

NOAA NMFS ROV Operations

USE OF A REMOTELY OPERATED VEHICLE AS A FISHERIES SURVEY TOOL

NOAA
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November 2004

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1. Executive Summary

To minimize negative impacts on organisms being studied it is important to use non-destructive sampling methods when possible. Depending on the life history characteristics and habitat type of the study organism this can be a large challenge. SCUBA diving surveys are a natural choice for non-destructive sampling, but animals that occur in relatively deep water (> 30 m) cannot be studied effectively by these means due to the time-consuming nature of SCUBA surveys. Manned submersibles have been used to study deep dwelling organisms, but are costly in general, especially when extensive and repeat surveying is necessary. The use of remotely operated vehicles (ROVs) is a relatively low cost, non-destructive method that is ideal for surveying many deep dwelling organisms.

The use of ROVs to survey invertebrates and fishes has moved from a design and development phase to a standard procedure at the NOAA Fisheries South West Fisheries Science Center (SWFSC). The aim of this manuscript is to document the scientific and technical knowledge of the SWFSC ROV program to assist others working with ROVs, and to compile the extensive knowledge acquired during the design phase of the ROV program. The study organisms to date have included the white abalone (*Haliotis sorenseni*) and various rockfish species. These case studies will provide examples of the ability of scientists to use ROV surveys to study organisms ranging from slow-moving invertebrates to highly active fish. Use of an ROV for stock assessment has proven to provide a large amount of information with a reasonable amount of effort and expense. Additionally, surveys are captured by video and still camera for permanent documentation. The ROV program design described in this manuscript has proven useful for many purposes and is worthy of emulation by others seeking similar survey methods.

2. Introduction

2.1 ROV Project Management

The sampling techniques used for stock assessment in fisheries biology could be described as trying to count trees, which you can't see, that keep moving around. While the use of SCUBA diving has allowed biologists to study a number of marine species, excursions are limited to shallow depths. When scientists want to conduct research on living creatures at depths greater than 20 or 30 meters below the surface, they often need to resort to increasingly complicated and expensive machines. In recent years the use of remotely operated vehicles (ROVs) has increased in popularity as a research tool for studies of deeper living organisms.

At the NOAA SWFSC a ROV program based around a Phantom DS4 ROV has been in place since 1999. Since the inception of the program, 22 ROV cruises have been completed, with studies focused on squid fecundity, rock fish population assessment, and abalone conservation.

Although ROVs are now commonly used by researchers, they are typically not "off the shelf" items. Rather, they are complicated systems comprised of mechanics, electronics, and computers, where, in most cases, each component has been designed for a broad range of applications and must be adapted for specific use on the ROV. When combined with the extreme operational conditions in which ROVs operate, this adaptive engineering means that there is a high potential for multiple equipment failures during cruises. In addition to these technical difficulties, ROVs are often tasked to multiple programs, and at least for research, must be used within the rigorous demands of scientific design.

All of these facts make project management of ROV operations a demanding task. In such a complex working environment, the in-house knowledge of protocols that resides in the cumulative experience of staff is vital to the smooth operation of ROV programs. The problem with in-house knowledge, especially in small teams, is that it can be easily lost when staff members leave the organization. To combat this project management dilemma this document attempts to consolidate the technical knowledge developed since the inception of the ROV program in 1999.

2.2 Examples of ROV research objectives

NOAA research on the endangered white abalone (*Haliotis sorenseni*) is focused on stock assessment at various locations in its geographical range. As the species has been over-exploited and lives beyond SCUBA-safe depths, ROV surveys are used to locate, count, estimate size and photograph abalone. A secondary aim is to map the locations of individual white abalone so at a later

date brood stock can be collected for a captive breeding program. The majority of suitable habitat in California is currently being sampled which will increase the confidence of the population estimate.

NOAA rockfish research has used ROV sampling techniques to assess southern California rockfish populations and to provide ground-truthing for sonar surveys aimed to identify rockfish assemblages. Additionally, the ROV is used to ground-truth sonar classification of rockfish habitat. The target rockfish species are found well below diver-accessible depths (~200 m), so the use of the ROV for video transects is very valuable. The ROV is used to survey fish schools, photograph fish for identification, and provide a view of the bottom for bottom-typing. Key species, such as cowcod and vermilion rockfish, are identified, counted, and measured.

3. Overview of the ROV System

3.1 The ROV

The specifications of the Phantom DS4 ROV were chosen based on the physical and biological requirements of the sampling design. The Phantom is powered laterally by four $\frac{1}{2}$ horsepower motors, vertically by two $\frac{1}{4}$ horsepower motors, and can dive to a maximum operating depth of 600 meters. The optical infrastructure consists of both streaming video and digital still cameras. While the base ROV unit is fairly simple, the system can be modified to fit the needs of a specific project (a list of overboard ROV equipment and specifications is provided in Appendix I). For example, in the case of the white abalone project, precise positioning data for the ROVs location on the bottom is necessary so brood stock can be collected by SCUBA divers. Obtaining this data requires implementing a vehicle tracking system that consists of a multi-beacon mounted on the ROV and a directional hydrophone mounted on the support vessel. The ROV also sends bearing, speed, depth, altimeter, temperature, and pitch and roll data back up the tether cable. These data are combined with a Differential Global Positioning System (DGPS) and Pitch and Roll sensor on the support vessel and then fed into a computer program called WinFrog. The program combines all of these data (and data from any other instrument that is added to the system) to be plotted on a computer screen displaying the ROVs position in real time. This allows for accurate estimates of transect distance to be obtained for each ROV dive.

Two sets of lasers are included on the ROV: one is spaced 10 cm apart for measuring abalone, and the second set is comprised of three horizontally aligned lasers with two fixed and one that is angled and therefore wanders. This second set of lasers provides a metric: when the wandering laser and outer fixed laser cross, the vehicle is ~ 2 m from this point. This allows for an accurate estimate of transect width.

3.2 The ROV console and heads up display

The more components to a ROV system the more complex the console arrangement becomes. It is also interesting to note that the system hardware and software are of varying ages. For instance, the Trackpoint technology is at least 30 years old. The ROV on-screen display that displays video and bearing information is also fairly antiquated, but like Trackpoint is robust technology. The on-screen display can also display text, allowing for meta-data to be recorded for each dive.

Due to the need to accurately plot the position of the ROV on the bottom the console arrangements for the abalone project are particularly complex, leading to the need for prior technical knowledge. To ease this reliance on personal knowledge the console components and arrangement are documented and diagrammed (Figure 1) so that set up and break down processes can be successful, even with inexperienced staff. A component list of the console equipment and software is provided in Appendix II.

3.2.1 Directional Hydrophone, Transponder and Trackpoint

By mounting a directional hydrophone on the side of the research vessel and a transponder on the ROV, surface tracking of the ROV during dives is possible. The transponder is located on the top of the ROV and needs to be activated before each dive. It “pings” at a rate of once every two seconds. The output data from these instruments are initially displayed on the Trackpoint monitor plotting the location of the ROV in relation to the relative position of the boat. This data is also sent to the ROV tracking program, WinFrog, for display on the computer monitor, hence the Trackpoint monitor provides a built-in redundancy in case of computer malfunctions. These data are crucial to launch, retrieval and piloting of the ROV as the ROV can never stray either too far from the vessel or too close to the propellers.

When moving between sites the directional hydrophone can remain bolted into position as long as the vessel does not exceed a speed of approximately eight knots.

3.2.2 DGPS

Positional data from a Differential Global Positioning System (DGPS) located on the surface are used along with the positional information obtained from the hydrophone/transponder in WinFrog to determine the actual location of the ROV. The distances from the DGPS antenna (ideally located near the center of the ship) to the bow and stern of the ship are measured and offsets are entered. This information, along with the directional hydrophone/transponder data collected by the Trackpoint system, is used to determine and display the precise location of

the ROV in relation to the ship at any given time. The estimated error of the current DGPS system is approximately 3 m. For accurate mapping of the ROV position onto both the WinFrog display and later into a geographic Information System (GIS) it is important that the datum used in the DGPS is known (the current system uses WGS 84). The latitude and longitude data from a particular dive (displayed as a track line) are exported from the WinFrog program and stored as permanent maps using ArcView GIS (ESRI, 2004).

3.2.3 Pitch and Roll Sensor

On a large vessel such as the David Starr Jordan, pitch and roll can be in the order of 20 – 30 meters in moderate seas, which means the DGPS positions also waiver by this distance, even if the ROV is traveling in a straight line. If estimates of ROV transect area are required this error needs to be removed. The pitch and roll sensor is a large gyroscope that provides data to the Trackpoint system to adjust the range and bearing to the ROV for the movement of the ship and correspondingly movement of the directional hydrophone. Like the directional hydrophone, the pitch and roll sensor needs to be correctly orientated, but in this case it is bolted onto the ship along its midline. It is important that the offsets of the hydrophone, GPS antennas and pitch and roll sensors are accurately entered into the WinFrog program.

3.2.4 Tracking and Data Processing Software- WinFrog & Ribbit

The positional information from the directional hydrophone, pitch and roll sensor data, DGPS and the ROV's flight data are all processed and displayed in the program WinFrog (Thales Geosolutions, 2004). The graphical display is used both for navigation of the ROV and to log dive data (Fig 2). For navigation the program can display both the ROV and ship sizes and positions relative not only to each other, but also to a geo-referenced background such as a bathymetry map. The display is simultaneously relayed to the bridge, allowing the helm to adjust the speed of drift of the research vessel to maintain position along a transect line. All data are saved in various file formats (see Appendix IX). The file types generated from WinFrog are .DAT, .LOG, and .RAW files. Comma delimited .DAT files are automatically created from the .RAW files, and include some of the main measurements of interest, including position, depth, and altimeter data. The .RAW files include all data collected during the dive, and can be viewed and saved in the ascii file format in the WinFrog sister program, Ribbit. WinFrog can also record text as .LOG files which allow for events of interest (such as the discovery of an abalone) to be logged manually during the dive. WinFrog has many other options that are very useful in ROV operation, including map overlays and distance calculations. There are numerous settings that must be properly adjusted prior to successful use of the program, so it is recommended that a sufficient understanding of the program be reached well before cruise time (see Appendix VIII).

3.3 The Tether

The tether secures the ROV to the boat and delivers power and commands from the console to the ROV via the junction box. It also carries images and data from the ROV, through its umbilical connection, and back up the cable to the console. To fulfill this task it contains 32 small wires bundled and sealed within plastic sheaths. Due to this complexity and the fragility of the wires, it is the weakest link of the ROV system. Tether care and management is crucial to cruise success. To maintain the integrity of the tether there should be no bends less than 2 feet in diameter, padding should be placed at any friction points, floats should be attached to the tether near the ROV, and nothing heavy should be placed onto the tether. It is also of great benefit to have a tether reel to coil and uncoil the tether. Effective on deck tether management is vital to maintaining the integrity of the tether.

Never reach the end of your tether. There are two ends of the tether, the end where the tether is attached to the boat, and the clump weight end. If the tether reaches either end, stress is placed onto the umbilical and the ROV pilot loses control of the vehicle and any extra length of tether that may be necessary to avoid problems.

3.4 Vessel and Cranes

ROV operations, even to a greater extent than most work at sea, are highly weather dependent. Surface conditions must allow the support vessel to maintain its position above the ROV, and subsurface conditions must also allow the ROV to maintain its position under the support vessel. The horse power of the ROV motors determines the speed through the water and is an important factor in whether operations are successful in the case that conditions are unfavorable. For the Phantom DS4 both surface drift and subsurface currents of less than 2.5 knots are required in order for safe and effective ROV operations to take place. The operation of the ROV is highly dependent on the vessel speed. If the vessel moves too fast across the bottom (> 1 knot) depending on the specific survey technique, it can be very difficult for the ROV pilot to keep the vehicle near the vessel, and in turn impede collection of realistic data. The skill of the helm to maintain slow speeds along a predetermined transect in variable wind and current conditions cannot be under-emphasized. For the abalone study, a ship speed across the bottom of ½ knot is ideal, although not always possible in certain conditions.

A crane is used to maneuver the ROV while it is on deck and at the surface of the water. Clear instructions and communication are needed between the vessel crew and research scientists for smooth ROV operations. The crane operator must be in excellent communication with the scientists, the ROV pilot, the clump weight tender, and the helm (Appendix VI).

3.5 Clump weight and cable counter

A 350 lb clump weight is used to minimize drag on the ROV tether cable. The weight is attached to a wire cable and lowered over the side of the vessel to a depth of 5 m. The ROV, after being flown 20-40 m away from the boat, is then joined by the tether to the wire by means of straps and carabineers. Both the tether and the wire are then lowered together and additional carabineers are attached at 10 m intervals. When lowering the weight a cable counter is used to determine the length of cable deployed. The first connection is 5 m above the clump weight and includes a protective plastic sleeve around the ROV cable, as this is the point of greatest strain. The length of “flying” tether is determined by the substrate conditions. In complex rocky terrain shorter lengths are used to minimize the chance of entanglement, while in habitat comprised of simple sandy bottoms longer lengths allow for greater freedom of movement. In strong currents longer lengths of tether may be needed to navigate down to the bottom.

Cable counter and depth sounder displays are useful to have in the laboratory, as the position of the weight should generally be maintained 10 m above the bottom. It is imperative that a weak link is established in the cable so that the vessel will not be dragged under if the clump weight snags onto the bottom.

4. Habitat Mapping and Transects

4.1 Habitat Mapping and Transects

When sampling is focused on specific habitats, bathymetric mapping prior to ROV surveys provides very useful information. Multi-beam sonar techniques are used to produce detailed contour maps of the bottom, with bathymetric relief used as a surrogate for rocky habitat type (Figure 1). Once a site has been selected the ship steams to a position up-wind from the likely habitat. The ROV is deployed to the windward side, dived to the habitat and a transect begins (Appendixes III – V). The helm then maneuvers the ship along a bearing that travels along the depth stratum and allows the ROV to maintain contact with the rocky habitat (Appendix X).

Each replicate is a strip transect of approximately 1-2 km in direct length with a field of view determined by the speed, height off the bottom, position, pitch, and roll of the ROV. The vehicle flies between 0.5- 1 m above the substrate along each transect, following the middle contour of a single depth strata. Transect tracklines of the ROV across the substrate are plotted for each dive on a map.

4.3 Data collection

A variety of data are collected by the ROV system including accurate position, speed, distance, temperature, date, and time. These data are collected and

recorded (WinFrog .DAT files) at 2-second intervals and provide the information necessary to calculate search effort.

WinFrog can also record text notes as events (pressing F10). The text notes are compiled in a log text file (.LOG) including the date, time, depth, and position of the ROV for each event recorded. The most important data events recorded, the counts of abalone on the transect, are generated in this manner by making a text note when an animal is spotted. Abalone shells and the sighting of any other abalone species are also recorded. In addition, any other pertinent information or events during the dive are recorded. For example, a text note of start transect is made once the ROV has reached operating depth and encountered rocky habitat. If traversing sand or other unsuitable abalone habitat a note of “off transect” is made and “on transect” is recorded when rocky habitat is once again encountered.

Other data collected include VHS and DVCAM video footage. The video footage is recorded continuously throughout the transect. The first data role of the video is to record metadata, generated as text on the ROV console. Another role is to record the position of the lasers fixed to the ROV. These lasers are used for measuring distances, field of view and the sizes of animals.

5. Analysis strategies

5.1 Determining transect area

The key information obtained by the ROV are counts of abalone along the transect line at each depth and the transect length and width. By determining the area of transect surveyed and averaging the number of abalone sited, a mean density, with known variation, can be produced for each depth stratum. With this information an extrapolation can be performed, using the total known area of habitat, to estimate the abalone population; hence testing the first null hypothesis (section 1.2).

Determining transect length, width, and quality with accuracy and precision involves a combination of automated and manual post-processing. The ROV trackline, data stream, and video feeds include “off-transect” components which need to be excluded from the calculation of transect area. Transects can go “off-transect” if the ROV loses the reef, needs to move long distances (>100m) between patches of reef, or is moving too fast to be searching effectively. Similarly, when the ROVs pitch changes radically, for instance to fly over an obstacle, the transect is no longer being searched for abalone and this section needs to be discarded from the area calculation. Transects can also be “off-transect” if the ROV does a complete loop and doubles over the previous path. This makes the sub-sample a pseudo-replicate and it must also be discarded from the transect.

Determining when transects are “on” or “off-transect” can be achieved in three ways: GIS analysis of the trackline over the Bathymetry layer, computer notes made on the WinFrog .LOG file by pushing the F10 button, and by post processing of the video. Of these analyses the post processing provides the most precise and accurate data for most off-transect occurrences. This is because bathymetry imaging is of a lower precision than the video footage and is not useful for pitch or speed, while there is the potential for F10 notes in the .LOG file to be forgotten by the operator during very active ROV flights.

Once those parts of the video footage that are “off transect” have been identified and excluded from analysis, the length and width of the transect can be calculated. Even when “on-transect”, the transect width is variable as the ROV dips and rises to maneuver over the substrate. Using reference lasers mounted in a fixed configuration within the video field of view, the width of these transects can be computed during post-processing. This is undertaken using Quantitative Measurement Software (QMS; Green Sky Imaging, 2004). The software can acquire and process video images based on a photo-overlap, fixed-time interval, fixed-distance interval, or randomly sampling. In the case of our abalone transects, photo-overlaps will be used, as total transect area (τ) rather than sub-samples of the transect are needed for the mean density of abalone (\bar{X}) to be determined (See section 2.1.6).

The software uses the geometry of the laser references on each overlapping video frame to determine the range to center of the image, center width of the image, area below center and the x-y scale information over the entire field of view (Figure 3). By using this data from the overlapping video images both length and width and hence transect area (τ) can be calculated (Figure 3).

The measures of the laser path over the transect need to be further adjusted to take into account the roll of the ROV and the pitch of the camera array. Even though this data is captured every two seconds (unlike the continuous collection of laser sightings by the video-photo overlaps), an extrapolating algorithm in the QMS software provides a correction, filling in the gaps between each “ping” of data.

5.2 Population estimates

To answer the primary research question of the white abalone population estimate, the following extrapolation using survey counts of abalone and areas of known habitat can be performed. This base model assumes that locations where suitable white abalone habitat exists yet are not sampled are similar in abalone density to those locations sampled. If all areas of suitable habitat are not included in the extrapolation then the population size will be an underestimate. Alternatively, if areas sampled are where the main remnants of the population

remain, then the extrapolation will be an over-estimate. Densities at sampled sites will be compared and evaluated to determine the best estimate to use for extrapolations to sites that are not sampled so that a total population estimate can be obtained.

The population estimate and variance, expressed as a confidence interval, can be determined as follows:

First, define the mean densities of abalone (\bar{X}) within each depth strata at each location,

$$\bar{X}_x = \frac{1}{N_x} \sum_{i=1}^{N_x} \left[\frac{v_i}{\tau_i} \right]$$

$$\bar{X}_y = \frac{1}{N_y} \sum_{i=1}^{N_y} \left[\frac{v_i}{\tau_i} \right]$$

$$\bar{X}_z = \frac{1}{N_z} \sum_{i=1}^{N_z} \left[\frac{v_i}{\tau_i} \right]$$

where, v = transect count of abalone
 τ = transect area m² ("effort on" transect length m x field of view in m)
 x = 30 – 40m depth strata
 y = 40 – 50m depth strata
 z = 50 – 60m depth strata
 N = Number of samples per strata

Second, determine the location population estimate (μ) as,

$$\mu = \Sigma [X_x(\phi_x), X_y(\phi_y), X_z(\phi_z)]$$

where, φ = total area of sampled location habitat, for each depth stratum (x, y, and z)

Third, calculate the 95% confidence intervals of the locations population estimates as:

$$CI = \Sigma [(\bar{X}_x \pm 1.96 (\sigma_x/\sqrt{n_x}), (\bar{X}_y \pm 1.96 (\sigma_y/\sqrt{n_y}), \bar{X}_z \pm 1.96 (\sigma_z/\sqrt{n_z})]$$

If all locations where suitable white abalone habitat exists are sampled, then the global population (μ_t), that is all members of the species, can be calculated as,

$$\mu_t = \mu_i + \mu_{ii} + \mu_{iii} \dots \mu_n$$

and the confidence we have in this estimate can be expressed in confidence intervals as,

$$CI_t = CI_i + CI_{ij} + CI_{ijk} \dots \dots \dots CI_n$$

5.3 Refinements to the base model

A major constraint of the model is the spread of sampling over all possible habitats within the global distribution of white abalone and the variability of abalone densities throughout its range. The model assumes that the population estimate is based on a representative sample. Power analysis using the current sample may provide insight into how much more sampling is necessary to achieve an estimate with a predictable error for management purposes.

6. Project Management

6.1 Timing and Logistics

The planning horizon for each ROV cruise commences 6 months ahead of the cruise with a request for ship time. Ship time is a block of NOAA resources dedicated to each facility. How the time is allocated is related to the research priorities included in the NOAA corporate plan and implemented by each facilities director of research. Ship time is also dependent on the US federal budget.

To test gear, procure spares and pack the ROV, the team needs several weeks of preparation prior to the first cruise of every sampling season. A checklist for logistics is provided in Appendix XII.

6.2 Team structure

Running a ROV program requires a team of personnel with a variety of divergent skills. Of critical importance is staff with technical experience in ROV systems. These include mechanical skills (for replacing thrusters, maintaining vacuum seals and managing the cable systems), electrical/electronic skills (for trouble shooting and repairing tether connections, running power safely and repairing the various electronic boards in the system), piloting skills (for flying the ROV to collect data) and computer skills (to integrate the ROV data producing hardware with real time computer logging of the ROVs position).

With so much expensive technical equipment to worry about the scientific aims of the project can be overshadowed. It is therefore important that other staff take ownership of the survey design, data collection, metadata logging, data back-ups, archiving and analysis. Writing of cruise reports, internal reports to NOAA

management, popular articles, and journal publications are another set of tasks where one or several team members should focus their efforts.

The bridge officers are another integral part of the team and require fine helm skills to navigate safely in the hazardous operating environment where cables and a ROV are deployed from the deck. The project also requires skilled deck crew with crane, winch and cable experience. In particular, the bosun works closely with team scientists when loading and unloading at the dock as well as during ROV deployment and retrieval.

The project also needs personnel that can “translate” between all of these various specialists as jargon and incorrect assumptions over roles and responsibilities can foil the projects objectives.

6.3 OH&S

Occupational health and safety is the responsibility of all staff, including both NOAA corps and scientists. A modern method of controlling risk is Job Safety Analysis (JSA). This involves all members of teams involved in particular tasks meeting and breaking the task into its component steps, identifying the risks involved in each step and developing safe work practices to remove these risks. JSA's are not prescriptive documents, but rather are verbal, collaborative agreements that are performed by the team for each new task and are adapted to each new experience. When a new member joins the team they are briefed in the safe work practices developed by the JSA. This briefing occurs on site immediately before the task is performed.

In JSA the use of protective gear should be a last resort. Rather, removing personnel from the area of risk is the first principle. The key is to develop safe work practices. ROV tasks, which require Job Safety Analysis (JSA), include loading and unloading vessels, Laboratory and ROV setup, ROV deployment, ROV transects and ROV recovery.

6.4 NOAA Corps and Scientists on-board communications

ROV operations require clear communications between the lab, the helm, and the deck. This allows for not only successful science, but also the avoidance of catastrophic events, such as entanglement of the propellers by the ROV tether or the snagging of the clump-weight on the bottom. Communication needs to involve both ROV personnel and ship personnel, as the rigors of the scientific technique must be consistent with safe boating and the limitations of tide, sea, swell and wind. The language of sailors and scientists is also often infused with colloquialisms and jargon adding to the potential for confusion.

The key to successful ROV operations is early and repeated briefings between the scientists, the captain, the officers, and the boson. From these briefings standard guidelines (Appendix X) can be developed so all staff are working under the same assumptions.

Smaller vessels can allow for direct verbal communication between scientists and crew during ROV flights. The complexity of communication links increase, however, with the size of the boat. Larger vessels often have various watches, so the helm rotates between a number of officers and communication between the lab, bridge and deck is often conducted via radio. On an ocean going vessel, such as the 53m R/V David Starr Jordan, radio/ships telephone communication links need to be established between the lab and the bridge, the lab and the deck scientists, the deck bosun and the bridge, the deck bosun and the crane operator, and the bridge and the engine room (to stop propeller rotation in an emergency).

An additional communication tool is to run two screens from the computer running the WinFrog program to both bridge and the lab. This allows the bridge to see what the lab sees for the location of transects and of the ROV in relation to the ship. Of added interest to the bridge is that the WinFrog view allows for an excellent visualization of the ship rate and direction of drift.

7. Discussion

As the focus of marine science moves from extraction to conservation the use of ROVs will inevitably increase. This is because conservation focused research requires that non-destructive sampling techniques be developed. As marine biologists increase their use of ROVs a prime consideration is how can ROV systems be adapted for quantitative ecology? Precisely determining search effort is the main problem of video analysis and it is in this area that the SWFC research on white abalone is establishing a robust solution.

By integrating DGPS, directional hydrophones, and pitch and roll sensors with frame analysis of the ROV path, for the first time an accurate and precise estimate of ROV search effort can be achieved. This will allow for a precise stock estimate to be produced for white abalone.

Following stock assessment the next phase of the work is to continue sampling to develop an extended time series. The time series will provide performance assessment of the recovery plan by monitoring the response of the abalone population to protection and other conservation measures, such as re-seeding. To avoid seasonal confounding of the data, or pseudo-replication, a single yearly data point should be established for each sampled location by repeating surveys at the same time each year.

As the project moves into this new phase the efficiency of the current transect length should be scrutinized. The key questions are:

1. Is the current transect length optimal for developing time series data?
2. What is the power of the current design and is it acceptable to management?

What will be the most efficient designs over the long term involves a number of considerations and may be an ideal question for modeling using computer simulations of the data already collected. Of primary importance is the biology of the white abalone. If the species is patchily distributed rather than uniformly or randomly, then a greater number of shorter transects within more detailed strata may be ideal. The power of time series to detect change is also greatly enhanced if the design moves from being randomized to including repeated measures (Bausell and Li, 2002).

These statistical considerations, however, are limited by the logistical constraints of transiting to sites, launching and retrieving the ROV, crew fatigue, and the weather. While power modeling may indicate one design optimal, cost benefit analysis and unforeseen technical difficulties may limit what can actually be achieved. The combination of modeling and cost benefit analysis is necessary to find the level of sampling necessary to detect a change in the population that can be discussed with management for future funding opportunities.

A further task that is included in the planning horizon is the establishment of a captive breeding and release program. Once again the ROV will be an invaluable tool for this project, providing dive-planning information. Due to the depth and scarcity of the white abalone distribution, divers collecting abalone will have limited dive times. The ROV will be used to conduct the search and then direct divers to the location of specimens. Following the establishment of a captive breeding program the ROV could also be used in experiments to determine the optimum size of white abalone for release back into the wild.

8. Acknowledgements

Thanks to Scott Mau and David Murfin for participating in the preparation of the logistics section, Frank M. Caimi for help with the statistics, and Benjamin Maurer and Anthony Cossio for their participation in the cruises and help with the ROV system.

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10. Tables

Table 1

Site	Year	Number of transects	Mean transect area (m ² ; ± se)	Total area surveyed (m ²)
Tanner Bank	2002	15	8,367.6 (± 1,264.2)	125,514
Cortes Bank	2003	17	10,543.5 (± 4,433.1)	52,727
San Clemente Island	2004	19	2,351.2 (± 335.3)	41,000
Tanner Bank	2004	23	5,936.2 (± 2,847.3)	68,266

11. Figures

Figure 1

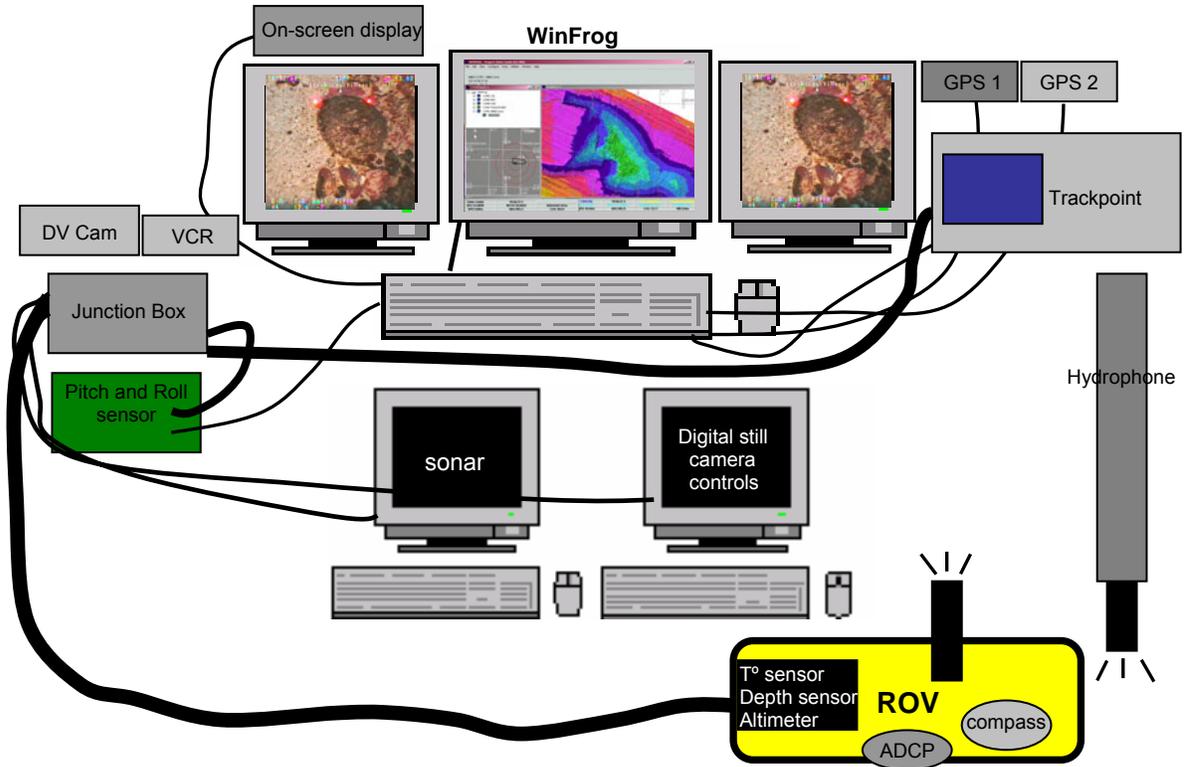


Figure 2

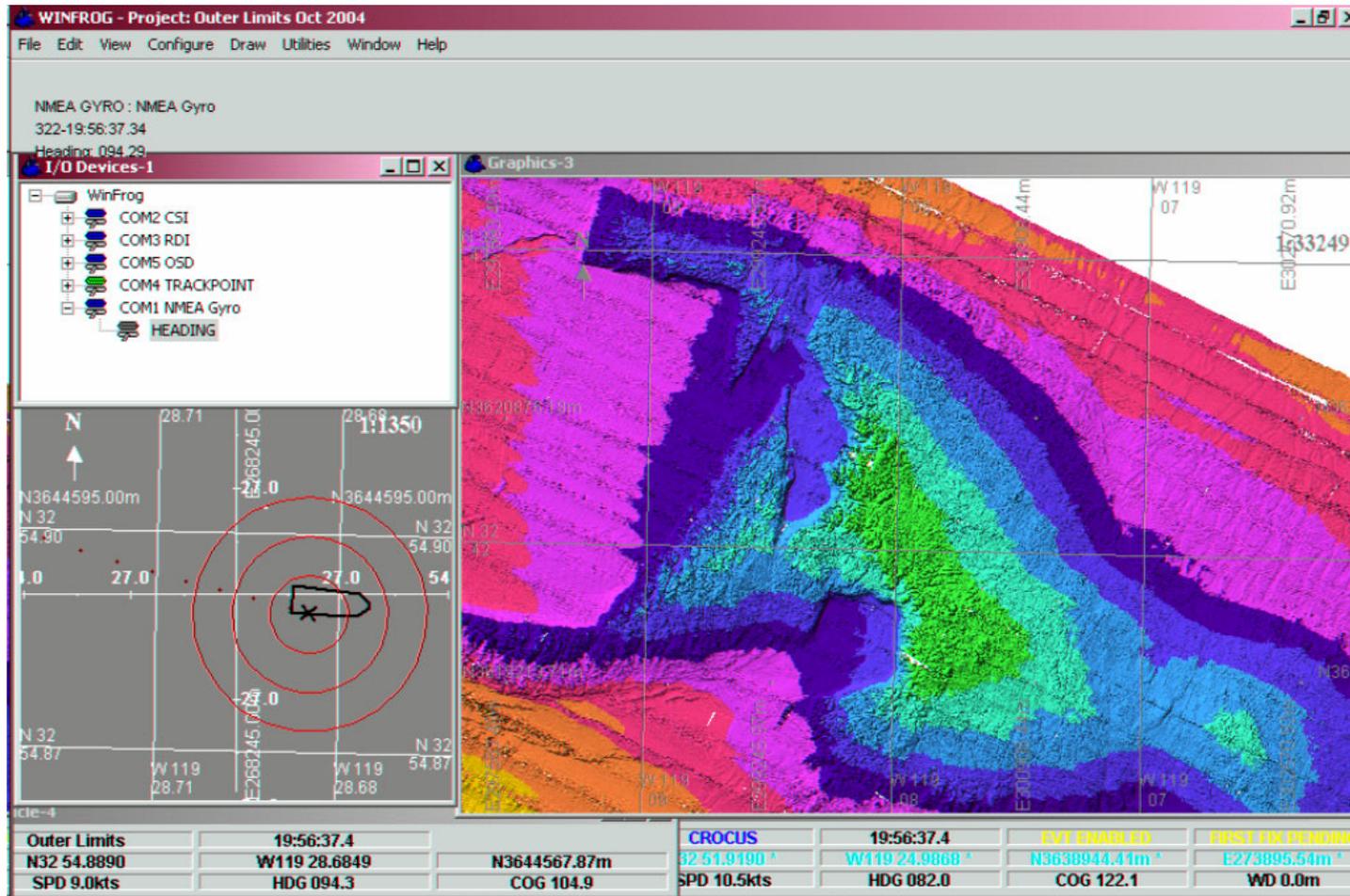


Figure 3

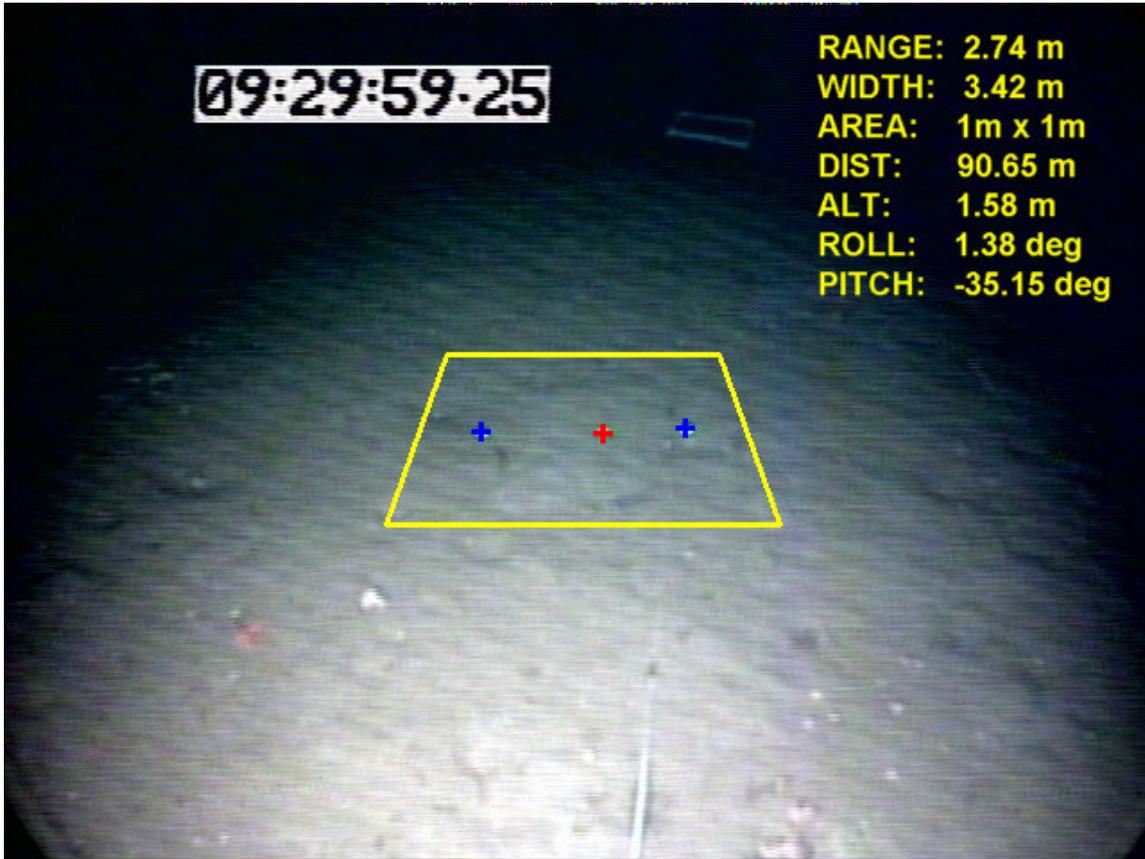
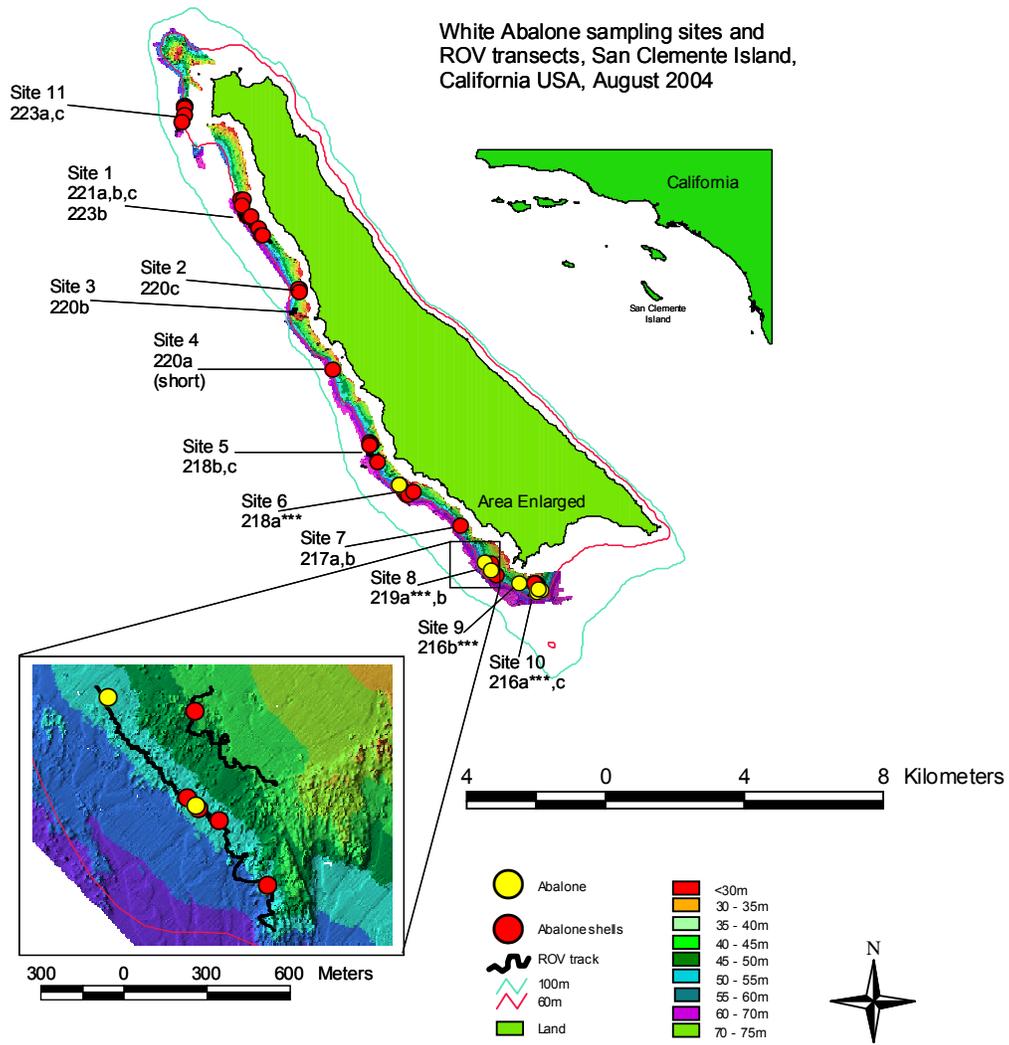


Figure 4



12. Appendixes

Appendix I- Overboard Equipment and ROV Configuration

- DOE Phantom DH2+2 Remotely Controlled Vehicle (rated to 600 m)
- Four forward/reverse 0.5 hp electrical thrusters
- Lateral 0.25 hp thruster
- Vertical 0.25 hp thruster
- CCD high definition video camera w/ 180° tilt
 - >450 lines of resolution
 - F1.8 to F2.7 lens
 - 12:1 zoom
 - Sensitivity = 7 lux (without added lighting)
- Flux-gate compass
- Altimeter sensor
- Depth sensor
- Temperature sensor
- Lights 2 250 Watt Deep Sea Lighting
- Kongsberg simrad 650m digital "Mini Red" sonar head (P/N 971-20650000)
- ORE 4330B transponder/responder
- RDI ADCP/DVL
- Five horizontal lasers
 - Class III Diode
 - 635 nm
 - 15 milliwatt
 - 300 m depth rating
 - 2 Fixed 60 cm apart, 1 wandering
 - 2 Camera mounted 10.5 cm apart

Appendix II- Onboard Equipment and Software

- #1 and #2 14" Sony display monitors PVM-14N5A/14N5E/14N5U
- DOE On Screen Display Unit
- Panasonic SVHS recorder AG-7400
- Panasonic AC adaptor AG 640
- Kongsberg simrad sonar receiver unit
- Garmin GPSmap 182
- KVH Azimuth 1000 flux gate compass
- Edgeport 8 multiport unit
- ORE Trackpoint II Plus C/DM 4410D-01
- ORE 4610 hydrophone (22-30kHz)
- Hydrophone deck cable 4110B
- ORE 4324C multibeacon charger
- DOE PCU-78 hand control unit
- ROV umbilicals
 - #1 ~ 600ft DOE (Type N 19)
 - #2 ~ 450ft DOE (Type N 19)
 - #3 ~ 2250ft DOER
- Dell laptop Inspiron 5000 computer
 - IPS tracking software
- Dell laptop Inspiron 8000 computer
 - Kongsberg Simrad MS 1000 scanning sonar processor software
- Dell laptop Inspiron 3000 computer
 - Backup

Appendix III- Work Day Start Up Check list

1. Confirm that heading, depth, and altimeter readouts are displayed on monitors.
2. Confirm that information from the on-screen display are streaming to data files by simulating a dive and checking the raw data files.
3. Check DVCam (DSR25) preferences to be sure that time stamp is in real time (Set the clock to GMT, then set time code: Menu- time code- TC1-free run- time code: make preset; h:m:s).
4. Proceed with pre-dive checkouts

Appendix IV- Pre-deployment Checks

A. Vehicle checks

- 1) Are the bridle and umbilical and rig (ties –ropes) secured on the ROV?
- 2) Are all the plugs secure?
- 3) Are there any tools or other equipment sitting on the ROV?
- 4) Does the ROV have good vacuum seals?
- 5) Turn power on – is there 240 volts?
- 6) Are the video and still cameras working (zoom, tilt, strobe)?
- 7) Are the lights working?
- 8) Are the lasers working and calibrated?
- 9) Are all four thrusters working?
- 10) Is the transponder plug moved to the on position?
- 11) Have the batteries for the strobes been changed?

B. Console Checks

- 1) Has the heads up display been checked for new date, dive id, locations, drivers?
- 2) Are new VHS and DVCam tapes in the recorders?
- 3) Have the WinFrog .DAT and .LOG files been named for the next dive?
- 4) Have the cameras dates and times been checked?
- 5) Are the WinFrog I/O devices showing green for the Trackpoint,CSI, Leica, KVH, OSD, DVL?

Appendix V- Transect Checks

A. Start Transect Checks

- 1) Activate WinFrog session (Fx button).
- 2) Mark 'Start Transect' with F10 when habitat is first encountered.
- 3) Start video and DVcam tapes recording (hold down rec. and push play).
- 4) Enter into Access log: start time (GMT) start position (Lat. Long – Deg, min, dec secs), Start depth.
- 5) Push text button to display console information for 5 seconds (also must be done every time a tape is switched).
- 6) Periodically check depth of clump weight vs. depth and maintain contact with deck to adjust when necessary.
- 7) Record all events with F10- *especially* when ROV is off transect (i.e. out of suitable habitat or driving complications) and back on transect.

B. End Transect Checks

- 1) Mark 'End Transect' with F10.
- 2) End WinFrog session (Stop button).
- 3) Stop VHS and DVcam tapes.
- 4) Turn off lasers.
- 5) Enter into Access log: stop time (GMT), stop position (Lat. Long – Degrees, minutes, decimal secs), stop depth, number of abalone spotted, notes.
- 6) Monitor clump weight depth as ROV is ascending.
- 7) Alert pilot of number of turns in cable prior to surfacing.

Appendix VI- ROV Deployment

A. Personnel

1. Minimum of 5 scientists and 2 crew members, comprised of the following:
 - S₁- Reelperson, deck communications
 - S₂- Reelperson/tether manager
 - S₃- sling/wire tender
 - S₄- ROV pilot
 - S₅- Recorder, lab communications
 - C₁- crane operator
 - C₂- clump weight tender

B. Hydrophone deployment

1. Loosen bolts securing hydrophone pole (S₁ or S₂).
2. Hydrophone lowered to vertical position on starboard side using the main winch, and hydrophone mount stays (C₂).
3. Hydrophone stays (2 forward, 2 aft) secured (S₁ and S₂).
4. Hydrophone checked for approximate 90° position (using wood block) and secured to side of boat with strap (C₂ and S₂ or S₂).
5. Hydrophone should be positioned using aft stays (C₂), and secured using forward stays (S₁ or S₂).

C. Clump weight (C₂ and S₂)

1. Clump weight (~300 lbs) deployed with CTD winch off port side 5m below the surface.
2. Tighten clamps on clump weight cable and secure one line to the cable, one line to the tether, and clip cable and tether together.
3. Lower clump weight until desired depth is reached (10m above the bottom, 15m in high relief areas), securing the cable to the tether every 5m.
4. Last umbilical tag is secured to cable in a triangular fashion when clump is 10-15m off the bottom.

D. ROV

S1 assigns tasks to S2, S3, S4 and S5

1. ROV deployed using main crane off port side. (Note: vessel should always be positioned so port side deployment of ROV is done on the windward side. This prevents the vessel from being blown down onto ROV or its umbilical).
2. Alert bridge that ROV is in the water (C₂).
3. ROV will run out to the port side of vessel, between the bow and the clump weight to its working radius (~30-40m; S₃).
- 4.
5. ROV umbilical attached to the clump weight cable (~ 5m above weight), and tether held taught.
6. ROV and clump weight lowered simultaneously with depths of both ROV and weight called out to both the CTD winch operator and the ROV pilot.

7. ROV pilot surveys the bottom while staff monitor sea floor depth (S_3), ROV depth (S_3), position of the vessel (S_3), and the clump weight depth (C_1 , C_2 , S_1 , S_2 , S_3 , S_4).

E. General notes

Launch should not be started until bridge has alerted deck and lab that screws are disengaged. Depending on conditions it may be necessary to position the boat at a given distance from the target site.

Appendix VII- ROV Recovery

S₁- Reelperson, deck communications
S₂- sling/wire tender
S₃- ROV pilot
S₄- Recorder, lab communications
C₁- crane operator
C₂- clump weight tender/bosun

S₁ assigns personnel to S₂, S₃ and S₄

1. Lab alerts deck and bridge that recovery is desired (S₄).
2. ROV pilot (S₃) tilts the cameras down and turns off the lasers and lights.
3. Captain will position surface vessel for recovery, with wind on port side, and advise the lab when recovery can begin.
4. ROV will run out to vessel's port side to a length that will allow it to surface in a safe manner (S₃).
5. Clump weight will be raised simultaneously with ROV, ~5m at a time in order to allow ROV team to detach umbilical from the cable (S₂, C₁, and C₂).
6. Deck crew (S₂) will alert pilot when ROV is visible from the surface so pilot can position his/herself on the deck for surface driving.
7. Once the final tag has been detached, clump weight will be brought aboard (S₂, C₁, and C₂).
8. ROV will then be recovered using the main crane and a recovery hook and lanyard ((S₁, S₂, S₃, C₁, and C₂).
9. Once ROV has been recovered the hydrophone stays can be released and hydrophone will then be raised and secured (see Appendix V, section B).

Appendix VIII- post dive checks

A. Vehicle breakdown

1. Secure vehicle with straps to the deck.
2. Download digital camera pictures.
3. Connect laptop to USB download whip on vehicle.
4. Click *download* button on Nikon view camera screen three times.
5. Once download complete click *download* button again until letters are black.
6. Replace camera strobe batteries with fresh set.
7. Power down.
8. De-activate transponder by moving transponder plug to the off position.
9. Clear thrusters of debris.
10. Check seal integrity.
11. Re-vacuum hull and motor canisters is necessary.
12. Rinse vehicle with fresh water.
13. If last dive of the day, do a complete system check (see Appendix III, section A).

B. Lab breakdown

1. Turn off sonar.
2. If last dive of the day, backup data files.
3. Collect radios and recharge.

Appendix VIII- Setting up the WinFrog Program.

Prior to the first dive, the WinFrog settings must be entered and/or adjusted. If a previous WinFrog project has been saved, it is best to work from the saved project and make necessary edits. To begin a completely new session requires a large number of settings to be entered, although there is a project wizard to start the process (details listed below):

I. Starting using the Project Wizard

A. Start a new project: File-'project configuration'-new project

1. Set 'General Projection' to appropriate time/date period (WG584 UTM for California)
2. Set 'Specific Projection' to appropriate lat/long zone (Zone 11 for Southern California)
4. Step through remainder of the project wizard as is required for specific project
- 5.

B. Set up graphics to be displayed

1. View- Graphics (1 for small ship window and 1 for large ship/ROV/map window); I/O Devices; Vehicle text (1 for vessel and 1 for ROV)

C. In I/O Devices window add all devices

1. specific for each set up, but for NMFS ROV use the following:
GPS- (NMEA GPS for Leica and CSI); double click to assign com and Baud rate
Gyro- KVH; double click to assign com and Baud rate
OSD- Generic; double click to assign com and Baud rate (4800)
Trackpoint- USBL; double click to assign com and Baud rate
ADCP- Speed log- RDI; double click to assign com and Baud rate

D. Edit I/O Devices

1. Right click to edit devices in the following order:
Time (dummy), depth (ROV depth), Altimeter (ROV), temperature (magnetometer signal), Roll (ROV), Pitch (ROV), and one extra dummy
2. Settings are automatically saved in C://Nav Dat/OSD_settings

E. Add Vehicles: Configure- Vehicles- add new vehicle

1. If the vessel is one that has not previously been entered, add the new vessel
2. Turn off any ships not used
3. Configure vehicle outline: outline-ship

F. Configure vehicle devices

1. Turn off Kalman filter
2. Uncheck Dead Recon

G. Add devices:

1. Enter all specifications for GPS, gyro, Trackpoint
2. Edit all devices: make CSI primary GPS and add offsets (measure from central reference point); make Leica secondary GPS and add offsets; check with ships heading and add offsets for Gyro heading if necessary; configure Trackpoint conductor 1 by adding offsets

H. Configure vehicle rings

1. Number of rings= 3; Separation= 10.0 m

I. Set up ROV (Crocus II) configurations

1. Make primary vehicle
2. Configure vehicle- Devices- add all speed log options, all OSD options, and Trackpoint beacon
3. Edit devices: Speed log/RDI= primary; Speed log heading= secondary; ROV= check Altimeter and depth of ROV as no offsets; OSD= make primary; USBL Beacon= make primary, no offsets, and accuracy 7.0 m

J. Add offsets to Trackpoint

1. F2 (system)- F2 (offsets)- F1- enter X , Y , and Z offsets of hydrophone

II. Procedures once the WinFrog primary settings are established

A. Before each dive

1. Configure- Data Events- Setup- change to 'Manual Start'- save with appropriate filename
2. File- Edit working files- choose Logs- enter appropriate filename

Appendix X- NOAA Corps and Scientist operation briefing

- The lab places a cross on the WinFrog display at the point where the transect is to start.

The bridge is to advise the lab when the ship is ready - 15 minutes of drift time away from the transect start (10 minutes for ROV deployment, plus 5 minutes for the ROV to dive to operating depth).

- One scientist, who is also the observer on the ROV console, sends and receives all lab communication between the bridge and the deck.
- The bridge navigates the ship so the wind is on the port side for deployment.
- The ideal speed of the boat over the ground for ROV transects is between 0.3-0.5 knots
- If the end of the tether is reached, from the clump weight, then the ROV begins to be towed by the boat and control is lost.
- The lab is to keep the WinFrog display on-line during deployment to assist the bridge in navigation and drift prediction. At all other times, unless necessary, the display should also be available to the helm for navigation.
- Abort the ROV launch if ROV cannot dive to the bottom and stay with the ship at the same time (usually when the drift is greater than 1-knot).
- The bridge is to advise the lab when the speed and direction of the ship needs to be changed to maintain transect depth or ship safety.
- The command “De-clutch” is to be used to stop propellers if the tether is in immediate danger of fouling the props.

Appendix XII- Mobilization logistics checklist

Shore

- Check inventory with the MS Access asset database Re-supply inventory as needed
- Check spare propeller shafts and propellers are available and right size
- Book 24-foot stake bed truck for both loading and unloading (Be mindful of cultural events, for example the gay pride parade around the 1st of August, as stake bed truck availability becomes reduced)
- Book SWFC vehicles (F150 pickup or similar) for loading and unloading.
- Book a similar truck to unload.
- Book 3 personnel to drive trucks for unloading.
- Check availability of small forklift (SWFC) and large forklift (Camp Elliot) for loading and unloading.
- Retrieve Hydrophone Pole and mounting bracket from Camp Elliot
- TB checks for all ship board staff.

Boat

- Confer with NOAA Corps to obtain support vessel specs
- Power specifications for ROV a
- DS4 requires 110 v/AC with a 30 amp breaker or
- 220 v/AC with a 15 amp breaker for main transformer power
- Peripheral equipment requires 110 v/AC of clean continual power 3-4 outlets
- DS4 operations require one davit, or A-frame for clump weight deployment and one crane, or davit for vehicle deployment. Available deck space
- Cable and wiring routings and distances
 - Clump weight weighs 300 lbs
 - Vehicle weighs ~ 320 LBS
 - Umbilical reel weighs 800+ lbs (w/cable)
- Check availability of loading cranes and crane crew for vessel
- Check available lab space. The abalone project needs approximately 3x8 desk space required for control modules
- Seating for at least two (pilot, recorder)
- Berths for all scientific crew