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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

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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

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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

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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

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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.

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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),

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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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