Marine Habitat Mapping Technology for Alaska, J.R. Reynolds and H.G. Greene (eds.)
Alaska Sea Grant College Program, University of Alaska Fairbanks. doi:10.4027/mhmta.2008.10

Twenty Years of Research on Demersal Communities Using the *Delta* Submersible in the Northeast Pacific

Mary M. Yoklavich
National Marine Fisheries Service, Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, California

Victoria O'Connell[1]
Alaska Department of Fish and Game, Commercial Fisheries Division, Groundfish Project, Sitka, Alaska

Abstract

Visual surveys of demersal fishes and their associated habitats are being conducted regularly in deep water (i.e., 30-365 m) off Alaska and the West Coast of North America by numerous research groups using quantitative transect methods from the research submersible *Delta*. The use of *Delta* has been applied primarily to the characterization of fish habitats, with increasing applications to improve stock assessments, evaluate gear impacts, and identify new species. Using *Delta* is no longer an unproven concept, but rather an accepted survey tool as demonstrated in more than 85 peer-reviewed publications since 1988. Maps of seafloor substrata and bathymetric data are commonly used to identify and quantify survey sites, which serves both to increase the cost-effectiveness of the submersible and provide the frame within which to distribute sampling effort. In turn, direct observations from *Delta* can be used to validate the interpretation of such habitat maps. Values that are commonly measured or estimated during *Delta* dives include the number and length of organisms, distance to a fish, and distance along a transect, from which habitat-specific species density, total abundance, and biomass can be calculated. In this paper we review the research that has been conducted using *Delta* during the last twenty years, and consider some potential sources of methodological bias as well as the advantages and some strategies for conducting visual surveys using *Delta*.

Introduction

Continental shelf and upper slope ecosystems off Alaska and the West Coast of North America comprise diverse assemblages of demersal fishes and megafaunal invertebrates. At least 711 species of fishes live on the seafloor from Alaska to Baja California at water depths of 30-400 m (Love et al. 2005b). While there is not yet a comprehensive list of invertebrate species, dense aggregations of several large taxa contribute to the structure of seafloor habitats in this region (e.g., Bizzarro 2002, Heifetz et al. 2005a, Tissot et al. 2006). These demersal communities have been exposed to the pressure of both commercial and recreational fishing with various trawls, gillnets, lines, and traps over many decades. While most of the fish species and nearly all of the invertebrates have not been the direct target of these fisheries, all of these organisms perform critical functions and provide essential services to the ecosystem as a whole, and are vulnerable to fishery impacts.

Over the last decade, there has been increased interest by both state and federal management agencies in describing and conserving habitats of marine demersal species, identifying habitats in need of additional protection, improving stock assessments of demersal fish populations, and evaluating the ecological effects of fishing on these communities. Most of the demersal species in West Coast and Alaska management plans are found in deep water (i.e., >30 m). Yet, until recently, surveys of seafloor marine habitats and associated fishes and invertebrates were limited to observations in shallow water. This was largely because the technology and methods were not developed or available to adequately survey these systems at deeper depths. Additionally, many of the managed demersal species, especially those in the diverse rockfish (*Sebastes*) group, are associated with physically complex rocky habitats (e.g., ledges, crevices, boulder fields, and pinnacles) and are difficult or impossible to accurately survey using conventional methods, such as bottom trawl gear (O'Connell and Carlile 1993). This type of survey gear usually is not effective at sampling small species or fishes living in high-relief habitats, and in addition the species that are collected are integrated over large areas of the seafloor swept by the trawl nets and little or no information on habitat associations is collected.

Over the past twenty years (1988-present), a growing number of researchers from Alaska to California have

[1] Current affiliation is Coastal Marine Research, 107 Finn Alley, Sitka, Alaska 99835, victoria.oconnell@gmail.com.

Table 1. Specifications for the *Delta* submersible.

Maximum operating depth	365 m
Tested depth	520 m
Cruising speed	1.5 knots
Maximum speed	3.5 knots
Total view ports	19
Weight in air	4,536 kg
Length	4.6 m
Beam	1.1 m
Height	1.8 m
Payload	260 kg
Power	(8) 6-V lead acid batteries
Life-support	144 man-hours

developed the tools, technologies, and partnerships to characterize organisms in high-relief rock habitats at 30-365 m water depths. Their approach often integrates geophysical seafloor data collected using sidescan and/or multibeam bathymetric sonars and quantitative visual surveys of demersal fishes, invertebrates, and associated habitats conducted regularly from the research submersible *Delta*.

Using *Delta* is no longer an unproven concept, but rather an accepted survey tool in fishery research in the northeast Pacific. This submersible has successfully completed over 6,975 dives, which have resulted in at least 85 published papers on fisheries research. Additionally, numerous unpublished graduate theses and government reports have been produced from research conducted with *Delta*. From the beginning, this research was supported primarily with funds from U.S. Department of the Interior, Minerals Management Service (MMS), and two U.S. Department of Commerce, NOAA agencies: the National Undersea Research Program (NURP), West Coast and Polar Regions Undersea Research Center (Reynolds et al. 2001), and the National Marine Fisheries Service (NMFS). Most recently, funding also has been provided by the NOAA National Marine Sanctuaries Program, Office of Ocean Exploration, and Sea Grant Program; the North Pacific Research Board; state resource agencies (e.g., California Ocean Protection Council and California Department of Fish and Game); and nongovernment organizations such as the David and Lucile Packard Foundation and California Artificial Reef Enhancement Program (CARE).

Delta is not the first submersible to be used in fishery research in the northeast Pacific. In 1978, the two-person submersible *Nekton Gamma* (a precursor to *Delta*) was used to study bait loss from halibut longline gear (High 1980) and to explore rockfish habitats (Carlson and Straty 1981) in deep water off southeastern Alaska. Straty (1987) continued this research in 1980 and 1983, locating nursery areas and capturing small rockfishes using submersibles *Nekton Gamma* and *Mermaid II*. Richards (1986) and Murie et al. (1994) used the three-person *Pisces IV* in 1984 and 1986 to describe the spatial distributions and behaviors of deepwater rockfish communities off British Columbia. The first characterization of fish-habitat associations in deep water off Oregon was developed by Pearcy et al. (1989) from surveys conducted in 1987 using *Mermaid II*. During the 1970s and 1980s, *Nekton Gamma* and *Johnson-Sea-Link* submersibles also were used in a variety of fishery studies in mid-Atlantic submarine canyons, including a comparison of survey techniques (Uzmann et al. 1977), evaluation of fishing gear performance (Grimes et al. 1982), and abundance and habitat of tilefish (*Lopholatilus chamaeleonticeps*) (Able et al. 1882, Grimes et al. 1986), among others.

The use of *Delta*, as relevant to fishery research in the northeast Pacific, has been applied primarily to the characterization and conservation of fish habitats, with increasing applications to improve stock assessments and evaluate impacts of fishing gear on seafloor habitats. Additionally, new species have been discovered during several of these studies, many species have been photographed for the first time in their natural environment, and descriptions of habitats have been used to groundtruth coast-wide maps of seafloor substrata. In this article, we summarize these published studies, as well as consider the advantages and some strategies for conducting visual surveys from the *Delta* submersible.

Using *Delta* for quantitative surveys

Submersible specifications

Delta is a two-person submersible that is owned and operated by Delta Oceanographics (www.deltaoceanographics.com). *Delta* typically carries an observer and a pilot, operates to a maximum depth of 365 m, and has a cruising speed of 1.5 kts (see Table 1 for additional specifications). The submersible is small enough (4.6 m in length) to be packed in a steel container (about 6.1 m long × 2.4 m wide × 2.6 m high) and transported by aircraft, train, ship, or truck to the location of a research vessel of opportunity. This shipping container also serves as the dive operations shop aboard the support vessel. *Delta* is launched and retrieved using a ship's crane with a lifting capacity of at least 4,536 kg; no divers are required to be in the water at any time during these operations. Occupants and handheld equipment are loaded while the port side of the submersible is secured to the side of the ship against a rubber-tire mat (Fig. 1). Once the submersible is released from the ship, it operates autonomously and is not physically attached to the support vessel. The pilot communicates with Delta Oceanographics personnel via a two-way through-water telephone connection between the submersible and the ship. *Delta*'s maximum life support is 144 man-hours underwater, but generally research dives average about 1-2 hours duration and 6-8 hours of total dive time per day. The amount of time spent underwater is limited by eight 6-V batteries that supply power for submersible operations. Available battery power during a dive depends on submersible run time and speed and number and type of accessories (lights, cameras, sonar, etc.).

Figure 1. The *Delta* submersible is secured against a rubber-tire mat on the side of a support vessel off Mt. Edgecumbe volcano, southeastern Alaska.

The submersible is tracked from the support vessel using a combination of an ORE Trackpoint II Ultra-Short Baseline (USBL) acoustic system, an SG Brown meridian standard gyrocompass, WINFROG (v. 3.1, Fugro, San Diego, California) software, and a Furuno Navigator GP-36 differential global positioning system (GPS). Output from this integrated system allows the scientists to navigate the submersible in real time relative to depth, seafloor habitat maps, historic fishing grounds, dive sites, and other spatial data that have been stored in a geographic information system (GIS). Researchers recently have added other tracking tools, such as an integrated Doppler velocity logger (DVL; Fig. 2a) and ring laser gyro (Fig. 2b), which result in more accurate estimates of distance traveled.

The observer is positioned in the forward belly of the submersible. Observations typically are made through the front ballast chamber and associated view ports, or through the three starboard-side ports; cameras, lights, and lasers are mounted based on the selected viewing option. Equipment usually is not mounted on *Delta*'s port side to avoid damage while the submersible is secured to the ship's rubber-tire mat. The pilot's visibility is enhanced through eight ports in the conning tower. All nineteen ports on the submersible are flat.

Delta Oceanographics supplies two video cameras that can be mounted externally on the submersible: a custom-built color zoom survey camera (Fig. 2c) from DeepSea Power and Light (DSPL) that includes a Sony TR-81 camcorder with 400 lines of resolution and an illumination range of 2-100,000 lux (>100 lux recommended), and a Remote Ocean Systems Inspector underwater color zoom camera. A Horita KCT-50 time-code generator (TCG) is used to overlay time, date, and depth onto the video. An additional Horita PG-2100 TCG can be used inside the submersible to embed time onto the video from the external cameras; this critical step uses the time code to integrate data from video, navigation, and other sensors. Two parallel Marfab red helium neon-scaling lasers are fixed at 20 cm apart on either side of the external video camera (Fig. 2d) and used to estimate size of organisms and habitat features. Researchers have provided additional video cameras, for example a DSPL Super SeaCam 5000 monochrome, low-light video camera mounted externally on the bow of submersible (Fig. 2e), and a variety of handheld video cameras used internally to film through the many ports. External video images are captured on Sony GVD-1000 mini-DV decks mounted inside the submersible. Audio from within the submersible also is recorded on these tapes, allowing for real-time narration by the observer. The *Delta* has an external strobe that is connected to a handheld digital camera used from within the submersible. Ten 150-watt halogen lights are mounted outside the pressure hull, and two lights generally are used to illuminate the field of view of the main video survey camera. A high-intensity discharge light (HID) has been used in the past. However, it required significant power, malfunctions can be dangerous, and greater light intensity potentially can affect fish behavior (e.g., attraction or avoidance).

A Seabird SBE19 Plus Seacat Profiler gathers data on ocean conductivity, temperature, and depth, and is interfaced with a Benthos Data Sonic PSA916 programmable sonar

Figure 2. **Sensors mounted to the *Delta* submersible: (a) Doppler velocity logger; (b) ring laser gyro; (c) color video survey camera; (d) paired scaling lasers; and (e) low-light video camera.**

altimeter. An Imagenex 881 high-resolution sector scanning sonar is available to locate underwater targets. A mechanical arm is externally mounted on the submersible and used to retrieve samples from the seafloor; it is most effective at depths <180 m. A hydraulic arm can be attached to collect samples in deeper water, although this arm's large size and weight preclude effective maneuverability of the submersible and satisfactory surveys. A slurp gun can be mounted for suction sampling. There are spare electronic hull penetrators for installation of other instruments that are provided by the researchers.

The technology available for use on *Delta* continues to improve over time. In the late 1980s, for example, Stein et al. (1992) suspended a demarcated fiberglass rod from a chain in front of the submersible to assist the observer in estimating size of fish. Multiple lasers now are displayed in the video footage and camera frames, providing reference to estimate size both in situ by the observer and from the video and still images. Camera systems have improved from low-resolution to high-resolution color video. Multiple cameras also are being used, both inside and outside, to survey organisms forward and to the side of the submersible's track. High-resolution, monochrome cameras also are being used because they have especially low light requirements (0.001 lux sensitivity) and can result in improved visibility particularly at great distance. Changes in video recording media also have progressed from VHS, to Hi-8, to mini-DV tapes, although direct digital capability is not yet available.

Description of survey techniques

The majority of quantitative surveys conducted from the *Delta* submersible has used belt (strip) transect methods. Belt transects traditionally have been used in scuba surveys to quantify fish density, and many *Delta* surveys have continued to use this approach. Belt surveys must meet the assumption that all organisms of interest occurring within the belt width are seen by the observer. Given the inherent restriction of working with the submersible close to the seafloor, widths of belt transects generally are narrow (2 m or less). This type of survey is particularly well-suited for flat smooth terrain where all organisms can easily be detected, and also is practical in surveys where many fishes are identified and enumerated at one time or in quick succession, thereby making it difficult or impossible to estimate distance to each individual (Stein et al. 1992; Krieger and Ito 1999; Love et al. 2000; Yoklavich et al. 2000, 2002; Jagielo et al. 2003; Anderson and Yoklavich 2007).

Line-transect methods, which do not have a predefined strip width, also have been used to estimate fish abundance from *Delta* (O'Connell and Carlile 1993, Yoklavich et al. 2007). The crucial assumption with this method is that all fishes occurring on the transect line are detected and that there is a decreasing probability of detecting the fish with increased distance from the transect line. One-sided line transects have been conducted from *Delta* off the starboard side, and an accurate measurement of perpendicular distance from the transect line to each fish is required.

O'Connell and Carlile (1993) used line transect methods to survey yelloweye rockfish (*Sebastes ruberrimus*) because they found that the density of this species was too low to provide adequate counts of fish within the narrow belt width needed to meet the assumption of 100% detection in their rocky habitat. Line transects conducted from *Delta* were a superior method to survey some species of rockfishes compared to belt transects conducted either from submersible or remotely operated vehicle (ROV) (O'Connell and Carlile 1994). Recent surveys of cowcod (*S. levis*) also have applied line transect methods for similar reasons (Yoklavich et al. 2007). Both yelloweye rockfish and cowcod are large, distinctive species, which increases the probability of detecting individuals at greater distance from the transect line. Hybrid surveys also have been conducted, whereby one target species (cowcod) is assessed using line transect methods (Yoklavich et al. 2007) and, at the same time, all other demersal fish species are enumerated within a 2 m wide belt transect.

Quadrat sampling has been conducted from *Delta* by selecting video frames along a transect line (Zhou and Shirley 1997, Else et al. 2002). The camera's field of view forms a trapezoid on the seafloor, and the sample area can be calculated if camera angle and focus are fixed. This type of sampling is most effective on flat sediment, as steep slope and high relief of the seafloor will affect the field of view and estimated area of the sample.

Figure 3. Scientific observer estimates distance to an underwater target by using a handheld sonar gun from inside the *Delta* submersible.

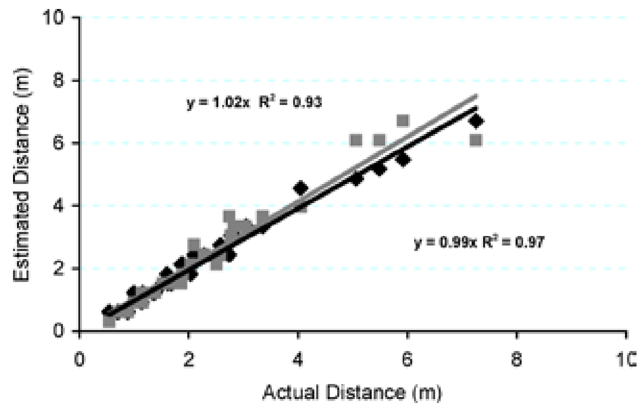

Figure 4. Regression of actual distance versus distance to targets estimated by an observer inside the *Delta* submersible as it moves along a transect line; symbols indicate two different surveys of the targets (David Carlile and Victoria O'Connell, ADFG, 2001, pers. comm.).

As with other assessment methods, quantitative visual surveys conducted from the submersible have potential bias and error associated with estimated densities, abundance, and biomass. Issues of concern that are common among all types of fish surveys relate to potential fish avoidance or attraction to the survey gear, correct identification of species (especially with visual surveys), and accuracy of measurements (e.g., distance to the fish in line transects, field of view of quadrat and belt transect, length of fish, distance traveled along the transect).

O'Connell and Carlile (1993) used a low-cost, handheld diver sonar gun to provide perpendicular distance from the transect line to the fish. The tip of the gun is fitted with a water-filled latex reservoir, dampened, and pressed against the port from inside the submersible in order to acquire a distance to target (Fig. 3). Other researchers are now using this method to calibrate the observers' abilities to estimate distance under water (Yoklavich et al. 2007; Love and Yoklavich 2007; Jon Heifetz, NMFS Auke Bay Laboratory, Alaska, 2008, pers. comm.). Experiments with diver-placed targets at fixed distances (unknown to observers) on the seafloor have validated the accuracy of this method (Fig. 4; David Carlile and Victoria O'Connell, Alaska Department of Fish and Game [ADFG], 2001, pers. comm.). Yoklavich et al. (2007) conducted similar experiments with four observers, and also included an evaluation of estimated fish size (using the paired lasers) and transect length (USBL navigation data versus known length of longline). Overall, underwater estimates of size of five demersal fish species were 4% less than actual measurements; distance to fish also was slightly underestimated (mean deviation = –0.1 m, SD = 0.1). Transect length was overestimated on average 7% (n = 23) using the *Delta*'s USBL navigation system. From this type of data, observer-specific correction factors can be established to improve survey results.

Kocak et al. (2002) have combined a multiple-laser/video photogrammetric system with navigation for use in quantitative benthic surveys from *Delta*. The system includes a roll/pitch motion reference sensor, CCD video camera, three microlasers, a DVL, ring laser gyro, USBL sonar, and integrated positioning system software. While this system is still undergoing development, the goal is to improve survey methods using image-processing techniques to allow perspective analysis, range to a point or locations, and scale in any region of the image, as well as to improve estimated area of the sample and estimated length and navigation of the track line.

The effect of the submersible on fish behavior is an important consideration when conducting visual surveys. Stoner et al. (2008) reviewed observations of the response to various underwater vehicles (e.g., small ROVs, towed cameras, and occupied submersibles such as *Delta*) for 46 demersal marine fish taxa, and suggest that almost all taxa react in some way under certain circumstances. Vehicle operations, including levels of light, sound, and speed, should be considered in context with the organism of interest when designing surveys. One of the authors (O'Connell) has noticed that pelagic yellowtail rockfish (*S. flavidus*) were both attracted and repelled by the submersible depending on operations; pelagic schools often were observed following the submersible, apparently feeding on plankton illuminated by the submersible lights. Conversely, these fishes startled easily if the submersible contacted the bottom quickly or expelled ballast air. Yelloweye rockfish generally appeared

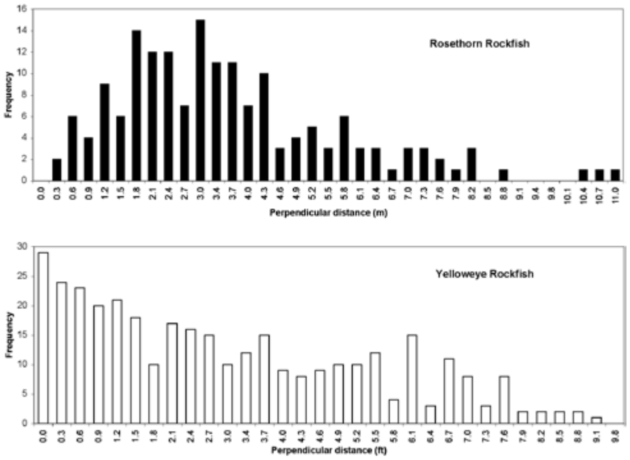

Figure 5. **Distribution of perpendicular sighting distances for rosethorn and yelloweye rockfishes surveyed from the *Delta* submersible in southeastern Gulf of Alaska (David Carlile and Victoria O'Connell, ADFG, 2001, pers. comm.).**

undisturbed by the submersible moving along a transect, but would approach the vehicle if *Delta* was stationary on the seafloor. Therefore, a slow constant forward movement is required when surveying yelloweye rockfish or similar species. There was minimal response of sedentary, solitary sablefish (*Anoplopoma fimbria*) to the approaching submersible, while groups of active sablefish reacted by moving a short distance away (Krieger 1997). Yoklavich et al. (2007) used a forward-directed low-light camera and documented no behavioral response (i.e., neither attraction or avoidance) of cowcod to submersible operations. Jon Heifetz (NMFS Auke Bay Laboratory, Alaska, 2008, pers. comm.) noted that juvenile rockfishes often hid in the interstices of closely packed cobbles as the *Delta* approached, making these small fishes difficult to detect.

Line-transect data also can reveal behavioral characteristics of some fishes. The distribution of perpendicular sighting distances collected using *Delta* illustrates reduced detections of rosethorn rockfish (*S. helvomaculatus*), a relatively small species, closest to the submersible, and no avoidance for a larger species (yelloweye rockfish) in surveys off Alaska (Fig. 5; David Carlile and Victoria O'Connell, ADFG, 2001, pers. comm.). Rosethorn rockfish seek shelter in the rocks as the submersible approaches, making them less visible to the observer.

Hixon and Tissot (2007) evaluated effects of the submersible on fish behavior by interspersing a "quiet period," when lights and motors were turned off for 10-15 minutes, between each pair of transects during a dive. No change in the local abundance or distribution of demersal fishes was detected when the submersible was reactivated, leading to the conclusion that the presence of the submersible caused little sampling bias.

Delta's contribution to fishery research

Describe and conserve essential fish habitats

Visual surveys of demersal fishes and their associated habitats have been conducted regularly since 1988 in deep water (i.e., 30-365 m) by numerous research groups using quantitative transect methods from the *Delta* submersible. These studies have resulted in at least 50 publications, which primarily focus on habitat-based, multispecies characterizations of seafloor fish assemblages.

The first of these *Delta* surveys was conducted off Oregon's Heceta Bank in 1988 (Stein et al. 1992), and additional surveys continued in this region in 1989-1990 (Tissot et al. 2007). Four habitats (i.e., shallow rock ridges-boulders, mid-depth boulder-cobbles, deep cobbles, and deep mud slope) were associated with distinct fish and invertebrate assemblages. While some of the survey tools have been improved over time, the general transect methods and classification of substratum types using binary codes (e.g., a habitat patch designated as "BC" comprised at least 50% boulders and at least 20% cobble) have served as templates for several similar studies that have since been conducted along the West Coast. Stein et al.'s (1992) historic surveys demonstrated the use of the *Delta* to collect meaningful information at spatial scales relevant to the distribution of fishes living in physically complex, deep, rocky habitats, and serve as a baseline for future evaluations of change in these assemblages. More recent research on the demersal communities of Heceta Bank has integrated the fine-scale fish-habitat associations determined from the early *Delta* surveys with broad-scale, high-resolution multibeam sonar imagery of the seafloor collected in 1998 (Nasby-Lucas et al. 2002, Wakefield et al. 2005).

In the early 1990s, several studies were conducted in the eastern Gulf of Alaska (GOA) using the *Delta* submersible to characterize habitat for a variety of sedentary deepwater fish species (Krieger 1992, O'Connell 1993, O'Connell and Carlile 1993, O'Connell et al. 1998, Krieger and Ito 1999, Else et al. 2002, Greene et al. 2007). Some of these species were observed in their natural environment for the first time. From these surveys, methods were developed to identify, describe, and quantify demersal species and habitats using direct observations. Most recently, Shotwell et al. (2007) characterized benthic habitats in the central GOA by integrating high-resolution acoustic information on seafloor substratum types with biological data collected from *Delta* submersible and bottom trawls.

Delta also has been used extensively to survey macroinvertebrates in deepwater habitats of the GOA. Hoyt et al. (2002) characterized movements and habitats of tagged golden king crab (*Lithodes aequispinus*), and Stevens et al. (1992; Pacific lyre crab, *Hyas lyratus*) and Stone et al. (1993; red king crab, *Paralithodes camtschaticus*) described the aggregating behavior of crabs. Masuda and Stone (2003) conducted in situ surveys of the weathervane scallop (*Patinopecten caurinus*) and reported on their orientation to prevailing bottom currents and association with other demersal macroinvertebrates.

There have been several surveys using the *Delta* submersible to investigate the diversity and distribution of deepwater corals and associated macroinvertebrates and fishes in the eastern GOA and Aleutian Islands. Data collected by ADFG during surveys conducted for rockfish assessments in the GOA have been re-analyzed to describe distribution of corals, sponges, and anemones (Bizzarro 2002). Ten megafaunal fish and invertebrate groups used the red tree coral (*Primnoa* spp.), in particular, for feeding and shelter (Krieger and Wing 2002). Freese and Wing (2003) used the *Delta* to evaluate associations between juvenile red rockfishes and sponges. Brooke and Stone (2007) collected several species of deepwater hydrocorals (Sylasteridae) using *Delta* in the Aleutian Islands, described their reproductive traits, and concluded that there is limited potential for these corals to recolonize following large-scale disturbance (e.g., removals). *Delta* was the primary collection platform for a comprehensive study of the distribution of deep-sea coral habitats in the Aleutian archipelago (Heifetz et al. 2007). Interactions among fisheries and structure-forming macroinvertebrates that share similar spatial distributions have been examined during *Delta* surveys in the GOA (Heifetz et al. 2005b, Stone et al. 2005) and the Aleutian Islands (Stone 2006), and were noted on the recently discovered sponge reefs off British Columbia, Canada (Krautter et al. 2001; Conway et al. 2001, 2005).

Delta has been used routinely off the central California coast since 1992, focusing primarily on diverse rockfish assemblages in deep water. Geo-referenced maps of the seafloor, acquired from sidescan sonar and multibeam bathymetry, have been used to identify, quantify, and select sites of appropriate bottom type and depth for visual surveys (Yoklavich 1997; Yoklavich et al. 1993, 1995; Anderson et al. 2005). Baseline data on fish densities, size, distribution, and habitat associations have been collected on the major rocky banks inside and outside marine protected areas (Yoklavich et al. 2002) and on the continental shelf and submarine canyons of Monterey Bay (Yoklavich et al. 2000). These visual methods have resulted in habitat-specific assemblage analyses on multiple spatial scales (Anderson and Yoklavich 2007), and in the implementation of eight new marine protected areas (MPAs) off central California. An extensive 43-day cruise, including researchers from Alaska to southern California, was completed in November 2007 using *Delta* and direct observation methods to monitor demersal communities inside and outside these newly established MPAs (Yoklavich, pers. observation).

The *Delta* submersible also has been a valuable tool in the development of innovative methods to tag and track rockfishes in deepwater habitats off central California (Starr et al. 1998, 2000; Voegeli and Starr 2000). These methods and *Delta* subsequently have been used to study movements and habitats of bocaccio (*S. paucispinis*) and greenspotted rockfish (*S. chlorostictus*) in a submarine canyon in Monterey Bay, California (Starr et al. 2002) and lingcod (*Ophiodon elongatus*) in Southeast Alaska (Starr et al. 2004, 2005).

For the last decade, the *Delta* submersible has been used to characterize fish assemblages around oil platforms and adjacent natural rocky areas off southern California. Several distinct assemblages, all dominated by rockfish species, live in the mid-water and bottom habitats associated with 19 platforms, and these assemblages vary with location, depth, and amount of shelter provided by the platform (Love et al. 2000, Love and York 2006). The importance of habitat structure, measured by size and number of rock crevices on nearby natural outcrops, has been demonstrated for several common demersal fish species (Love et al. 2006a, Love and Yoklavich 2007). Oil pipeline (Love and York 2005) and mussel mounds (Love and Yoklavich 2008) adjacent to the platforms represent habitat for young rockfishes and dwarf species in particular. These platforms potentially could help to rebuild overfished stocks (Love et al. 2006b), and some serve as de facto reserves (Love et al. 2005a). All of this research has implications for the ongoing process of decommissioning oil platforms.

Video archives associated with the many visual surveys conducted with the *Delta* submersible are now being re-examined to quantify the role that macroinvertebrates play as structural components of fish habitats. Distribution and abundance of structure-forming invertebrates (such as corals, sponges, anemones, sea pens, crinoids, and brittle stars) have been assessed in deep water (30-330 m) on major offshore rocky banks in the Southern California Bight (Tissot et al. 2006), Heceta Bank, Oregon (Tissot et al. 2007), and Southeast Alaska (Bizzarro 2002). Assessments continue to be made from previously collected video data elsewhere along the coast (Brian Tissot, Washington State University 2008, pers. comm.). Re-examining data from past *Delta* surveys is improving our understanding of essential fish habitat (EFH) for groundfishes and our ability to protect these systems.

A standard classification scheme, based on geophysical and biological descriptors, has been developed for shelf and upper slope habitats from Alaska to southern California (Greene et al. 1999), and is being widely used by local, state, and federal managers. This effort was catalyzed by the collaborative research efforts of geologists and biologists, and their use of the *Delta* submersible to verify interpretations of the seafloor and to characterize fish-habitat associations (O'Connell and Wakefield 1995, Yoklavich et al. 1997, Greene et al. 2007). While there are certainly more cost-effective tools available to groundtruth seafloor habitat maps under certain conditions (e.g., camera sleds in low relief habitats), the information on demersal habitats and associated fishes gathered during surveys using *Delta* has proven to be critical in describing and informing management decisions on EFH (Copps et al. 2007, NMFS 2008), and in designing and designating marine protected areas (O'Connell et al. 1998).

The general concordance of habitat specificity is remarkable among assemblages of demersal fishes and invertebrates that have been surveyed using *Delta* from Alaska to California. Based on these findings, textbooks have been assembled to help interpret this growing literature (Love et al. 2002, Love and Yoklavich 2006). The next step is the development of coast-wide geodatabases of habitat, fishes, invertebrates, and marine debris from the many *Delta* surveys that have used similar methodologies. From such a data set, we will be able to quantify patterns of habitat use, understand their function, and evaluate potential impacts on a broad scale.

Improve stock assessments and inform management decisions

The *Delta* has been an important tool in developing, evaluating, and improving stock assessment surveys for fishes that occur in rugged rocky terrain. Federal surveys for groundfishes are generally conducted using trawl gear. However, there are significant areas of habitat along the West Coast and the GOA that are not accurately surveyed using trawls, yet are inhabited by economically important species (primarily rockfishes) (Shaw et al. 2000).

ADFG began a habitat-based stock assessment survey for six species of demersal shelf rockfish (DSR) in 1989, using the *Delta* submersible to conduct direct observation line transect surveys in the Southeast Outside subdistrict of the Eastern GOA (O'Connell and Carlile 1993, O'Connell et al. 2001). Geophysical tools are used to map and delineate areas of rockfish habitat (O'Connell et al. 2005, 2007; Greene et al. 2007). Biomass estimates of DSR are calculated as the product of (density) × (estimated area of habitat) × (mean weight of adult fish). This was the first *Delta* survey to be used directly in stock assessment and management. Improvements to this survey have been made over time, and a biennial stock assessment is published as part of the North Pacific Fishery Management Council Gulf of Alaska Stock Assessment and Fishery Evaluation Document (e.g., O'Connell et al. 2001, 2005).

Jagielo et al. (2003) used belt transects conducted from the *Delta* to estimate densities of several demersal fish species in trawlable (e.g., low-relief, soft sediments) and untrawlable (e.g., high-relief rock) habitats in a relatively small area (about 85 km^2) on the continental shelf off Washington. The rockfish species complex was three times more abundant in untrawlable areas than in trawlable habitats. They concluded that relatively large-scale surveys of both seafloor habitats and associated fishes are needed to accurately estimate densities of demersal fishes in untrawlable areas. Although it may be possible to derive an area-specific correction factor for trawl-survey bias for some flatfish species, direct estimation of densities is needed for many demersal species, and visual quantitative transect methods from the *Delta* submersible are useful for this purpose (Jagielo et al. 2003).

A line-transect survey conducted in 2002 from the *Delta* submersible has been used successfully to assess the cowcod stock inside large cowcod conservation areas (CCAs; 14,750 km^2) off southern California (Yoklavich et al. 2007). The cowcod is one of several overfished rockfish species on the West Coast and has a relatively sedentary lifestyle among high-relief rocky outcrops and banks. This was the first visual, non-extractive, habitat-specific survey of this species, and the resultant fishery-independent data have contributed to an improved stock assessment used by the Pacific Fishery Management Council to manage and conserve cowcod (Dick et al. 2007). *Delta* also has been used off islands and banks in southern California to describe habitat of white abalone (*Haliotis sorenseni*) and to identify brood-stock and outplanting locations of this endangered species (Lafferty et al. 2004).

A series of studies on various species of demersal fishes has compared abundance estimated from trawl surveys with that from visual assessments using the *Delta* submersible in the GOA. Abundances of shortraker (*S. borealis*) and rougheye rockfish (*S. aleutianus*) were substantially underestimated by trawl surveys compared with the submersible assessment (Krieger 1993). Mean observation rate of fishes from the submersible was about twice that from bottom trawl surveys, likely because the trawl gear used in this study was not designed to effectively sample the steep-slope boulder habitats occupied by these species (Krieger 1992, Krieger and Ito 1999). Abundance of shortspine thornyhead (*Sebastolobus alascanus*) was several times higher from surveys using the *Delta* than estimated from bottom trawl surveys (Else et al. 2002). Bottom-trawl catchability coefficients, which can be critical for accurate interpretation of stock assessments of demersal fishes, also have been determined by comparing trawl catch rates to densities estimated from *Delta* for Pacific ocean perch (*S. alutus*) in GOA (Krieger and Sigler 1996).

A comparative study of relative abundance of rockfishes was conducted off Oregon using belt-transect survey methods from *Delta* and hydroacoustic methods (Starr et al. 1996). Densities of fishes estimated from the submersible were more than six times greater than estimated from acoustic surveys in the same depth stratum. A combination of the two survey methods provided the best estimate of relative abundance of rockfishes. Submersible surveys were useful in identifying acoustic targets and in surveying fish near and on the seafloor, while acoustic sampling was effective at surveying fishes in the water column, which is not well-sampled during submersible transects.

Evaluate gear impacts

Delta has played an instrumental role in the few studies that have evaluated impacts of fishing gear on the seafloor. The first study to document effects of trawling on benthic communities off the West Coast was conducted using *Delta* near Monterey, California (Engel and Kvitek 1998) and concluded that areas of high trawl intensity had reduced habitat complexity and biodiversity compared to less-trawled areas.

In the eastern GOA, *Delta* surveys have been used to document short-term effects of trawling on hard-bottom habitats (e.g., boulder, cobble, and pebble) in deep water (about 200-300 m) (Heifetz 1998, Heifetz et al. 2005b). Direct observations from *Delta* along the path of the trawl have been made immediately after trawling (Freese et al. 1999) and one year later (Freese 2001). A single pass of the trawl resulted in a significant decrease in density of sponges and anthozoans, and in displacement of boulders. There was a persistent reduction in the population density of sponges in the year following trawl impact, and damage to individual sponges also lasted at least one year. Damaged colonies of the red tree coral (*Primnoa* spp.), as evidenced by many broken branches, detachments, and displacements, were documented using *Delta* on the seafloor in the path swept seven years earlier by a single research trawl in the GOA (Krieger 2001). Freese (2001) concluded that reductions in habitat complexity caused by trawling may be more persistent in deep, cold-water habitats than in shallow, warmer water.

In another Alaska study using *Delta*, epibenthic communities on soft sediment in trawled areas were compared with those in areas closed to bottom trawling for over a decade in the central GOA (Stone et al. 2005). While there were significant differences in abundance and species diversity of epifauna between the two areas, the magnitude of these differences was considered minimal compared to the effects of trawling in more complex habitats (Stone et al. 2005). There was evidence, however, that change to the seafloor and associated biota can affect availability of prey for economically important demersal fish species. Masuda and Stone (2003) found no significant difference in densities of adult weathervane scallops surveyed with *Delta* inside and outside closed areas off Kodiak Island, but scallops were significantly larger inside the closures. The *Delta* submersible also has been used to document the diverse coral garden habitat off the Aleutian Islands (Heifetz et al. 2005b, 2007; Stone 2006), and the sponge reefs on the Canadian continental shelf off British Columbia (Krautter et al. 2001; Conway et al. 2001, 2005), highlighting fisheries interactions with these vulnerable habitats.

Most recently, Hixon and Tissot (2007) compared mud seafloor communities in trawled and untrawled areas using *Delta* off the coast of Oregon. Densities of fish and epibenthic invertebrates were higher in untrawled areas, and species assemblages were different from the trawled sites. They concluded that differences between the trawled and untrawled demersal fish and macroinvertebrate communities on these deep mud sites were the result of adverse trawl impacts rather than from local environmental differences.

Discover new species

Several new species of demersal macroinvertebrates recently have been discovered with the aid of the *Delta* submersible. Lehnert et al. (2005a,b; 2006a,b) described nine new species of sponges from collections and images taken with *Delta* off the Aleutian Islands, Alaska. The black Christmas tree coral (*Antipathes dendrochristos*) was discovered from *Delta* off southern California during fish and habitat surveys (Yoklavich and Love 2005) and described for the first time by Opresko (2005). From a dead colony collected from *Delta*, the Christmas tree coral reaches an age of at least 140 years and provides shelter to a diverse group of thousands of organisms (Love et al. 2007). Collections of the newly described gorgonian coral (*Alaskagorgia aleutiana*) were supplemented with specimens collected from *Delta* (Sanchez and Cairns 2004). Two new taxa of modern foraminifera were described from specimens attached to sponges collected using *Delta* on the continental shelf off British Columbia (Guilbault et al. 2006). Most aspects of the taxonomy, biology, and ecology are unknown for many macroinvertebrate species in deep water. Although *Delta*'s mechanical arm is cumbersome to use at depths >180 m (because of increased pressure with depth) and therefore not ideal for collecting material beyond that depth, species identification, distribution, and abundance of many of these organisms are being realized as a direct result of increased opportunities to explore deepwater communities using observational research platforms such as *Delta*.

Consideration of *Delta*'s attributes

One of the main goals of the Marine Habitat Mapping Technology Workshop for Alaska was to develop criteria to select appropriate and cost-effective underwater survey tools. While that choice is dependent on specific research objectives and available budgets, here we suggest some variables to consider in such a cost-benefit analysis, with information relevant to the *Delta* submersible.

1. Typical duration of operations. For *Delta* this is nominally 12 hours per day, with actual dive time between 6 and 8 hours depending on available battery power.
2. Total cost of operations, including initial cost of investment, pilots and support crew, maintenance, and insurance. As of 2007, this is about $6,000 per day for *Delta*.
3. Limitations and cost of a support vessel. The *Delta* is a portable platform that is relatively quick and easy to deploy from a variety of support vessels, which range in length from 18 to 91 m (but most typically are about 30-35 m). For *Delta*, the ship must have a crane with a 4,536 kg dynamic-lifting capacity. The cost for such a vessel, as of 2007, is about $5,000 per day.
4. Maximum depth of routine operations. This is 365 m for *Delta*.
5. Typical speed of operations in survey mode. This is 0.4-1.0 knot for *Delta*.
6. Seafloor substratum (i.e., flat or soft substratum versus rugged, rocky seafloor). *Delta* is highly maneuverable and tractable in high-relief, rocky topography, which results in an effective survey tool for such habitats.
7. The ability to identify fishes in survey mode. Detection and identification of diverse communities in complex, deepwater habitats are enhanced with an in situ observer in the *Delta* submersible versus observations made from videotape alone. This is especially true of small species and individuals, and of co-occurring species with similar morphological characteristics

(e.g., the *Sebastomus* rockfish subgenus with at least ten species off southern California). Observers using *Delta* typically identify an average of about 95% of the diverse rockfish species during surveys.

8. Magnitude of disturbance to behavior of target organisms caused by vehicle noise, lights, and motion. *Delta* is a non-extractive survey tool with relatively little environmental impact. *Delta* uses only 300 watts of halogen lighting with the survey video camera. Because it is autonomously operated and controlled in situ by a skilled pilot (and not towed remotely via a tether), disturbance from *Delta* to organisms and habitat is considered to be minimal compared to other survey vehicles (also, see discussion of potential impacts in this paper).
9. Limits of sea state and other environmental conditions during routine operations. These are variable and dependent on specific circumstances for most vehicles. *Delta* typically can be used up to a Beaufort Sea State of 4-5, but this is difficult to quantify because its use also depends on periodicity and direction of the sea swells, wind direction relative to swell direction, and atmospheric visibility coupled with the experience of a particular support crew. Multiple sea swells from different directions (i.e., cross swells) are especially problematic. Deployment and recovery of *Delta* require at least 1 km of horizontal visibility at the sea surface, and night operations require optimal conditions.
10. Biases in detection (see text in this paper).
11. Post-survey data processing. Optimally, this is about 1:3 (survey time: process time) for *Delta*, although this ratio can reach 1:10 to process data from extremely diverse habitats and assemblages.

Acknowledgments

We thank the past and present *Delta* owners (C. Ijames, D. Privett, D. Slater, and R. Slater) and pilots (especially J. Lilly) for consistently offering the scientists a safe and useful vehicle to observe and quantify demersal communities off Alaska and the West Coast. We acknowledge all the scientists associated with the *Delta* submersible for helping to develop the tools needed to produce an impressive collection of research papers. We thank our colleagues D. Carlile, G. Greene, J. Heifetz, C. Ijames, M. Love, T. Laidig, B. Stone, W. Wakefield, and three anonymous reviewers for their helpful comments on this manuscript. We thank J. Reynolds for convening the Marine Habitat Mapping Technology Workshop for Alaska, for our invitation to participate, and providing the opportunity to write this review. We especially acknowledge the NOAA West Coast and Polar Regions Undersea Research Center for its continued support of *Delta*. Thanks also to the North Pacific Research Board (NPRB) for their sponsorship of the workshop. NPRB publication no. 169.

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Marine Habitat Mapping Technology for Alaska

Edited by

Jennifer R. Reynolds
University of Alaska Fairbanks
School of Fisheries and Ocean Sciences, and

H. Gary Greene
Moss Landing Marine Laboratories
Center for Habitat Studies

Published by Alaska Sea Grant
for North Pacific Research Board

AK-SG-08-03

Elmer E. Rasmuson Library Cataloging in Publication Data:

Marine habitat mapping : what is it, and why do managers need it? / edited by Jennifer R. Reynolds, H. Gary Greene.—Fairbanks, Alaska : Alaska Sea Grant College Program, University of Alaska Fairbanks, 2008.

CD-ROM. (Alaska Sea Grant College Program, University of Alaska Fairbanks)

Notes: Proceedings of the workshop Marine Habitat Mapping Technology Workshop for Alaska, April 2-4, 2007, Anchorage, Alaska.

Includes bibliographical references.

ISBN 978-1-56612-131-6
doi:10.4027/mhmta.2008.00

1. Marine animals—Habitat—Alaska—Remote sensing. 2. Marine ecology—Alaska—Remote sensing. 3. Marine resources—Alaska—Remote sensing. 4. Marine resources—Alaska—Management. I. Reynolds, Jennifer R. II. Greene, H.G. III. Series: Alaska Sea Grant College Program report; AK-SG-08-03.

GC1021.A4 M37 2008

Credits

Published by the Alaska Sea Grant College Program, supported by the U.S. Department of Commerce, NOAA National Sea Grant Office, grant NA06OAR4170013, project A/151-01; and by the University of Alaska Fairbanks with state funds. The University of Alaska is an affirmative action/equal opportunity employer and educational institution. Funding for the publication is provided by the North Pacific Research Board, award no. 615 to the University of Alaska Fairbanks. This is NPRB publication no. 190.

Sea Grant is a unique partnership with public and private sectors combining research, education, and technology transfer for public service. This national network of universities meets changing environmental and economic needs of people in our coastal, ocean, and Great Lakes regions.

Page layout and cover design by Jen Gunderson, and editing by Sue Keller, of Alaska Sea Grant. Cover image: Seafloor bathymetry on the northeast slope of Bobrof Volcano, central Aleutian Islands. Image from J.R. Reynolds and H.G. Greene.

Alaska Sea Grant College Program
University of Alaska Fairbanks
P.O. Box 755040
Fairbanks, Alaska 99775-5040
Toll free (888) 789-0090
(907) 474-6707 fax (907) 474-6285

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