggested that reproductive females and young pups were in "good" nutritional status, and analyses by York (1994) suggested that low survival of juveniles contributed to the declining population. Because of these findings, it was decided that studies on health and nutritional status of juvenile sea lions were of high priority. However, traditional methods of capture such as darting with immobilizing drugs were inefficient for juvenile sea lions and new capture techniques were needed.

Shane Moore, a noted underwater photographer, suggested that juvenile Steller sea lions could somehow be captured under water using scuba because they often appeared to be attracted to divers and interacted closely with them. Divers with the Steller sea lion project of the Alaska Department of Fish and Game began diving with sea lions and confirmed Shane's observations that juvenile animals often closely approached divers and sometimes interacted with the divers, at times mouthing fins, hoods, and gloves. Adult animals appeared more wary and normally did not approach closely. Our experiences as well as discussions with other divers and a search of the literature suggested that diving with Steller sea lions was relatively safe. We were unable to document instances of serious injury or death to divers caused by Steller sea lions, although many divers felt intimidated by the close approach or contact with sea lions under water.

After many discussions and trials we focused on development of a noosing technique. A two-person dive team enters the water near a group of juvenile sea lions in the water, usually near a haulout. The divers settle on the bottom and young sea lions are enticed to stick their heads through a noose held on a short, maneuverable aluminum rod by baiting with a herring attached to another similar rod. The noose is fitted with a stop to prevent the noose from tightening to the point of strangling the animal and a lock to prevent the noose from loosening and releasing the animal. The noose is attached to a 15 m length of light, stiff rope with an inflated buoy on the other end. This limits the working depth to about 12 m. When the sea lion reaches through the noose to grasp the herring with its mouth, the noose is tightened around its neck and the line is then released by the diver. The divers then surface and a crew in a capture skiff retrieves the buoy and places the noosed sea lion into a restraint box in the skiff. The skiff delivers the captured sea lion to a research vessel where it is moved into a field laboratory, placed on gas anesthesia, and processed. Procedures performed include weighing, measuring, obtaining a variety of samples for heath and condition evaluation, and attaching telemetry devices for tracking and dive performance. The animal is returned to the sea after recovery from anesthesia.

As of 1 May 2001, 171 juvenile sea lions ranging from two months to three years of age have been restrained using this technique. No animals have been killed or seriously injured during the capture process. One animal died from an anesthesia-related accident.

We are continually refining the capture and handling processes to improve our efficiency and to increase safety for both the sea lions and capture personnel. Our greatest concerns for diver safety are entanglement in the capture line after an animal has been noosed and barotrauma injury. We have made several modifications to reduce the probability of entanglement, including using floating line to keep the capture line above the divers and streamlining dive gear to reduce the probability of entanglement. We have also made improvements in the equipment and procedures used to load sea lions into the capture skiff to reduce the probability of injury to both sea lions and personnel.

In order to extend this technique as a research tool we are cautiously pushing the envelope as far as size of animals we are attempting to capture and the geographic areas and water conditions where we are working. To do this safely and effectively we are obtaining advanced dive training and evaluating the use of such technologies as nitrox, full-face masks, dry suit insulation enhancements, underwater communication, and rebreathers.

We acknowledge the contributions of many colleagues in the development and utilization of this technique and particularly would like to recognize Walt Cunningham (now deceased). Walt was a key team member during the early development of the underwater capture technique who persevered despite tremendous skepticism, bureaucratic hurdles, and early disappointments.

Development of this technique and all captures have been conducted under authorization of Marine Mammal Act and Endangered Species Act permits issued by the National Marine Fisheries Service Office of Protected Resources. All diving has been conducted within the guidelines of the Alaska Department of Fish and Game Scientific Dive Safety Program.

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Photosynthetic Response of Arctic Kelp Forests to Stratospheric Ozone Depletion

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Exposure of marine organisms to increased levels of ultraviolet radiation (UVR) has increased dramatically as a result of stratospheric ozone depletion over the last two decades. Ozone losses are most pronounced over Antarctica, but ozone depletion has steadily increased over the Arctic Ocean throughout the 1990s. Episodes of ozone depletion have reached nearly 40% in the Arctic polar vortex, allowing for a 4-7% increase in ultraviolet radiation incident in the Northern Hemisphere (Madronich et al. 1998, Hansen and Chipperfield 1999).

Penetration of short-wavelength radiation into arctic ecosystems may result in annual declines in marine productivity. In contrast to antarctic seas, kelp beds are significant carbon sources in arctic shelf ecosystems. Kelp productivity rates in the Arctic approach 75 g C m^{-2} yr^{-1}, nearly doubling phytoplankton primary production in coastal waters (Chapman and Lindley 1981, Dunton and Schell 1986, Dunton and Dayton 1995). Short-term *in situ* inhibition of photosynthesis in response to UVR has been documented for kelp (Hanelt et al. 1997, Bischof et al. 2000, Dunton et al. in prep.), and physiological targets of UVR damage are becoming more lucid (Renger et al. 1989, Babu et al. 1999, Vincent and Neale 2000). Nevertheless, to answer whether increased UVR will result in decreased kelp production, researchers must consider production integrated throughout the depth range of the algal species.

Unlike vertically mixed pelagic communities, attached algae are permanently restricted in their light habitat. Increased particulate and dissolved matter typical in coastal waters decreases UVR penetration in the water column more rapidly than broadband (400-700 nm) photosynthetically active radiation (PAR) (Smith and Baker 1979). As a result, kelp in the lower intertidal receive saturating PAR irradiance but production is constrained by greater UVR exposure. Kelp deeper in the water column receive shorter periods of saturating PAR but are less UVR inhibited than near-surface kelp. Thus, algal production is depth dependent and reflects both stimulating and inhibiting functions of full spectrum solar irradiance. UVR induced photoinhibition is best described with a biological weighting function (BWF), or inhibition action spectrum for UVR. The BWF provides a continuous measure of UV photoinhibition as a function of wavelength which can be applied to kelp with different light histories (Cullen et al. 1992, Cullen and Neale 1997, Neale 2000).

Benthic kelp communities in northern Norway are particularly susceptible to heightened incident UVR in years of severe ozone loss (e.g., 200 Dobson units [D.U.]). In winter-spring 1996-1997, the edge of the polar vortex was situated over northern Scandinavia for sustained periods (Hansen and Chipperfield 1999). In the same year, 40% ozone depletion occurred in April and May, up from 32% in the polar vortex in 1995 (Goutail et al. 1999, Hansen and Chipperfield 1999). Kelp populations from subarctic Norway (north of Ålesund) were chosen for study because of the proximity of the spring ozone hole and the kelp's exceptional productivity along the Atlantic coast. Warmer seawater temperatures along Norwegian coastlines impede winter ice formation. Without winter ice scour, kelp grow higher into the lower intertidal and have greater potential for UVR exposure. The relatively warm waters of coastal Norway also result in extremely productive kelp beds throughout the various coastal islands and fjords. Dense forests of the kelp, *Laminaria hyperborea,* create extensive underwater canopy structure. Norwegian *L. hyperborea* beds produce standing crops approaching 40 kg wet weight m^{-2} (Sjøtun et al. 1995). Kelp carbon flows to higher trophic levels via both herbivorous and detrital (particularly microbial) consumers (Dunton and Schell 1987, Duggins et al. 1989). Consequences of decreased kelp production include interruption of carbon flow between trophic levels, changes in food web structure, losses of essential nursery habitat for fisheries, and decreases in commercial kelp harvests (Sjøtun et al. 1995, Christie et al. 1998, Fredriksen in prep.). Further, long-term deterioration of carbon produced by kelp and other oceanic producers would influence larger scale global carbon cycles by reducing sink capacity for atmospheric carbon dioxide (Falkowski et al. 1998, Joos et al. 1999).

The principal objective of our research was to estimate total carbon production of a Norwegian kelp forest under potential ozone depletion scenarios. A depth-integrated primary production model was formulated for *Laminaria hyperborea,* which incorporates full spectrum responses of photosynthesis to both PAR and to UVR inhibition. This model will provide a basic framework for predicting whole population production under different column ozone concentrations. The project was completed in two phases. The first phase quantified the principal photosynthetic and incident solar radiation variables of the production model. *In situ* measurements

Table 1. Experimentally measured input variables into the depth integrated primary production model.

Symbol	meaning	Units	Comments
Light			
E_{PAR}	Solar irradiance at PAR wavelengths (400–700 nm)	µmol photons m^{-2} s^{-1}	Measured at site with LI-COR terrestrial sensors; data can also be estimated from solar models (Cullen, unpubl.).
$E_{UV}(\lambda)$	Wavelength specific irradiance at surface (UV only).	mW m^{-2}	Measured at site with the SR-18 terrestrial radiometer; data can also be estimated from solar models.
k_{PAR}	PAR attenuation coefficient	m^{-1}	Calculated at site from E_{PAR} and $E_{PAR.z}$. Values can be estimated from attenuation coefficients determined from Jerlov's water-type attenuation models.
$k_{UV}(\lambda)$	Wavelength specific attenuation coefficient (UV only)	m^{-1}	Calculated from $E_{UV}(\lambda)$ and UV attenuation models. UVB wavelengths calculated from PUV-500 water column profiles.
$E_{PAR.z}$	PAR irradiance at depth	µmol photons m^{-2} s^{-1}	Measured at site with spherical 4π LI-COR sensors. Values can be estimated from attenuation coefficients determined from water-type attenuation models.
$E_{UV.z}(\lambda)$	Wavelength specific irradiance at depth	mW m^{-2}	Calculated from $E_{UV}(\lambda)$ and $k_{UV}(\lambda)$. UVB determined directly from PUV-500 profiles.
Production			
P*	Daily depth integrated production	mg C m^{-2} day^{-1}	End result calculated from model, couples P_z, H^*_{inh} and biomass at depth. Sum P* equals depth integrated production.
P_z	Photosynthetic yield at depth	µg C mg dry wt^{-1} hr^{-1}	P vs. I result.
P_{max}	Photosynthesis at PAR saturation	µg C mg dry wt^{-1} hr^{-1}	P vs. I parameter determined at site for kelp collected at depth intervals.
E_k	Saturation parameter of photosynthesis	µmol photons m^{-2} s^{-1}	P vs. I parameter determined at site for kelp collected at depth intervals.
E_c	Light compensation point	µmol photons m^{-2} s^{-1}	P vs. I parameter determined at site for kelp collected at depth intervals.

Table 1. (continued)

BWF			
E^*_{inh}	Biologically weighted irradiance	dimensionless	Calculated from model.
τ	iteration time	min	1 min intervals of daily light cycle (multiplied by 60 to sum for each second) — model parameter.
$e_H(\lambda)$	Biological weighting coefficient for radiant exposure	$(mW\ m^{-2})^{-1}$	Determined at SERC for each species at each depth interval.
Other			
B_z	Biomass	kg wet wt m^{-2}	Optimally determined at site, otherwise estimated from literature values.
c	Dry wt to wet wt ratio	%	Measured at site.
z	Depth range	m	Determined on site.

mW = milliwatt

were completed during three field excursions to kelp forests adjacent to the Island of Finnøy, Norway. The second phase involves the synthesis of a computer production model from *in situ* data for sensitivity analyses under current and predicted ozone quantities.

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A Year in the Life of a Piling: Recruitment of King Crabs and Other Fauna to Dock Pilings

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Previous observations suggest that juvenile king crabs use wooden dock pilings as habitat structure. In order to test that hypothesis, six structures were constructed from spruce pilings and placed in pairs at three different locations. NMFS divers conducted a year-long study of faunal recruitment by making quarterly visits to count organisms on the pilings and adjacent seafloor areas. Seafloor counts were made by two divers carrying 1 m wands on each side of a measured transect line.

Problems included being harassed by sea lions. Abundance of juvenile (age 0 to 1+) king crabs was significantly higher on pilings than on adjacent bottom, was significantly higher at one exposed site than at the other (more sheltered) sites, and increased steadily over the year, as crabs recruited to the structures. There was no difference between the paired structures at each site.

Development of Virtual Field Trips/Site Briefings for the Internet

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The development of instructional materials for education and science has benefited from recent technical advances. In particular, the advent of digital video and still cameras, the development of user-friendly video and still editing and web page production software, and faster computers and internet connections have facilitated the production and delivery of customized instructional materials via the Internet. These materials can provide orientation information for scientists before they visit a new research site or employ a new technique. Alternatively, these instructional materials can provide non-divers with a flavor for the experiences that they would gain if they were to visit a specific site (a virtual field trip).

I am developing a series of virtual field trips to expose students to the biology of species and communities that they cannot visit because of financial, time, or training constraints. The target audience includes juniors enrolled in Introduction to Marine Biology and seniors and graduate students enrolled in Ichthyology. These virtual field trips include (1) offshore rocky and artificial reefs, (2) open water and *Sargassum* mats in the Gulf Stream, (3) sand beaches and offshore flats, (4) eelgrass beds, (5) kelp forests, and (6) temperate rocky intertidal. The first four focus on marine communities off the North Carolina coast, the last two from the Pacific Northwest. The students should feel that they are swimming through a kelp forest or following a spotted pinfish as it searches for food around a shipwreck.

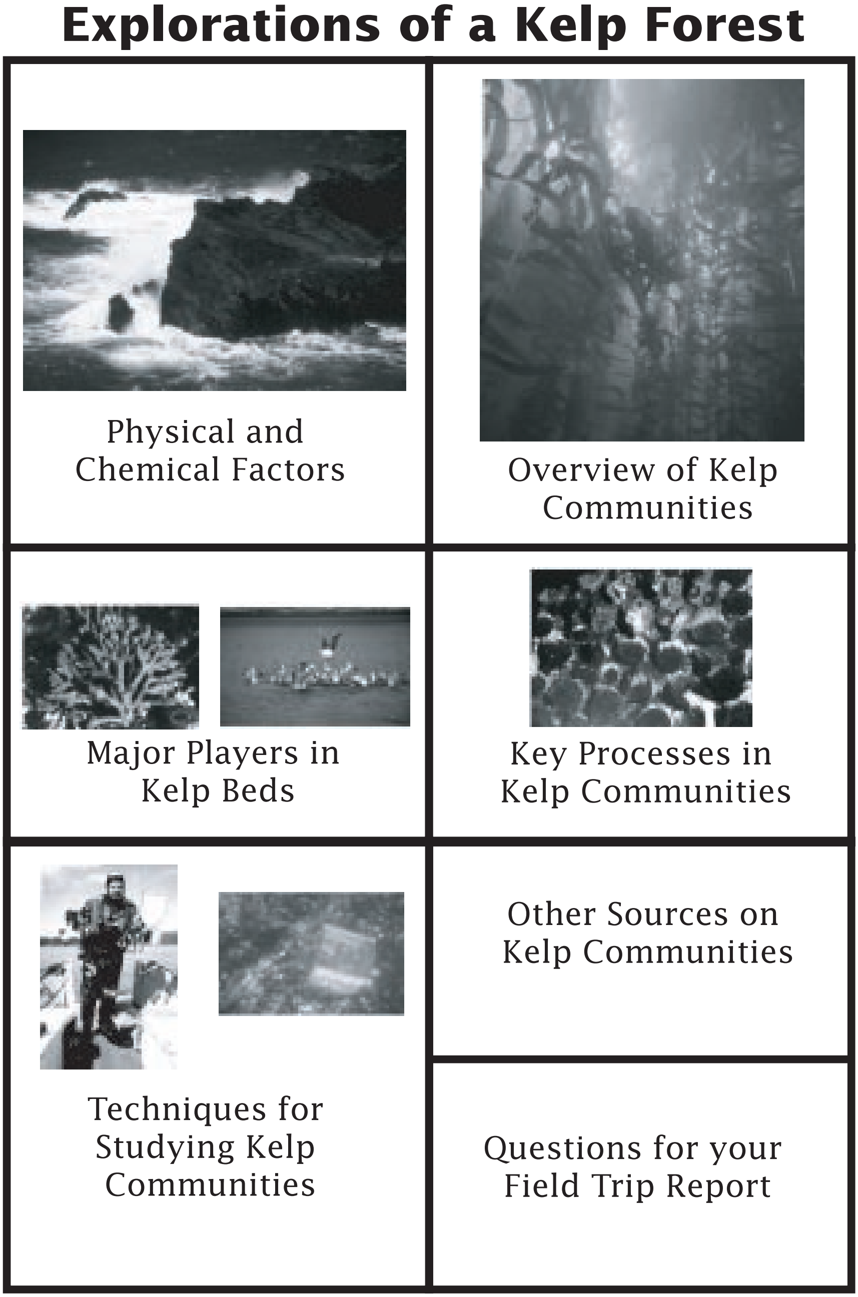
The students will navigate through these exercises via the Web, supported by the fast fiber-optic backbone at East Carolina University (ECU). Each exercise will provide a description of the physical and environmental conditions at the site, introduction to the major organisms that shape these communities, the processes that structure them, and the tools (including diving) that have been used to study them. Each exercise will mimic an actual field trip, with still images and video as their eyes and text prompts and audio as their ears. At the end of each exercise the students will prepare a field-trip report, addressing questions and issues brought up during their exploration of these habitats. An example of the layout of these elements is shown in Figure 1 for the kelp forest exercise.

Like the production of any feature film or short documentary, creation of these exercises requires several stages: development of an overall outline, acquisition of the raw materials, editing the raw materials, and assembly of the edited materials. The outline (storyboard) includes a description of the desired materials (stills, video, maps, diagrams, etc.) and their relative placement in the overall project. Most materials in these exercises have been acquired specifically for this project from sites in North Carolina and Washington. Lacking an extensive Hollywood-style budget for “re-shoots” in the field, I have been opportunistic, incorporating video whenever available and integrating stills or diagrams from other sources when not.

For this project, the underwater video is acquired with a SONY PC 100 digital video camera in a Light and Motion Mako housing with Sunray HID lights. Additional video footage from older analog video cameras is transferred to digital format via a SONY Analog to Digital hard CODEC box. The still pictures include frames extracted from video and 35 mm slides of key habitats, interactions, organisms, etc. taken with Nikonos cameras and scanned as jpeg files with a Nikon Coolscan III. Site maps and figures from scientific publications are digitized with a flatbed scanner.

The key to transforming these exercises from an elaborate slide show to a more interactive format rests in the wide application of digital video. Editing raw analog videotapes and composing the final product is very time-consuming. However, new digital tools facilitate the editing of raw digital videotapes, integration of video segments, and compression of the digital video information that allows playback at reasonable speeds and sizes. Continued innovation in all these areas will only make the process easier and improve the quality of the final product.

Editing and assembly is accomplished with a personal computer and user-friendly software (Figure 2). The field images and other materials are edited and manipulated on a PowerMac G4 (466MHz processor, 256Mb of RAM and a 60Gb hard drive). Sections of the raw digital or digitized video are transferred to the G4 using iMovie software. A tremendous advantage of this system is that the computer controls playback from the digital video camera via a Firewire connection. Individual clips can be trimmed in iMovie or another video editing software (e.g., Adobe Premiere or After Effects). These software packages can also integrate clips with appropriate transitions. The finished video sequences are output as QuickTime movies with a frame rate and image size appropriate to the bandwidth of the network. ECU’s network will permit one quarter to one half screen, full speed (30 frames per second) video without significant delay for users connected via the fiber-optic network, but this level of resolution will not be possible for users who access these exercises via a dial-up modem. The scanned still materials are edited with Adobe PhotoShop as jpeg files.



Explorations of a Kelp Forest

Physical and Chemical Factors

Overview of Kelp Communities

Major Players in Kelp Beds

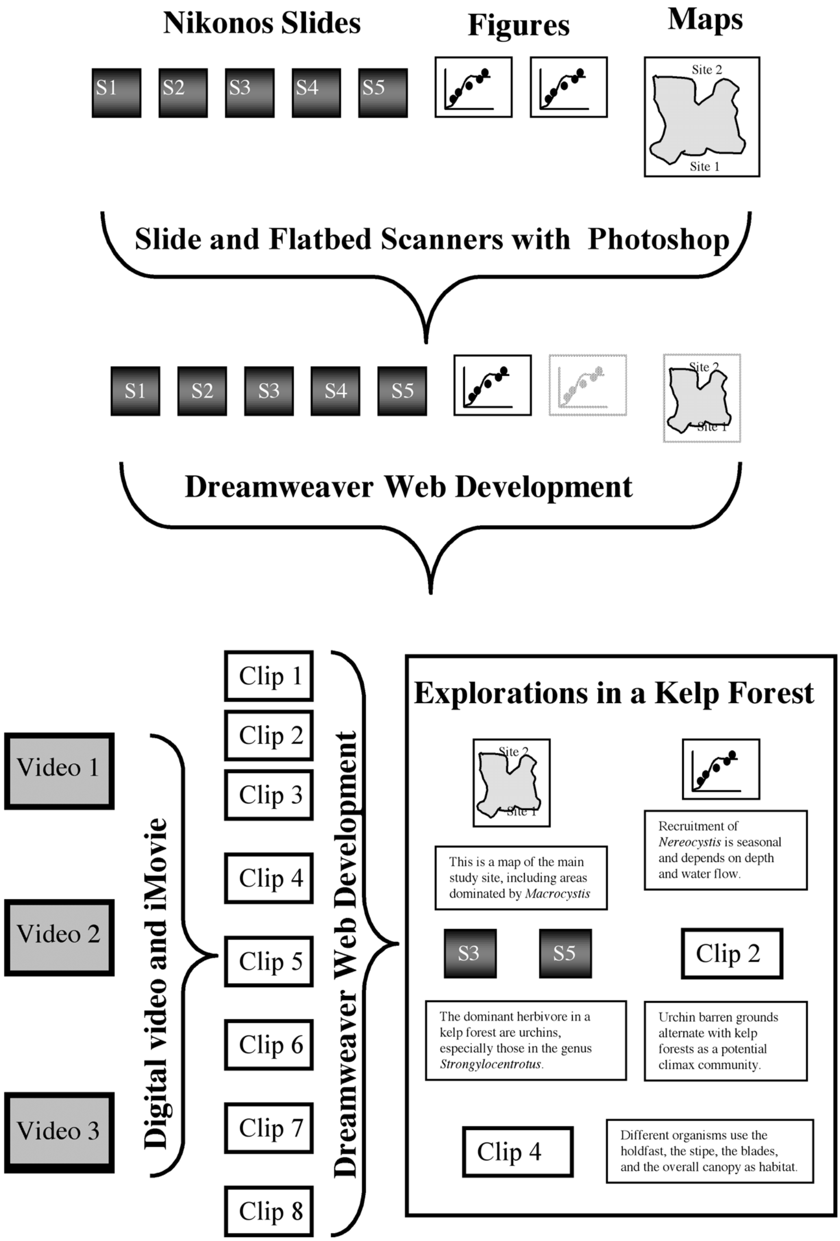
Key Processes in Kelp Communities

Techniques for Studying Kelp Communities

Other Sources on Kelp Communities

Questions for your Field Trip Report

Figure 1. An example of the introductory Web page for a virtual field trip. The elements on this page link to others that investigate these areas in more depth.



This is a map of the main study site, including areas dominated by *Macrocystis*

Recruitment of *Nereocystis* is seasonal and depends on depth and water flow.

The dominant herbivore in a kelp forest are urchins, especially those in the genus *Strongylocentrotus*.

Urchin barren grounds alternate with kelp forests as a potential climax community.

Different organisms use the holdfast, the stipe, the blades, and the overall canopy as habitat.

Figure 2. A flow diagram of the processing of image materials in the development of these Web pages.

I am using Dreamweaver by Macromedia to assemble the QuickTime movies, jpeg files, and text into the finished Web exercises. Dreamweaver allows sophisticated Web site development either by hand-coding HTML or through a visual-editing environment (especially nice for an HTML novice). Each exercise includes links to other Internet sites with information on these topics. The finished exercises are then uploaded to a core server. Students will be directed to the appropriate location on the core server via links on the course Web page.

Ultimately, the goal of this project is to provide students with the experiences and insights of a traditional field trip for places that they cannot visit themselves. The Web has many advantages and some major disadvantages in attempting to reach this goal. It cannot substitute for the camaraderie and team-building that result from a traditional field trip. It also cannot provide the full sensory experience of the field environment. However, the virtual field trip option removes the tedium of travel to and from the site; a virtual field trip is never cancelled because of bad weather. Because a virtual field trip integrates information from multiple sites and visits, it provides a temporal or spatial dimension that may be impossible in the limited time available for a field trip.

While my application has focused on classroom teaching, many of these advantages and disadvantages would also apply to a training or orientation Web site for a specific scientific diving project. A Web-based presentation has several advantages over other presentation formats (e.g., slide show or videotape). One advantage is depth; a standard lecture, slide show, or video is limited to the linear presentation of information. Students can tailor their navigation through these Web exercises to match their level of experience and inquisitiveness: skipping familiar material, revisiting material that is unclear, and digging deeper into interesting topics. In addition, the Web-based formats are easily updated to buttress areas that are difficult or to add new information. Web-based presentations can be accessed anytime and almost anywhere, increasing flexibility.

Financial support has been provided by a teaching enhancement grant from East Carolina University; technical and equipment support has been provided by the ECU Diving and Boating Safety Office, ECU Instructional Technology Consultants, and Friday Harbor Laboratories.

Movement Patterns of the Chiton *Katharina tunicata* in Kachemak Bay, Alaska

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Introduction

Katharina tunicata is the most abundant intertidal chiton in Alaska as well as one of the most prevalent of all littoral species (Ricketts et al. 1985). Because of *K. tunicata*'s high densities, it has the potential to significantly impact community structure. Generally, chitons are thought to be slow-moving grazers with limited directional movements, although quantitative studies of *K. tunicata* activities have not been conducted.

Most movement studies have examined three tropical species of *Acanthopleura* (Santini et al. 1991). All three species exhibited homing, but to different degrees (Santini et al. 1991). Homing is the ability of an organism to move some distance away from an area to forage and then return to this preferred location after each foraging event. Other chiton species have also exhibited homing behavior, such as *Mopalia mucosa, Cyanoplax hartwegii,* and *Ischnochiton dispar* (Chelazzi et al. 1983). Individual behavior has not been studied in *K. tunicata.*

The grazing effects of chitons of different sizes are unknown, but grazing rates and area grazed per unit time could be a function of animal size. Because *K. tunicata* grazes on algal sporlings (Duggins and Dethier 1985) and barnacle ciprids and has the ability to eat crustose corallines and leathery macrophytes (Steneck and Watling 1982), it is possible that this chiton plays a major role in structuring intertidal communities. To date no studies have examined the relationship between chiton size and movement.

Previous chiton movement studies have only taken measurements during low tide (Randall and Martin 1987) so researchers have only been able to speculate about submerged chiton movement. Other studies have examined movement at high tide with the use of underwater cameras (Chelazzi et al. 1990); however, this is expensive and logistically difficult. This is the first study to use scuba as a tool to assess chiton movement under water.

Whether these animals "home" or roam freely could determine the extent of *K. tunicata*'s role in the community. Also, how and when these animals move may be important in determining their effect on the community. The main objectives for this research are as follows: (1) quantify direction and distance of *K. tunicata* movements to ascertain if *K. tunicata* exhibits homing behavior or migrates to new locations; (2) determine if there is a relationship between body size and movement; and (3) determine when *K. tunicata* moves in relation to the daily tidal cycle.

Methods

This study examined *Katharina tunicata* movements at Outside Beach in Kachemak Bay approximately one mile from Seldovia, Alaska. Two 24-hour-movement studies were conducted at this site during May and June of 2001. The May study consisted of tracking seven chitons while the June study tracked ten chitons. The chitons were marked with colored cable ties attached to their plates with super glue. Although the colors used for the two studies may have been the same, each chiton was used only once. Of these 17 chitons, nine were small (≤4.5 cm) and eight were large (≥5cm). By measuring from a fixed point to the chiton each time, the triangulation method was used to determine how far and in what direction each chiton moved. A protractor was centered on the fixed point, and angles as well as distance were recorded relative to the point. Measurements were recorded approximately each hour for each chiton. Scuba was used as a tool when the chitons were submerged. After each movement study, the chitons were brought back to the lab to be measured and weighed.

Results and Discussion

Distance and angle measurements were analyzed using the triangulation method, and paths were constructed for each chiton (Figure 1). This method accounts for turning angles and direction, which will determine whether or not these organisms are homing (Doak 2000). The data from this study indicate that although chitons have been regarded as relatively sedentary organisms, they are able to move great distances in a relatively short amount of time. This movement appears random, at least over a 24-hour period, and homing is not apparent from the results. Marking and tracking chitons over a longer period of time will be necessary to determine whether or not these organisms "home" after days or even weeks.

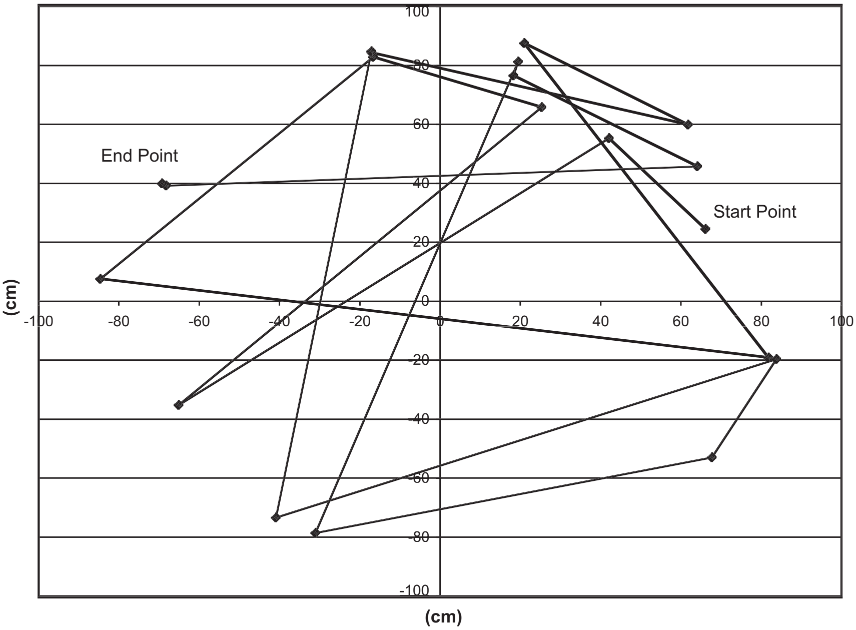

Figure 1. Example of a typical path for Katharina tunicata constructed using coordinates obtained from the triangulation method. This particular path is for the black/yellow chiton during the June movement study.

This study also suggests that distance of movement varies greatly between individuals but that there is no correlation between movement and chiton size. Randall and Martin (1987) attribute their lack of correlation between movement and size of chiton to small sample size. Although the sample sizes in these studies were larger than that of the aforementioned study, the lack of a relationship between movement and size in this study may also be due to a relatively small sample size.

Finally, through the use of scuba, this study has determined that *K. tunicata* moves only while submerged. *K. tunicata* could possibly display this activity pattern because of predation risk by seabirds and other terrestrial organisms or because of increased environmental stresses. Additional statistical analyses are being done to obtain total movement of each chiton as well as averages for each movement study. Further studies are also being conducted to ascertain the impact of *K. tunicata* movement and grazing on intertidal community structure.

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Scientific Diving Injuries in Southeast Alaska

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Scientific diving records for the Alaska Department of Fish and Game Division of Commercial Fisheries in southeast Alaska were reviewed and compared to the number of documented diving-related injuries. For the 1990 through 2000 dive survey seasons, over 10,933[1] scientific dives were performed, ranging from 266 dives in 1990 to over 1,943 dives in 2000 (Figure 1).

As many as 18 divers have participated during a single survey season, though typically only six divers participate per specific project survey trip. The average number of dives per diver per season has steadily increased each year (Table 1).

Air was used as the breathing gas for 6,041 (55%) dives and 32% nitrox for 4,892 (45%) dives. Maximum depth for all dives was no greater than 22.5 m (70 fsw [feet seawater]) with an average dive time of approximately 20 minutes per dive. Typical survey schedules and protocols require multiple reverse-profile (shallow to deep) dives per day for periods often lasting two or more weeks. During the early 1990s, divers averaged three dives per day but by 1997 through 2000 were averaging six dives per day.

Although most training agencies discourage the type of repetitive dive profile described above, relatively few dive-related incidents have been encountered. A physician was required for four diving-related injuries, including one case of DCS (decompression sickness), from 1990 through 2000 (Table 2).

The DCS injury was considered an “undeserved hit” following an “innocuous” (hyperbaric physician’s terminology) dive profile and was completely resolved following recompression treatment. The remaining three injuries are considered diver error and could have been prevented by the diver. No permanent damage remains from any of the injuries. The one

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[1] Total does not include geoduck show plots, red urchin tagging, cucumber sampling, cucumber/urchin/abalone genetics, herring calibration samples, or temperature recorder placement.

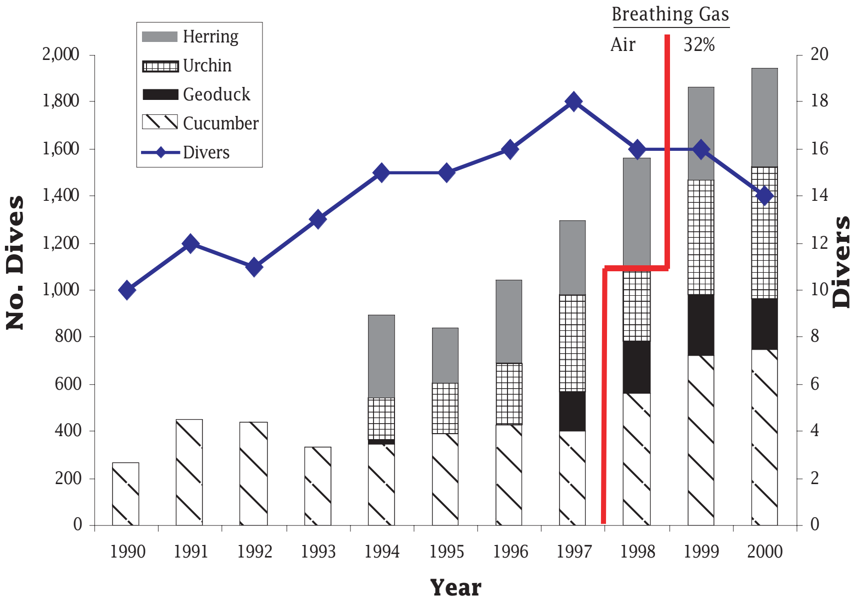

Figure 1. *Number of scientific dives performed from 1990 through 2000 in Southeast Alaska, by project, by dive season, by number of divers available per season, and by breathing gas used.*

Table 1. **Number of scientific divers available per survey season and the number of dives performed per diver.**

		Dives per diver per season	
Year	Divers	Avg.	Min / Max
1990	10	27	2 / 54
1991	12	38	9 / 94
1992	11	40	13 / 99
1993	13	26	6 / 58
1994	15	60	9 / 162
1995	15	56	10 / 159
1996	16	65	18 / 129
1997	18	72	6 / 187
1998	16	98	16 / 252
1999	16	117	3 / 294
2000	14	139	6 / 358

Table 2. Dive-related injuries requiring treatment from 1990 through 2000.

Year	Injury
1992	“Raccoon eyes” (mask too tight)
1994	Ruptured ear drum
1999	DCS (Type I, pain wrist/elbow)
2000	Reverse squeeze (diving congested)

DCS injury computes to a 0.0091% accident rate for recorded dives between 1990 and 2000, and 0.020% for 32% nitrox.

Concern for the type of dive profile and number of dives scheduled prompted the project leaders to begin using nitrox (32%) exclusively in the spring of 1998. Currently it is not expected that the number of dives completed each season will significantly increase nor will the season’s dive schedule decrease in the foreseeable future. The one case of DCS cannot be explained from the individual’s dive profile (all dives and ascent rates were well within accepted decompression limits). The seasonal increase in the number of dives per day and the increase in survey trip length may have contributed. The recommendation to increase department divers’ margin of safety will be to begin using a 36% oxygen mixture. The project’s standard dive profile methodologies allow the use of 36% nitrox and remain within the department’s 1.4 partial pressure O_2 limit.

A Mountain in the Sea: Exploration of Gulf of Alaska Seamount with the Submersible *Alvin*

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Declining crab fisheries in Alaska have caused fishers to begin exploratory fishing on seamounts. However, biological knowledge of seamount species is poor. In July 1999, we conducted eight dives on Patton Seamount in the DSV *Alvin* to study the depth distribution and habitat use of deepwater species. Ten species of crabs were observed. The most abundant species (1,245 observed) was a galatheid. The large-clawed spider crab *Macroregonia macrochira,* previously unreported from the Gulf of Alaska, was the most abundant brachyuran crab (186 observed) and ranged to at least 3,240 m, the deepest depth achieved. Mating pairs of some species were observed only on or inside vase sponges. Community analysis suggests that species can be grouped into representative shallow, midwater, and abyssal communities.

Voyage to See What's on the Bottom: Methods of Visualizing the Ocean Floor

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Introduction

In 1990 we began to study the mating behavior of Tanner crabs, *Chionoecetes bairdi,* in Womens Bay, Kodiak, Alaska. Our goal was to ascertain the size relationships of mating pairs, in order to determine if the current minimum size limits allowed male crabs to mate prior to capture by the commercial fishery (Stevens et al. 1993). Paired crabs in premating embrace ("graspers") were captured by scuba, but all males captured in this manner were below the commercial size limit. In order to capture larger, legal-sized crabs, we needed to search deeper water (>100 m), so obtained a grant from the National Undersea Research Program. In 1991, using the *Delta* submersible, we discovered that female Tanner crabs form high density aggregations in adjacent Chiniak Bay, where crabs form mounds containing hundreds to thousands of animals, at 150 m depth (Stevens et al. 1994). Over 100,000 crabs were present in about 200 mounds covering an area of 2.5 ha. In subsequent years, we examined the reproductive conditions of females in Chiniak and Womens Bays (Stevens et al. 1996), and the timing of larval release relative to temperature, currents, tides, and plankton blooms. Results to date suggest that aggregation, mating, and larval release are synchronized with spring tidal cycles (Stevens et al. 2000a). During the course of this research program over the last decade we have used a variety of *in situ* tools to locate, visualize, observe, quantify, and study crab behavior.

Tools and Techniques

At the beginning of our study, we used the two-person *Delta* submersible for several years (http://azstarnet.com/~delta/index.html). The *Delta* can be launched from a 100-foot boat with a five-ton crane; turnaround time between dives is less than 15 minutes. The *Delta* carries a pilot and one observer who looks out through twelve 6″ viewports. It is highly maneuverable and can make many types of observations and collections, including sediment and plankton sampling. We built a crab basket for collecting up to 40 crabs per dive. The main advantage of the *Delta* is that it can be precisely positioned in order to take samples on a closely defined scale. It is very important to know the exact spatial and behavioral context from which specimens are collected, i.e., if they were foraging or resting, buried or active, what animals they were adjacent to. It also allows very close observation by the observer, and a 180-degree view around the sub. There is no better tool for depth perception than the human eye. The *Delta* has a high-quality digital video system which can be configured in a variety of directions, and provides depth, time, and temperature data on the tapes. It can also take 35 mm photos by either an external underwater camera or an internal hand-held camera (the best option). Its main disadvantage is price ($3,500/day, plus a support vessel of equal cost). Some people find subs to be claustrophobic, and they can be dangerous, although the *Delta* has a perfect safety record with over 4,000 dives (more than *Alvin*).

High resolution 35 mm photography is the best way to image objects, animals, or habitats on the seafloor and is the holy grail of underwater *in situ* research. Photographs generally capture a small area (a few m^2) and have very high resolution (mm). But getting the camera where you want it and taking a large enough photograph is very problematic. Furthermore, visibility, turbidity, resolution, color frequency, and light quenching prevent making underwater photos of large areas with current technology. And using small photographs to map habitats or search for objects is very inefficient. Using the *Delta* to position the camera is ideal but expensive. Dropping a camera from the surface is cheaper, but you can't predict where it will land. Likewise, using the *Delta* to make close-up videos or photos is very productive, but using it to search for objects or survey habitats is very time consuming and expensive.

Searching for objects or survey habitats requires a device that can cover larger areas at a "bite." Sidescan sonar (SSS) uses a towed "fish" to create "sound" images of the bottom. The size of the area viewed depends on the frequency range of the transmitter and its altitude above bottom. In 100 m of water, with the transducer 10 m off bottom, a 100 kHz transducer can sweep 150 m to each side of the vessel with resolution of 50 cm, whereas a 500 kHz transducer can sweep 50 m with resolution of 10 cm. We used SSS to survey an area of 4.5 km^2 and map lost crab pots for a study of ghost fishing in Chiniak Bay (Stevens et al. 2000b). In some cases we could see the webbing and ropes of individual pots, although we could not see individual crabs or other organisms with the sonar.

Sector scanning sonar is very similar, but in a smaller package. A high resolution, 325 to 600 kHz unit (e.g., Mesotech™) can have a resolution of 5 cm. When mounted on a remotely operated vehicle (ROV), just a few feet off bottom, it can detect individual fish and crabs, and aggregations of crabs show up like a constellation in the night sky. In order to avoid entanglement with ghost pots and derelict fishing gear and lines, use of sector scanning sonar with any ROV or submersible is a necessity in Alaska, although many do not have it yet.

For even better resolution, the next best thing to a 35 mm photograph is the laser line scan system. It works like sonar, by scanning a pencil-thin blue-green laser across the seafloor, and building a picture by pixels. It is a good compromise between sidescan sonar and photography, with a medium sweep (10-20 m) and fairly high resolution (<1 cm). However, turbidity is still a problem; in order to obtain good images, we had to tow the fish at 5 m off bottom. Trying to follow an undulating seafloor at that altitude by adjustments of the winch is difficult, and sometimes we plowed it into the bottom. Newer models are smaller, higher resolution, and make color plots, but still require too much power to mount on the *Delta.*

In order to reduce the cost of *Delta* sub time and survey large areas for crabs, we began building underwater video camera sleds. The most recent version of this is the BRAD-3, or Benthic Resource Assessment Device, Model 3. It carries a large battery, two 25 watt lights, and a Sony™ digital video camera in a watertight aluminum cannister. A pressure switch turns on the lights and camera below about 30 m, thus saving power while launching and recovering the sled. The cannister and wiring were developed by Scott McIntyre at the Alaska Fisheries Science Center (AFSC) in Seattle for use on trawls. The sled is relatively cheap (<$2,000) and electronics cost $5,000-6,000, for a total of about $8,000. Similar sleds were built for the NMFS Auke Bay Lab and the Kodiak Alaska Department of Fish and Game (ADFG) office, and the interchangeable camera systems can be traded and loaned between laboratories. Once built, it requires only the cost of a vessel charter. We tow it from the 95 ft FV *Big Valley,* using an A-frame and 3/8″ wire winch. It works best when towed in a straight line at 1.8-2 knots. We cannot see the image in real time, because there is no data cable. After a one-hour tow, we recover the sled, remove the video, and review it while making another tow. The image is narrow (about 1.5 m wide), and is good for searching over long distances of several km, effectively accomplishing a strip survey. Because we can't see the bottom when towing, it often runs into obstacles such as crab pots (which it was designed to ride over) and occasional rock pinnacles (which makes a spectacular crash, with sound effects). It can also tangle with longlines and lines from crab pots. For the same reason, we cannot stop the sled to examine objects closely. And studying videotapes of the seafloor sliding by at 2 knots can be either dizzying or stupefying, depending on conditions such as sea state, boat ventilation, and the observer's coffee intake.

After surveying an area with the BRAD-3, we use an ROV for examining small areas. The one we have used most often is a Phantom HD-2, from Deep Ocean Engineering (http://www.deepocean.com). We deploy the ROV in one of three modes; stationary, moving, or towed. In stationary mode, we drop a heavy (200 kg) weight from a winch, attaching the ROV umbilical at intervals with longline clips. The downweight keeps the ROV tether going straight to the bottom and prevents snarling it in the ship's propellor or rudder. The weight is hung a few m above the seafloor, and the ROV has about 100 m free tether to move around it. With the sector scanning sonar, crabs or aggregations can be seen if they are present, then the ROV is flown to them or the boat is gently nudged into a closer position. In moving mode, the boat either drifts or is driven slowly along a predetermined course, and the ROV flies along near the weight, with freedom to go off to the side to examine sonar targets (crabs) or avoid them (crab pots). In towed mode, the ROV is attached to a rope bridle, and towed about 20 m behind the weight while the boat is driven.

ROVs come in many sizes and prices, from $10,000 to $1 million. They provide a real-time image via a multiwire umbilicus. They can be easily deployed to 150 m with a standard 335 m cable. Most can be configured to carry video, sonar, depth, compass heading; some also have manipulator arms, multiple cameras pointed in different directions, and sampling apparatus.

The newest generation of *in situ* equipment is the AUV, or autonomous underwater vehicle (Bellingham 1997). It operates like an underwater cruise missile. It can be sent on a mission over a predetermined path and depth. It carries sampling equipment for various water parameters, depth, and/or video. At intervals, the AUV returns to its mothership, or a docking station, or surfaces and broadcasts data to a satellite. They may be deployed for hours, days, or weeks. These were developed jointly by Massachusetts Institute of Technology (Odyssey) and the Woods Hole Oceanographic Institute (REMUS), and some are now in commercial production. The major problem with current models is that they are designed to work at programmed depths in the open ocean, and most cannot fly at a fixed altitude above a bottom contour, or avoid obstructions (including scuba divers) (Patterson et al. 2001).

Navigation and Positioning

The biggest problem in underwater research is determining where the data was collected. Several systems have been developed but all are costly and complicated.

Vessel navigation is done with GPS, the Global Positioning System. This is such a standard now, it needs little explanation. Prior to May 2000, the Department of Defense (which administers the program) intentionally degraded the signal to prevent misuse by "terrorists." Standard Positioning Service (SPS) reduced the accuracy to +/–100 m. For several years we used a military GPS unit which was capable of receiving Precise Positioning Service, if a key code was installed, and produced position accuracies of 5-10 m. However, this unit was never convenient because of the requirement for annual rekeying, specialized batteries, and difficulty of obtaining parts, so we stopped using it after SPS was discontinued in May 2000. Differential GPS (DGPS) systems require a surveyed base station to compute the difference between the calculated and actual position, and broadcast corrections via VHF radio signal; accuracy is +/–1-2 m. In 1995 we leased a commercial system for $45,000 per month, but the U.S. Coast Guard now broadcasts a DGPS signal in Kodiak and a commercial receiver costs less than $1,000. We routinely install our own DGPS receiver and notebook computer on chartered vessels, then record positions and tracks of the vessel at 1 minute intervals using commercial navigation software such as the Nobeltec Visual Navigator™.

However, GPS does not work under water, so tracking of the sub or ROV requires another system. Usually this involves multipoint positioning. A long-baseline positioning system consists of a network of "pingers" on the seafloor, within which the sub or ROV is navigated and its position determined by triangulation. The distance between pingers may be hundreds of meters. This system is highly accurate, but expensive, so is only used by the largest survey vessels. It may take a complete day to set up, and another to retrieve.

A more convenient system is the Trackpoint™ ultra-short baseline system. A transmitter sends a signal to passive transponder on the sub or ROV, which pings in response. The time differential for the return signal is measured between nodes only millimeters apart (the ultra-short baseline). If depth is manually input, the system provides range and direction to the target. We use a Trackpoint to determine where the *Delta* or ROV is relative to the vessel. If the ship is positioned directly above the sub, or within a few meters, vessel position can be used as a proxy for sub position. Trackpoint systems can be deployed from any vessel larger than about 10 m.

Data Integration

Knowing where the ship is, and the sub relative to the ship, are two pieces of the puzzle. Connecting them is the next. Several commercial programs integrate the vessel and sub positions. WinFrog™ and HiPack™ are commercial survey software developed for the offshore oil industry (as are most of these products). Most commercial underwater survey companies employ some type of system. These programs will plot the position of Sub/ROV as determined using GPS and trackpoint input data. However, none are easy to use, and they don't always work well. Depending on depth, bottom contour, and sea state, the accuracy of calculated positions may be variable. A standard backup is always needed: write everything down every few minutes.

If all these systems work, they can produce a data file of ROV/sub positions at some interval (30-60 s). As yet there is no standard way to georeference the data, i.e., to attach position data to video or CTD data. Some expensive systems can write positions to the videotape, but retrieving them in usable format can be difficult and often requires copying them from tape by hand.

After surveying a grid of lines with the *Delta,* ROV, or the BRAD-3, we review all videotapes in the lab. Using commercial software called The Observer™, we code all crabs seen by species, sex, maturity, activity (buried, exposed, mating, feeding), and context (aggregated or not). We can also code any other species and conditions observed. The program produces a data file with each observation and a time code to the nearest 0.01 second. This data file with time codes is then run through a visual basic program called Crabtime, which aggregates the observations by type into user-defined intervals of 1-10 minutes, usually 2 or 5 minutes. The resulting histogram of crabs per time interval can be plotted along with vessel positions using a GIS program such as ArcInfo. In practice, we spend a day on the water making 4-6 hours of sled or ROV tows. These require 1-2 days to examine properly and less than an hour to integrate the data and plot it on a paper chart. The chart can then be used to guide the next survey trip. If necessary, we can analyze tapes on board ship while recording (with the ROV) or reviewing (with the sled), create the summary file, and plot by hand on the navigation computer, in a few minutes between sled tows. However, observations made by this method (at sea, on a pitching, rolling ship) are not as accurate as those made by a rested observer sitting at a stable desktop computer and video console.

Now that we have all this data, what do we do with it? According to Bob Ballard, dealing with the vast amounts of information supplied by underwater research equipment can be "like sipping water from a fire hose" (MacDonald and Juniper 1997). Indeed, it may be so difficult to catalog, store, and analyze all the data, that much of it never gets utilized or integrated. We store our summary crab observations (numbers per unit interval) and position data in a Microsoft Access™ database. Then, crab numbers can be matched up with positions for plotting, and it can even be used to calculate offsets for the position lag between ship and sled. Most large research vessels put all the data from a cruise on CD-ROMs. Then, observations of organisms or habitats can be cross-referenced with depth, time, temperature, and other data, using a database. Needless to say, underwater research requires a good data manager.

Conclusions

There are many ways to conduct underwater research at depths below safe scuba depth. These range from inexpensive video sleds to expensive submersibles with lots of data integration. Selection of the best system for any research project always involves a compromise between cost and data quality. Fortunately, technological improvements are occurring at such a pace that inexpensive, high-quality systems that were unavailable five years ago are now relatively affordable. We have been fortunate to cooperate with several labs in developing equipment that can be traded and loaned, with interchangeable parts that can be swapped as needed. Thus, the BRAD-3 sled was built by the Kodiak Lab, paid for by the Auke Bay Lab (ABL), uses a camera housing developed by the Alaska Fisheries Science Center (AFSC), and includes camera and lighting equipment which is owned by either the ABL, AFSC, or ADFG. As camera systems improve in the future, the sleds can be modified or built anew to accommodate them.

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Jellyfish Effects on Food Web Production in the Bering Sea

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In recent years, gelatinous plankton, including large jellyfish, have been shown to have a substantial impact upon fish populations by preying on eggs and yolk-sac larvae. In the Bering Sea, there has been a tenfold growth in the biomass of the large jellyfish *Chrysaora melanaster* over the past decade (Brodeur et al. 1999). Other than a small, one-time snapshot in late summer (Hamner 1982), their feeding habits have not been examined and nothing is known about diets in spring; when with other species, predation rates as high as 60% of the ambient fish eggs per day have been recorded (Purcell et al. 1994). In some systems, growth in jellyfish biomass has been accompanied by failure in recruitment of fish stocks. This study tests the hypothesis that *Chrysaora melanaster* significantly depresses the annual production and biomass of other members of the pelagic food web of the Bering Sea, including walleye pollock *(Theragra chalcogramma)* and other forage fishes. The hypothesized mechanisms operate through trophodynamic processes, including competition with fishes for common prey, and predation on fish eggs and larvae.

Several species of jellyfish actively select for fish eggs among the plankton (Fancett 1988, Purcell et al. 1994). When sufficient high-quality food is available, medusae often experience exponential growth and can quickly become the dominant species in an ecosystem. In nonintroduced species, this is often limited by predation from other medusae. In the Bering Sea there is only one documented case of this occurring (Hamner 1982), where the large jellyfish *Cyanea capillata* preyed upon *Chrysaora melanaster. Cyanea capillata,* however, tend to be located in the outer shelf and oceanic regions. Thus there may be little predation pressure upon *Chrysaora* in the middle and inner-shelf regions of the eastern Bering Sea.

The study encompassed a two-month period from early April through early June 2000, the period of peak spawning of pollock on the southeastern shelf as well as the suspected period of maximum growth for the medusae. It was conducted from a relatively inexpensive 9.8 m Bristol Bay gillnetting vessel. The vessel size necessitated working out of a safe harbor, such as False Pass, where shelter could be taken whenever weather conditions were too severe for the boat or for diving. The chosen sampling site was the north shore of Unimak Island near the entrance to False Pass in depths less than 20 m. This is an area of historic high jellyfish biomass and near the center of distribution of spawning pollock. The 20 m depth was chosen because it provides a floor that can be utilized for equipment as well as for safety concerns.

For the process studies, collection via diving was chosen. Due to the fragile nature of jellyfish, trawling often produces unusable specimens, since they are damaged and net contamination makes stomach content analysis dubious. Much of the feeding takes place on the oral lobes, which hang below the animals and may be three meters long in Bering Sea *Chrysaora.* These are often torn off in plankton trawls. Due to the vertical composition of the population (Brodeur 1998), dip-nets are also likely to collect specimens nonrepresentative of the population and damage the oral lobes in small waves and choppy conditions. This leaves diving as an alternative to collect samples.

Since there are no diving facilities in the region, a compressor was needed at the site. A low-pressure, surface-supply system was chosen because it is a small portable system weighing about 250 kg and can be placed aboard a small vessel and run on diesel. This system also allows for ease of communication and cooperation with the support vessel through the tether. One advantage of this system is that divers are not time-limited by tanks and are thus more able to complete tasks. The tether is needed due to the currents, low visibility, and lack of spatial references for the divers. This system is widely used by commercial abalone, sea cucumber, and geoduck divers in Alaska waters and is suitable for many of the remote diving conditions encountered here.

Although the project was designed to test different methods of collection for *Chrysaora melanaster* via diving, the jellyfish distribution in 2000 proved to be too deep, and specimens had to be collected with an otter trawl. In future studies modifications (such as a completely ship-based study and incorporation of ROV use) will need to be made in order to follow swarms of jellyfish away from safe harbors.

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A Fisheries Habitat Survey Method for Nearshore Environments Utilizing Scuba

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Nearshore coastal environments are important fishery habitats that are hard to survey by traditional methods. Water depth is shallow and variable due to numerous objects and tides, making it impossible for access by large research vessels. Using scuba, these areas can be surveyed from shore or by small boat.

More research is required to identify and describe nearshore coastal essential fish habitats (EFH). In addition, more information is required for all life history stages complete with identification of habitat requirements and species interactions within these environments. For most commercially managed species, only presence/absence data and habitat-related densities are known. Very little information exists for growth, reproduction, or survival, as well as production rates.

We have developed a protocol utilizing the Linear Point-Intercept (LPI) Method (Ohlhorst et al. 1988, Aronson and Precht 1995), to accurately survey nearshore habitats for substrate and organisms. The recreational diving community can utilize this relatively inexpensive and easy-to-use method. Hundreds of divers visit these areas every week. With proper training, these groups can conduct surveys of nearshore coastal environments. This utilization of recreational divers to conduct these surveys would significantly increase the areas surveyed. Large amounts of fishery habitats could be surveyed, something which could not be done within the scientific or fisheries management community due to limited labor force.

We conducted a pilot study with recreational divers to determine the feasibility of utilizing recreational divers to conduct these surveys. We present the protocol and compare results obtained using recreational divers versus scientific divers.

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Hyperpycnal Plumes in Shelf Waters of the Exuma Cays, Bahamas: A Trigger for Coral Bleaching?

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The formation and transport of warm, high-salinity water from Great Bahama Bank to shelf waters of the Exuma Cays, Bahamas, during summer months has been documented by a number of studies (Smith 1995, 1996; Pitts 1999). This research has shown that during summer months the effects of incoming solar radiation and high evaporation on the relatively shallow waters of Great Bahama Bank can raise the temperature and salinity of bank water by up to 2° C and 2 psu (practical salinity units), respectively, above those found in nearby Exuma Sound water. During the ebb half of the tidal cycle, the warm hyperpycnal bank water is forced through tidal channels between cays onto the narrow shelf on the Exuma Sound side of the island chain. It is over this narrow shelf where most of the region's coral reefs are found.

Like most regions in the world where coral reefs are found, bleaching can be a problem for corals in the Exuma Cays. First reports of bleaching in this region occurred in 1987, and since that time a number of bleaching episodes have been reported. Some studies have suggested that when the warm, high-salinity bank water ebbs onto the shelf it inundates nearshore reefs and causes or contributes to bleaching (Lang et al. 1988, Dennis and Wicklund 1994). However, the evidence linking warm, high-salinity water originating from Great Bahama Bank to bleaching of Exuma Cays reef corals is based mainly on inference. The physical data from these studies are limited to comparisons of median monthly bank and shelf-water temperatures, which obscures fluctuations over the shorter time scales. Meteorologically forced fluctuations, which are the most important for raising temperature and salinity above mean values, occur over time scales of several days to about two weeks.

While studies have established the differences in characteristics between bank and sound water, none have described the behavior of the hyperpycnal bank water as it moves across and along the shelf after exiting through tidal inlets on the ebb tide. This paper uses hydrographic data collected over the shelf just seaward of a tidal inlet to characterize the top-to-bottom temperature, salinity, and density structure of hyperpycnal plumes after they have exited Great Bahama Bank. The objective is to characterize the behavior of warm, hypersaline water as it is transported by density currents to near-bottom shelf areas where it may trigger bleaching.

Hydrographic profiles were made at five to six equally spaced sites along the shelf seaward of Adderley Cut. This channel experiences vigorous exchanges between Great Bahama Bank and Exuma Sound, and warm, hyperpycnal bank water has been repeatedly observed moving onto the shelf through this channel. Profiles were made at or near the end of the ebb tide. Water temperature, salinity, and density were recorded every 0.5 seconds from the surface to the bottom at each site using a SeaBird SeaCat SBE-19 deployed from a small boat. Water depth at the sites ranged between 6 and 24 m. Results from two of these hydrographic transects are described below.

Measurements made on July 7, 1998, showed a very distinct warm, high-salinity plume over the shelf seaward of Adderley Cut (Figure 1). For reference, at the time of sampling bank water in the channel had an average temperature and salinity of 30.5° C and 39.8 psu, while Exuma Sound water temperature and salinity generally averaged 29.7° C and 36.8 psu. Thus, bank water was 0.8° C warmer and 3.0 psu saltier than sound water. The top plot shows that temperatures in the plume ranged between 29.8° C in the upper layer and 30.2°C in the near-bottom layer. These values are 0.1-0.5° C above the ambient sound temperature and 0.3-0.7° C below bank water temperature. Thus, if the plume water sampled along the transect was full strength bank water when it exited Adderley Cut, then by the time the plume water reached the transect site it had entrained and mixed with sound water to the point that it was diluted between 38% (lower layer) and 88% (upper layer). It is important to note that the weakest mixing occurred in the lowest layer so water temperatures were warmest near the bottom where the corals are found. The bottom plot shows that salinity in the plume ranged between 37.5 psu in the upper layer and a little over 39 psu near the bottom. Using salinity as a tracer, calculations suggest a dilution of bank water by 27% near the bottom and 77% in the upper plume layer due to entrainment of sound water. A plot of water density (not shown) indicates that the increase in water density due to the higher salinity of bank water is greater than the decrease in salinity associated with warmer temperature, thus the bank water exits the channel as a hyperpycnal plume that sinks below ambient sound water.

An important feature of the plots is the lateral spreading of the plume along the shelf in the near-bottom layers. The hyperpycnal water moved laterally along the shelf past the northernmost and southernmost hydrographic stations—a distance of about 0.5 km in either direction from the center of the plume. The hyperpycnal water occupied most of the lower

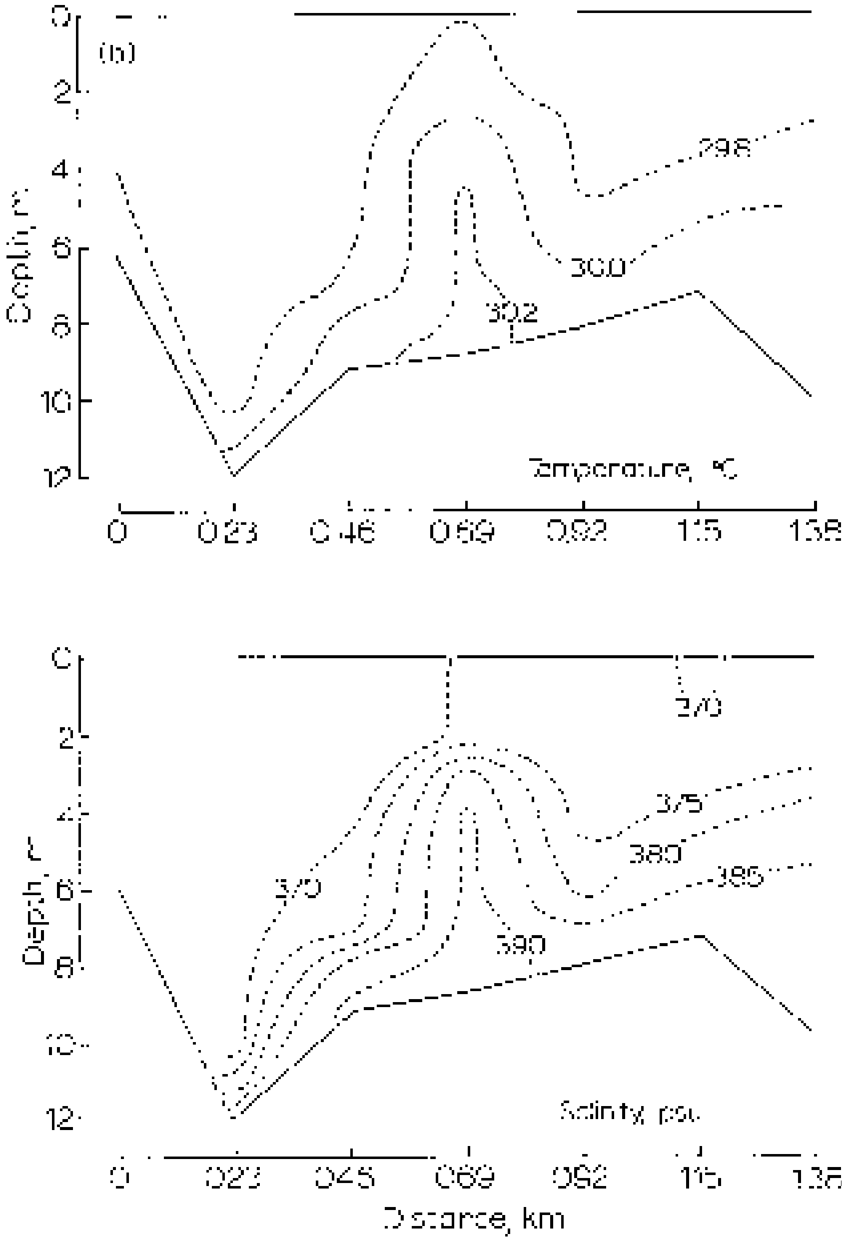

Figure 1. Contour plots of top-to-bottom temperature (top) and salinity (bottom) profiles taken over the shelf seaward of Adderley Cut, July 7, 1998.

half of the water column as it spread to the north (toward the right on the plot), a process that was probably aided by the prevailing northward-directed along-shelf current.

Hydrographic profiles obtained on August 31, 2000, also indicated a hyperpycnal plume over the shelf (not shown), but its characteristics were distinctly different from the plume observed on July 7. The data indicate that lateral spreading of plume water was minimal, confining the hyperpycnal water to a relatively narrow segment (only about 0.2 km in width) of the shelf seaward of the inlet. Within this narrow segment two regions of hyperpycnal water were observed—one at mid-depth and one very near the bottom. Temperature and salinity of core plume water at these two levels were 37.5º C and 29.8 psu, which was approximately 0.5º C warmer and 0.3 psu saltier than the surrounding Exuma Sound water. Unfortunately, data were not collected from Adderley Cut, so temperature and salinity differences between bank and sound waters are unavailable for estimating mixing.

In conclusion, the hydrographic data reported here suggest that as the hyperpycnal bank water exits the tidal passes between Exuma Cays, it sinks and can spread significant distances laterally along the shelf. While entrainment and mixing with Exuma Sound water is relatively strong at the top of the plume, it is weak near the bottom and the plume moves across and along the bottom relatively intact. Thus, it appears that warm hyperpycnal bank water can expose the benthos on the shelf to increases in temperature and salinity above conditions to which they are normally acclimated. This supports the hypothesis that density currents are a mechanism for triggering coral bleaching, at least during summer months and near the tidal inlets.

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