REVIEW OF DIVE SURVEY METHODS FOR NORTHERN ABALONE IN BRITISH COLUMBIA

Context

Northern Abalone (*Haliotis kamtschatkana*) populations have been surveyed by Fisheries and Oceans Canada (DFO) since 1978 in British Columbia (BC) using the Breen survey method (Breen and Adkins 1979); the original survey method used during the commercial fishery to assess populations at index sites. Since 2001, two new survey methods were developed: random transect (Lessard et al. 2002) and plot (Lessard et al. 2007). Each survey method was developed with different objectives, such as long-term monitoring, population distribution assessments, impact monitoring, or monitoring rebuilding efforts. All three methods produce an estimate of Northern Abalone density with associated error, but each method has trade-offs.

Defining the survey objectives is essential to determining which survey method (Breen, transect or plot) to select. Each method was designed to answer specific questions and, as such, no protocol is inherently better than the others. However, certain methods can be better suited to answer specific types of questions. Once the objectives of a survey have been defined, the most suitable survey method can be selected and a specific survey design can be implemented (i.e. selection of survey locations). This report provides an overview of each survey protocol, the strengths and weaknesses of each protocol, and discusses its application and suitability in relation to specific survey objectives.

DFO Species at Risk (SARA) program has requested guidance on the selection and use of appropriate survey methods for Northern Abalone. This information will support First Nations and other stakeholders to ensure surveys are executed consistently and in a manner such that data can be used to reliably assess population densities and monitor species recovery. Specifically, this Science Response provides information on the following objectives:

1. Describe the existing DFO Northern Abalone survey methods: Breen Survey Method (Breen and Adkins 1979), Transect Survey Method (Lessard et al. 2002, 2007) and Plot Survey Method (Lessard et al. 2007).
2. Review the strengths and weaknesses of each method, and describe the appropriate application for each method.
3. Provide guidance on the information required for developing a survey design.

This Science Response results from the Science Response process of March 11, 2016 on the Review of British Columbia Northern Abalone Survey Methods.

Background

Northern Abalone, *Haliotis kamtschatkana*, (herein referred to as ‘Abalone’) are patchily distributed along exposed or semi-exposed coastlines from northern Alaska to Baja California (McLean 1966; Geiger 1999, COSEWIC 2009). The BC Abalone fishery was closed in late 1990 to all users: First Nations, recreational and commercial. The closure was based on survey results which indicated that the Abalone population had declined by 75% (Farlinger 1990). The lack of rebuilding after the closure prompted the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to assess Northern Abalone as threatened in Canada in 1999 (COSEWIC 2000). COSEWIC re-assessed Northern Abalone status as endangered in 2009 because there was little or no recovery of the wild Abalone population (COSEWIC 2009). Abalone are listed as endangered in Schedule 1 of the Species at Risk Act (SARA).

Abalone occupy hard bottom marine habitats (boulder and/or bedrock) with moderate to high sea water exchange (Sloan and Breen 1988). Abalone mainly occur near shore in exposed or semi-exposed waters at depths less than 10 m chart datum (Breen and Adkins 1979). Given these considerations, Northern Abalone occupy a wide variety of habitats along the BC coast (Sloan and Breen 1988).

Lessard et al. (2007) provided a list of physical and biological attributes as indicators of Abalone habitat (in order of importance):

Physical factors include:

1. primary substrate comprised of bedrock and/or boulders
2. normal salinity (not low salinity as found close to river mouths)
3. generally less than 10 m datum depth
4. good water exchange (tidal current or wave action present)
5. secondary substrate: some cobble may be present but little to no gravel, sand, mud, or shell is present

Biological factors include:

1. presence of encrusting coralline algae (e.g. *Lithothamnium*)
2. presence of sea urchins (*Strongylocentrotus franciscanus, S. droebachiensis*), Red Turban Snails (*Lithopoma gibberosa*), and sea stars
3. presence of kelp: particularly *Nereocystis, Macrocystis, Pterygophora*, or Laminarian species
4. presence or absence of Abalone

Generally, adult Abalone are found on exposed substrates (i.e. out in the open) whereas juveniles inhabit cryptic habitats such as rock crevices or underneath boulders and articulated coralline algae. However, these generalizations may be shifting in response to re-establishment of Sea Otter (*Enhydra lutris*) populations along the BC coast where adult Abalone occupy cryptic habitats in regions where Sea Otters are present (Lessard et al. 2007). With the exception of surveyed sites, data is generally lacking on the distribution and abundance of Abalone throughout the BC coastline (Lessard et al. 2007).

There are three main survey methods commonly used by DFO to assess Abalone populations: Breen surveys (Breen and Adkins 1979), random transect surveys (Lessard et al. 2002), and plot surveys (Lessard et al. 2007). Each method was developed for different applications and is accompanied by unique strengths and weaknesses.

Definition of terms used in this paper

1. **Survey location**: any location where a Breen, transect, or plot is surveyed.
2. **Site**: a continuous length of shoreline along which survey locations are placed. For example, a length of shoreline less than 2 km in length (Lessard et al. 2002).

3. **Area**: an area encompasses several sites. For example, Pacific Fishery Management Area (PFMA) or subarea.
4. **Region**: five regions, or biogeographic zones, were identified for Northern Abalone in BC based on environmental, management and/or biological considerations (Fisheries and Oceans 2012). These regions include intertidal and subtidal waters surrounding the following land areas:
    a. Haida Gwaii
    b. North and Central Coasts (Cape Caution north to the Alaska border)
    c. Queen Charlotte and Johnstone Straits (Seymour Narrows near Quadra Island north to Cape Caution)
    d. Georgia Basin (San Juan Point to Seymour Narrows near Quadra Island)
    e. West Coast of Vancouver Island (San Juan Point north to the Scott Islands)
5. **Exposed Abalone**: for stock assessment purposes, are Northern Abalone that are found on the top and sides of rock, or in crevices and that can be detected by divers without turning over rocks.
6. **Cryptic Abalone**: for stock assessment purposes, are Northern Abalone that cannot be seen by divers without moving the substrate (i.e. turning over rocks).
7. **Chart datum depth**: recorded dive depth corrected to 0 m tidal height (i.e. dive depth minus tide height).

Assessment

Overview of Survey Methods

1) Breen Survey Method

The Breen survey method was developed in the late 1970s to establish index sites to monitor Abalone populations over time during the commercial fishery (Breen and Adkins 1979). Several survey locations were selected within each of several areas in the BC North Coast (Hankewich et al. 2008; Hankewich and Lessard 2008). Most surveys were conducted in northern BC where historically the bulk of BC commercial Abalone harvest occurred and Abalone were considered most abundant (Sloan and Breen 1988). Consequently, the results from surveys at index sites in northern BC have been used by DFO, and others, notably COSEWIC, to make management decisions. The survey procedure was designed to produce the most data in the shortest possible time, enabling broad survey coverage in commercially harvested areas of the north-central coast and Haida Gwaii (Breen and Adkins 1979). Periodic re-survey of these index sites every 4 to 5 years since 1978 has generated a time-series of data enabling long-term monitoring of population trends. DFO Breen survey locations were initially established in areas of commercially harvestable Abalone density and where fishing intensity was high prior to the fisheries closures in 1990. New index site surveys were initiated in other areas of the coast in the 2000’s. These recently established index locations have been randomly selected, retaining only the ones that contain Abalone habitat (Atkins and Lessard 2004, Egli and Lessard 2011). Breen survey locations each contain sixteen 1 m x 1 m quadrats (Figure 1). Sixteen surveyed quadrats were originally chosen because they generated acceptable confidence limits around the estimate of Abalone density and could be completed with reasonable diving effort (Breen and Adkins 1979). Several locations are surveyed in each Breen survey; however, the ideal number of locations is unknown. DFO index site surveys, using the Breen protocol, have between 6-12 survey locations per area. The Breen method surveys Abalone habitat only and provides density estimates for medium to high quality Abalone habitats; therefore, the density estimates cannot be extrapolated to all areas of the coast.

Breen survey projects include:

1. Estimation of density at DFO Abalone index sites
2. Mapping of Abalone distributions in an area or region
3. Quick assessments of Abalone density at a location or area

2) Random Transect Survey Method

Random transect survey methods have been used extensively in BC for stock assessment of shellfish resources (e.g. sea urchin: Leus et al. 2014, Waddell et al. 2010, sea cucumber: Duprey et al. 2011, Geoduck: Bureau et al. 2012). Random transect survey methods have also been used to assess Abalone populations across sections of coastline up to ~5 km long (Cripps and Campbell 1998). The Abalone random transect survey protocol was formalized in 2002 (Lessard et al. 2002) with the original purpose of providing un-biased estimates of Abalone density and population size in areas selected for brood stock collection, supporting stock rebuilding studies.

For each survey, several survey locations are randomly selected and transect lines are placed perpendicular to the shoreline at these positions. The primary sampling unit is a transect, made up of a variable number of secondary units: quadrats. Each transect is one meter wide and variable in length, depending on the slope of the substrate.

Transect survey projects include:

1. Estimation of Abalone density at a site or area
2. Mapping of Abalone distributions in an area or region
3. Random and unbiased population density estimation

3) Plot Survey Method

The purpose of the plot survey protocol is to intensively survey a small defined area of Abalone habitat to monitor population trends over time. Periodic re-surveying is therefore required. The plot survey method focuses greater survey effort over a small area (e.g. 40 m wide). As a result, this method may produce more precise estimates of Abalone density, but these estimates are applicable to the area of the surveyed plots only. Survey methods that yield more precise estimates can be favourable when monitoring populations over long time frames, or when studying the effects of rebuilding efforts or environmental impacts, particularly if changes in population densities are expected to be small.

The plot survey is based on a stratified random sampling design. Two permanent reference lines are placed in the middle of the two depth zones (0-5 m and 5-10 m) that are to be sampled (i.e. two strata in a stratified random sampling design). Perpendicular to each of the reference lines, 1 m wide transects are surveyed, alternating on either side of the reference lines to minimize disturbance. Ten transects are surveyed in the shallow depth zone and eight in the deep zone.

Plot survey projects include:

1. The comparison of Abalone densities between an impacted site and a control site before and after a potential disturbance (Before-After Control-Impact survey design-BACI design)

2. Long-term monitoring projects that track population fluctuations over time or population level responses to other factors such as climate change or sea otters
3. Projects that investigate the effectiveness of enhancement efforts (e.g. wild stock aggregations or installation of artificial habitat structures) on Abalone abundance and juvenile recruitment

Guidance on Selection of Survey Type

General applications for each survey method can be identified based on the objective of the project:

1. Is the objective of the project to rapidly determine relative density and/or population estimates for a large area?
    a. Yes: Breen Survey Method
    b. No: Continue to step 2
2. Is the objective of the project to unbiased density for a site or area?
    a. Yes: Random Transect Survey Method
    b. No: Continue to step 3
3. Is the objective of the project to monitor change over time at specific locations, to monitor potentially impacted sites, or study population re-building efforts?
    a. Yes: Plot Survey Method
    b. No: May have to consider alternative methods not described in this document

Survey Methods and Design

The three published protocols to survey Abalone in BC all use a 1 m^2 (1 m x 1 m) quadrat as the basic (secondary) sampling unit. The sampling that takes place within each quadrat is virtually identical between protocols. The protocols differ in the number and arrangement of these quadrats at a given survey location (e.g. straight lines for transects vs. a grid pattern for Breen surveys) and in the selection process for survey locations.

Although most Abalone can be measured in place, others must be removed from the substrate to enable proper measurement of shell length. In these circumstances, it is extremely important to detach Abalone gently and to avoid prying or twisting individuals (Abalone shells and tissues are fragile and easy to damage). The use of a knife or bar to pry Abalone off is prohibited under SARA, as this is likely to cause shell breakage and injury to the Abalone, possibly causing mortality. To safely detach Abalone, divers use legs of the Sunflower Star (*Pycnopodia helianthoides*), a predator of Northern Abalone, to induce an escape response. This is accomplished by placing a Sunflower Star leg over top of an Abalone, or tickling the epipodium of the Abalone with a Sunflower Star, which usually causes Abalone to detach and 'flee'. This enables divers to easily pick an individual up for measurement. Sunflower Stars are commonly found in Abalone habitats. Any Abalone that cannot be safely detached should be left, measured in place if possible or just counted, with a comment stating that shell length could not be measured. Care must be taken to ensure the maximum shell length is measured on each Abalone and all individuals are returned right side up on rocks outside the quadrat. Algae are not to be cut or removed from quadrats to minimize habitat disturbance.

Breen Survey Methodology

Breen Placement

A Breen survey consists of several survey locations - the ideal number of survey locations is unknown. DFO index site surveys using the Breen protocol cover several areas, each of which has between 6-12 survey locations (Hankewich et al. 2008; Hankewich and Lessard 2008). In the North and Central Coast and east Haida Gwaii regions, DFO Breen survey locations were initially selected because they supported strong Abalone populations which were deemed harvestable. In recent surveys, there has been an effort to increase the number of locations surveyed in areas with few (i.e. 4-7) locations. Since little information is available on Abalone abundance and distribution on the south coast, in these areas, DFO index site survey locations were initially randomly selected and only locations that contained Abalone habitat were repeated in subsequent surveys (Atkins and Lessard 2004, Egli and Lessard 2011). Since one of the main threats to Abalone recovery is poaching, DFO index site survey locations are not disclosed. For new Breen surveys, the locations should be randomly selected. If the survey is repeated at a later time, locations where Abalone habitat was found can be surveyed again and/or new random locations can be selected to expand the survey.

The Breen survey method consists of surveying Abalone in sixteen 1 m x 1 m quadrats positioned in a grid pattern that covers an area 16 m long x 7 m wide. The 16 quadrats are arranged in four transects, each 4 m apart. Each of the four quadrats within a transect, are 1 m apart (Fig. 1).

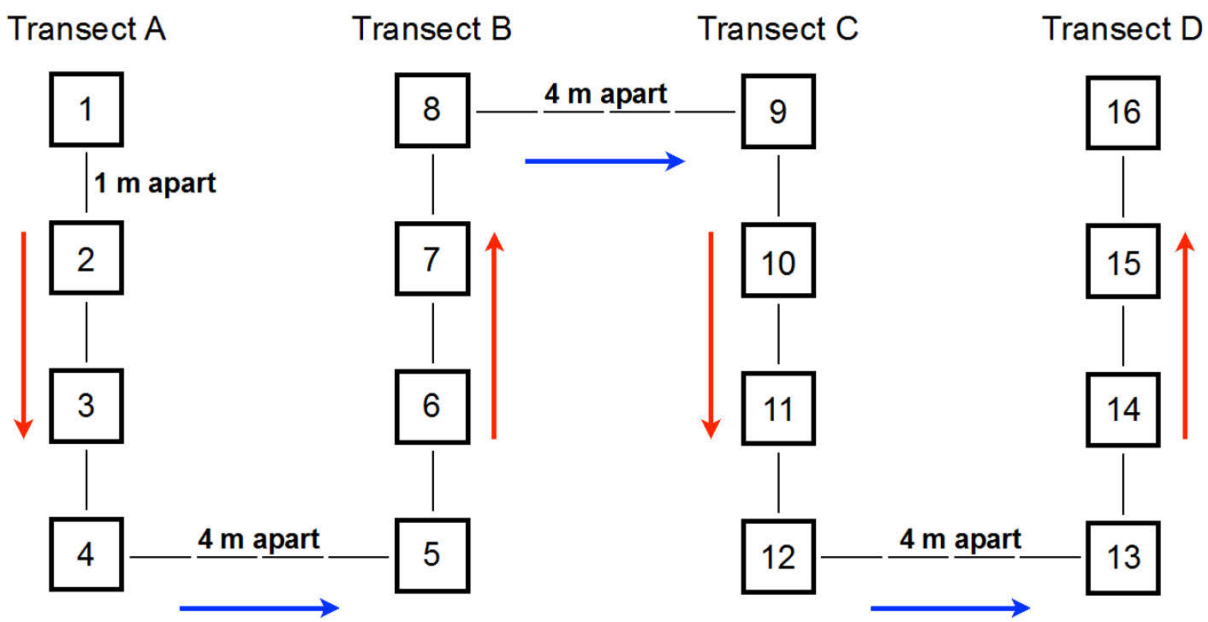

Figure 1. Breen survey location design consisting of 16 1 m x 1 m quadrats. Survey locations are surveyed as 4 transects (A-D) each spaced 4 m apart. Each transect consists of 4 quadrats that are spaced 1 m apart. The shallow part of the survey location is represented at the top of the diagram and the deep end at the bottom.

The Breen survey protocol requires a two-person dive team working together. Generally, one diver records data and the other diver places the quadrat and measures and counts animals, indicating numbers to the data recorder.

Survey Equipment

1. 1 m x 1 m quadrat
2. Dive calipers for measuring Abalone shell length to the nearest mm
3. Clipboard with pencil and underwater data sheets

Survey Protocol

1. For each survey location, record: date, divers, dive times (start and end) and latitude and longitude.
2. Start the first quadrat at the shallow limit of Abalone habitat. If possible, depending on surge and/or tide height, the first quadrat is placed just below where intertidal *Fucus* and/or mussels and/or barnacles end. If surge or tide height make this impossible, then the shallowest safe point should be chosen.
3. Transects are oriented perpendicular to shore, up and down the slope. If no slope can be determined, the transect bearing should run perpendicular to the shoreline. Measure spacing between quadrats or transects by flipping the survey quadrat along the transect bearing (flip twice between quadrats, and flip 5 times between transects). The arrows in Figure 1 indicate the survey pattern to follow, showing quadrats in numerical order 1-16. Compass bearings should be referenced regularly to ensure consistency in transect direction and proper grid formation.
4. For each quadrat, record the following on the *Breen Survey Data Sheet* (Appendix A. Table A2):
   a. Carefully count and remove sea urchins by species (red, green and purple).
   b. Measure the shell length of each visible Abalone in place underwater with calipers. Use a *Pycnopodia* (as described above) to elicit an escape response if necessary. If cryptic Abalone are surveyed, note cryptic individuals by recording a ‘c’ after the corresponding shell length measurement. If an Abalone is seen but cannot be measured, add “+1 count” in the measurements section of the data sheet.
   c. If cryptic Abalone are to be counted and measured, survey every second quadrat for cryptic Abalone for the first 8 quadrats. That is, quadrats 2, 4, 6, and 8 would be cryptically surveyed. Surveying quadrats for cryptic Abalone should be the last task, i.e., the quadrat needs to be examined for exposed (i.e. ‘normal’ survey) Abalone, recording all other data first before turning rocks. The cryptic survey is accomplished by gently turning over moveable boulders and cobbles taking care to not damage substrate or organisms. Identify all cryptic Abalone with a ‘c’ after that Abalone measurement. Once finished carefully replace all moved substrate to original location within quadrats. Quadrats surveyed for cryptic Abalone should be identified on the data sheet.
   d. Additionally record: (1) depth, (2) time, (3) up to 3 substrate types (Appendix A. Table A1) in order of abundance, (4) number of Abalone predators (Sunflower Stars, Dungeness and Red Rock crabs, octopus, etc.), and (5) percent cover and dominant species of algae (see below).
   e. Record the percent cover of all algae combined by category:
      i. Canopy: tall shading surface reaching algae, (i.e. *Nereocystis* and *Macrocystis*);
      ii. Understory: species ranging from 30 cm to 2 m in length (e.g. *Laminaria*);

   iii. Turf: small foliose and branched species 0 cm – 30 cm in length (e.g. articulated corallines, *Porphyra*);

   iv. Encrusting: species which form a thin crust on rocks (e.g. *Lithothamnium*).

 f. Record the dominant two algae species, to species level, for canopy and understory algae. Use general codes to record turf algae (Appendix A. Table A2). Record only percent cover for encrusting algae. Record percent cover for each category considering all the algae in that category as a whole (***not*** as percent cover for each species within that category).

5. Complete survey of all 16 quadrats regardless of Abalone presence.
6. Fill out dive logs for each dive.
7. Enter and verify all the field data daily.

Data Analysis

Each Breen survey location is considered one sample unit.

Data from each survey are used to calculate a mean and variance estimate of Abalone density. The mean Abalone density, d_B, for a survey is calculated as:

$$d_B = \frac{\sum_{i=1}^{n} d_i}{n} \tag{1}$$

where n is the number of Breen survey locations and

d_i is the density of Abalone at location i (for each location d_i = total count/16)

The standard deviation, sd_B, and standard error, se_B, of the mean density estimate are calculated as:

$$sd_B = \sqrt{\frac{\sum_{i=1}^{n}(d_i - d_B)^2}{n-1}} \tag{2}$$

$$se_B = \frac{sd_B}{\sqrt{n}} \tag{3}$$

where n is the number of Breen survey locations

d_i is the density of Abalone at location i

d_B is the mean Abalone density for the survey.

Transect Survey Methodology

In transect surveys, quadrats are sampled along a line, perpendicular to shore, from 10m chart datum depth to the shallowest workable depth. Location of transect survey positions within a site or area are selected randomly. Once a site or area is selected for survey, the first step is to determine the amount of coastline (potential Abalone habitat) that is to be surveyed. Examples include areas of coastline not previously surveyed where little is known about local Abalone populations or areas of conservation concern (Lessard et al. 2007). Lessard et al. (2007) recommended at least ten transects should be surveyed in each Abalone habitat site. For the purpose of pre-broodstock collection surveys, Lessard et al. (2002) recommended site width between 500m and 1500m. If the width of the site is less than 300m, a fewer amount of transects may be considered (Lessard et al 2007).

If coastline length to be surveyed exceeds 1500 m, it is recommended that the number of randomly placed transects to survey should equal the shoreline length (in m) divided by 150 (i.e., one transect for 150m of shoreline). The ratio of number of transects to coastline length to be used for surveying Abalone at sites or areas greater than 1500m long has not been evaluated. These transect / length of coastline ratios are preliminary estimates and require further analysis. If a large area is to be surveyed, surveying a transect every 150m of shoreline may not be logistically feasible and a different ratio of number of transects to shoreline length may be needed.

The random transect survey protocol is described in both Lessard et al. (2002) and Lessard et al. (2007) for different applications. Lessard et al. (2002) describe this technique to assess areas for potential collection of Abalone broodstock. To be conservative, they applied the lower 90% confidence interval (CI) of the mean density calculation from survey data to calculate allowable numbers of Abalone to collect as broodstock. Contrastingly, Lessard et al. (2007) describe this technique to assess Abalone populations in areas subject to development proposals. In this case, an Abalone density greater than or equal to the threshold of 0.1 Abalone per m^2 or higher recommends no development in the area. Therefore, the upper 90% CI of the mean density estimate is applied for precautionary reasons. These two examples show how variants of the same protocol can be applied for different purposes.

Transect Placement

Transect locations must be randomly selected within the length of shoreline to be surveyed, for each site, prior to the survey. Based on analyses by Lessard et al. (2002) the number of transects to be surveyed per site (300 to 2000 m) is:

1. 10 transects if every quadrat is surveyed along a transect
2. 11 transects if every second quadrat is surveyed along a transect

There are several ways to randomly select transects. Geographic information system (GIS) methods are now most commonly used to select random survey locations along a section of shoreline. Various extensions for ArcGIS are designed specifically for this purpose. Another approach would be to use GIS software to assign a random position for the first transect (random start point) with other transects systematically spaced along the section of shoreline to be surveyed. If GIS software is not available, the transect positions can be selected randomly along the coastline defined as the linear distance between the two furthest points of the coastline to be surveyed, measured (in mm) on the best nautical chart for the area, as in Cripps and Campbell (1998). Transect positions are marked on nautical charts before the survey begins. Transects run perpendicular to the shoreline at these positions.

This protocol requires a two-person dive team working together. Generally, one diver records data and the other diver places the quadrat and measures and counts animals, indicating numbers to the data recorder.

Specialized Equipment Required:

1. 1 m x 1 m quadrat

2. Dive calipers for measuring Abalone length to the nearest mm
3. Clipboard with pencil and underwater data sheets
4. Transect lines
5. Weights and floats for ends of transects

Survey Protocol

1. The shoreward location of each transect is located using nautical charts or navigation software (GPS coordinates). The dive boat is positioned as close to shore as safely possible at a transect location with the bow towards shore. A dive tender then throws the transect line, weighted with a piece of lead clipped to the end, shoreward into the shallows. Transect lines are comprised of lengths of lead line marked every metre and joined by 5/16" cc-links at the ends. The boat is then reversed seaward on a heading perpendicular to shore while the transect line is deployed off the side. It is important to keep some tension on the transect line to ensure it deploys straight underwater. The transect line is deployed until the desired depth is reached according to the boat's depth sounder. The target depth is 10 m (~33 ft) corrected to chart datum so actual depths will vary based on tide height. For example, if tide height is +1.5 m when the transect line is deployed, then the target depth will be 10+1.5=11.5 m. Once the target depth is reached, a float line is clipped to the transect line and lead line is unclipped at the next set of cc links. The float line has a lead weight to sink the free end of the transect line to the bottom. Divers descend the float line and survey the transect from deep to shallow ends. If deploying transect line from the boat is not possible due to thick kelp beds or other environmental factors, then divers should deploy the transect line under water starting at the deep end and follow a compass bearing perpendicular to shore. The compass bearing must be strictly followed to avoid possible bias in the density estimate(s). Transects are sampled from 10 m chart datum all the way into the shore, or to the point where wave surge makes it too difficult to work effectively (Lessard et al. 2002). It is recommended that survey depths be limited to above 10 m chart datum to minimize time spent at depths where adult Abalone are sparse (Sloan and Breen 1988). The boat tenders must record information for each transect on a dive log sheet including latitude and longitude of both shallow and deep ends of a transect, date, divers and dive times (start and end for each transect). Recording latitude and longitude should be done while deploying the transect line.
2. The primary sampling unit is the transect. The secondary sampling unit consists of a 1 m^2 quadrat. The first quadrat is placed at 10 m datum depth, lining the quadrat up with the closest metre mark on the transect line and is kept 1 m to the left or right of the transect line to avoid the area potentially disturbed during transect line placement. All surveyed quadrats run the length of the transect line to the shallow end and every quadrat or every second quadrat is surveyed (depending on whether 10 or 11 transects are surveyed at the site).
3. For each quadrat, record the following on the *Random Transect Survey Data Sheet* (Appendix A. Table A3):
    a. Carefully count and remove sea urchins by species (red, green and purple). Algae should not be removed to minimize habitat disturbance.
    b. Measure the shell length of each visible Abalone in place underwater with calipers. Use a *Pycnopodia* (as described above) to elicit an escape response if necessary. If an Abalone is seen but cannot be measured, add "+1 count" in the measurements section of the data sheet.

c. If cryptic Abalone are to be surveyed, a subset of randomly selected quadrats (e.g. 3 quadrats) can be surveyed for cryptic Abalone in each transect. The quadrat needs to be examined for exposed (i.e. 'normal' survey) Abalone, recording all other data first before starting cryptic surveying. Surveying quadrats for cryptic Abalone should be the last task. Divers must also take great care to not disturb Abalone in upcoming quadrats. Identify all cryptic Abalone with a 'c' after that Abalone measurement. Once finished carefully replace all moved substrate to original location within quadrats. Quadrats surveyed for cryptic Abalone should be identified on the data sheet.

d. Additionally record:

   i. depth

   ii. time

   iii. up to 3 substrate types (Appendix A. Table A1)

   iv. number of Abalone predators (Sunflower Star, Dungeness and Red Rock crabs, octopus, etc.)

e. Record the percent cover of all algae combined by category:

   i. Canopy: tall shading surface reaching algae, (i.e. *Nereocystis* and *Macrocystis*)

   ii. Understory: species ranging from 30 cm to 2 m in length (e.g. *Laminaria*)

   iii. Turf: small foliose and branched species 0 cm – 30 cm in length (e.g. articulated corallines, *Porphyra*)

   iv. Encrusting: species that form a thin crust on rocks (e.g. *Lithothamnium*)

f. Record the dominant two algae species, to species level, for canopy and understorey algae. Use general codes to record turf (Appendix A. Table A3). Record only percent cover for encrusting algae. Record percent cover for each category considering all the algae in that category as a whole (not as percent cover for each species within that category).

4) It is very important to ensure that the sampling frequency used, such as collecting data on every quadrat or every second quadrat, is clearly recorded on the data sheet.

5) Fill out dive logs after each dive.

6) Enter and verify all the field data daily.

Data Analysis

Multiple transects should be surveyed within a site or area. The estimated mean density d_T (Abalone per m^2) and standard deviation sd_T for each site (or area) are calculated as:

$$d_T = \frac{\sum_{i=1}^{n} (c_i / q_i) \times L_i}{\sum_{i=1}^{n} L_i} \qquad (4)$$

$$sd_T = \sqrt{\frac{\sum_{i=1}^{n}(((c_i / q_i) \times L_i) - (d_T \times L_i))^2}{(n-1) \times L_T^2}} \quad (5)$$

$$se_T = \sqrt{1 - \frac{n}{T}} \times \frac{sd_T}{\sqrt{N}} \quad (6)$$

where n is the number of transects surveyed,

c_i is the number of Abalone counted in surveyed quadrats on transect *i*,

q_i is the number of quadrats surveyed in transect *i*,

L_i is the length of transect *i*,

L_T is the mean length of surveyed transects,

N is the total possible number of transects that can be sampled in the surveyed area and is equal to the site width.

This method accounts for the variable length of transects and for the variable proportion of quadrats surveyed along each transect. The standard error is calculated the same way as Equation 3. To estimate the mean density and standard error for a specific size group *j* (i.e. 81-120 mm SL), the value c_i is substituted with the counts of size group c_{ij} in transect *i*.

Plot Survey Methodology

Plot Location

Plot surveys are most suitable to study changes in Abalone density at a fine spatial scale (survey location). Site selection for plot surveys is not random and requires preliminary surveying to identify appropriate areas. Sites can include locations subject to a proposed development, a location with historically abundant Abalone populations, an area of cultural importance to First Nations, or a location with optimal Abalone habitat suitable for long-term research and rehabilitation efforts. Timed swims (see “Additional Considerations” section) are often used to select specific locations to establish plots.

If plots are used to monitor Abalone density in response to potential impacts (e.g. finfish aquaculture), a control site is also required (Lessard et al. 2007). However, plot surveys can also be conducted without the use of control sites to monitor long-term trends in Abalone abundance and how populations may respond to factors such as sea otters, rebuilding efforts, or climate change.

Plot Design

An Abalone survey plot is defined as an area 40 m in width along the coastline and extending from shallow to 10 m chart datum depth (Lessard et al. 2007). Stratified random sampling design is used to survey plots (Figure 2). Two reference lines are installed at 2.5 m and 7.5 m chart datum depth and run the width of the plot. Reference lines usually consist of lead line, marked every metre, which are anchored to permanent markers at each end of the plot. Reference lines are placed in the middle of the two depth zones (two strata), 0-5 m and 5-10 m, to be sampled (Lessard et al. 2007). Reference lines should be installed permanently to ensure surveying of the same habitat each time. Reference lines should be maintained so metre marks remain visible. It is also important to install permanent anchors at the ends of each reference line (e.g. concrete blocks) and to record the location of each anchor to enable relocating in subsequent years. Reference lines should follow depth contours at 2.5 m and 7.5 m chart datum depth and will not be straight lines.

Abalone are surveyed along transects within the plot. Transects are randomly placed perpendicular to reference lines and alternate above and below each reference line to minimize disturbance (Figure 2). The start location of each transect (i.e. distance along reference line where each transect begins) is randomly selected prior to the start of each survey (transects are randomly selected each time a plot is surveyed). Ten starting locations (between 1 and 40 m) are randomly selected along the shallow reference line (2.5 m) and 8 locations along the deep reference line (7.5 m) (Lessard et al. 2007). Additionally, the side of a reference line where the first transect is placed is randomly selected and subsequent transects alternate thereafter, each marked as “Start Up” or “Start Down” on the data sheet (Figure 2).

This protocol requires a two-person dive team working together. Generally, one diver records data and the other diver places the quadrat and measures and counts animals, indicating numbers to the data recorder.

Specialized Equipment Required

1. 1 m x 1 m quadrat
2. Dive calipers for measuring Abalone to the nearest mm
3. Clipboard with pencil and underwater data sheets
4. Transect lines for reference lines
5. Weights and floats for ends of transects
6. Permanent site markers to be left in the water

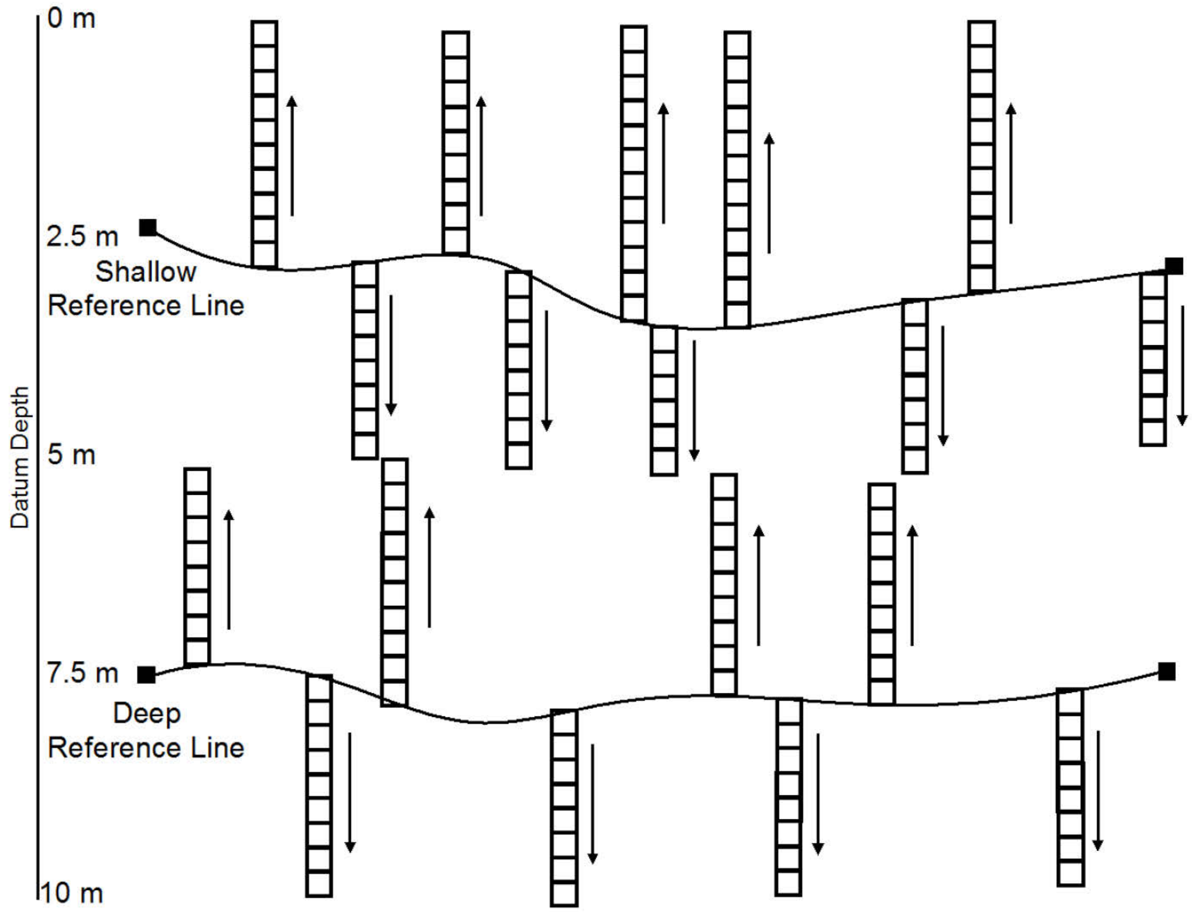

Figure 2. Plot survey design consisting of two horizontal reference lines at 2.5 m and 7.5 m datum depth. The shallow and deep reference lines each have 10 and 8 randomly selected transects respectively. Every quadrat is surveyed for each transect. Arrows indicate the direction each transect is surveyed starting at reference lines.

Survey Protocol

1. Each transect begins at the randomly chosen location on the reference line.
2. The quadrat is flipped perpendicular to the reference line until the top, or bottom, of the depth zone is reached, making sure to not overlap into adjacent zones. This means that known depths, adjusted for tide, during the expected duration of the dive have to be written on the datasheets so the divers know at which depth to stop surveying. For the deep strata, depths for the middle of the plot (5 m) as well as the deeper end (10 m) are necessary. Unlike the random transect protocol, transect lines are not used. Instead, divers flip the quadrat following a compass bearing perpendicular to the reference line.
3. For each quadrat, record the following on the *Plot Survey Data Sheet* (Appendix A. Table A4):
   a. The boat tender must record the date, location name, plot number, latitude and longitude of the plot, diver names and dive times (start and end).
   b. Carefully count and remove sea urchins by species (red, green and purple). Do not remove algae in order to minimize habitat impacts.

c. Measure the shell length of each visible Abalone in place underwater with calipers. Use a *Pycnopodia* (as described above) to elicit an escape response if necessary. If an Abalone is seen but cannot be measured, add "+1 count" in the measurements section of the data sheet.

d. If cryptic Abalone are to be surveyed, a subset of randomly selected quadrats (e.g. every 10th quadrat) can be surveyed for cryptic Abalone. The quadrat needs to be examined for exposed (i.e. 'normal' survey) Abalone, recording all other data first before turning rocks. Surveying quadrats for cryptic Abalone, i.e. turning over rocks, should be the last task on the quadrat. Divers must also take great care to not disturb Abalone in upcoming quadrats. Identify all cryptic Abalone with a 'c' after the Abalone measurement. Once finished carefully replace all moved substrate to original location within quadrats.

e. Additionally record:

   i. depth

   ii. time

   iii. up to 3 substrate types (Appendix A. Table A1)

   iv. number of Abalone predators (Sunflower Star, Dungeness and Red Rock crabs, octopus, etc.)

f. Record the percent cover of all algae combined by category:

   v. Canopy: tall shading surface reaching algae, (i.e. *Nereocystis* and *Macrocystis*)

   vi. Understory: species ranging from 30 cm to 2 m in length (e.g. *Laminaria*)

   vii. Turf: small foliose and branched species 0 cm – 30 cm in length (e.g. articulated corallines, *Porphyra*)

   viii. Encrusting: species that form a thin crust on rocks (e.g. *Lithothamnium*)

g. Record the dominant two algae species, to species level, for canopy and understorey algae. Use general codes to record turf (Appendix A. Table A2). Record only percent cover for encrusting algae. Record percent cover for each category considering all the algae in that category as a whole (not as percent cover for each species within that category).

4. Once a transect is complete, divers move to the next pre-selected transect location along the reference line and repeat the procedure until all transects have been completed (Lessard et al. 2007).
5. Fill out dive logs after each dive.
6. Enter and verify all the field data daily.

Data Analysis

For each strata, shallow and deep, the methods to calculate the mean, standard deviation and standard error for individual depth strata within a plot are identical to the formulas in the previous section for transect surveys (Equations 4-6). The estimated mean density d_P (Abalone per m^2) and standard error (se_P) for an entire plot are then calculated as:

$$d_P = \frac{(N_s \times d_s)+(N_d \times d_d)}{N_P} \quad (7)$$

$$se_P = \frac{(N_S \times se_S) + (N_d \times se_d)}{N_P} \quad (8)$$

where N_P is the total size of both strata

N_s is the size of the shallow strata

d_s is the estimated mean density in the shallow strata (using Equation 4)

N_d is the size of the deep strata

d_d is the estimated mean density in the deep strata (using Equation 4)

se_s and se_d are calculated using equation 6

Strengths and Weaknesses of Survey Methods

The following assessment of the strengths and weaknesses of each survey method are based on experts' opinions. Additional quantitative analyses are possible with existing datasets, however, these analyses are outside the scope of this document.

Each protocol was designed to answer specific questions or meet certain objectives and, as such, no protocol is inherently better than the others. Some protocols can however be better suited to answer certain types of questions. Defining the question(s) to be answered is therefore an essential step in deciding which protocol to choose for a survey.

Breen Survey Method

The Breen survey was developed to monitor Abalone population trends over time. A large number of sites have been surveyed repeatedly along the BC coast with this method. It is the method used by DFO to monitor relative differences in density between areas and track long-term population trends (i.e. decline vs. recovery). These broad-scale surveys are taken to be representative in terms of providing time-series trends of populations (Fisheries and Oceans Canada 2007). If the objective of a survey is to compare relative Abalone densities over long time periods in a large area or region, then Breen surveys would be suitable.

Strengths

Area coverage. Breen surveys require less time than Plot surveys and therefore allow for more locations to be surveyed, potentially over a broad spatial area. Consequently, density estimates may apply to larger areas. Sampling more locations can be helpful for mapping population distributions.

Logistically simple. The Breen survey method does not require the laying of transect or reference lines or floats, making them logistically more simple than the other two methods.

Weaknesses

Imprecise density estimates. If sampling locations are chosen randomly and occur across areas that incorporate a variety of habitat types, mean density estimates can be imprecise with large confidence intervals.

***Depth range surveyed not consistent*.** Breen grids have the same number of quadrats regardless of slope, therefore the depth range surveyed is dependent on the slope at the survey location and not consistent between locations. Start depth can also vary between survey locations. Surveying different depth ranges between sites makes between site comparisons difficult.

Results cannot be compared to Transect or Plot surveys. Since Breen plots are 7 m in length the largest depth range that can be surveyed is 0 to 7 m chart datum depth (on a vertical wall). In practicality Breen plots often survey a narrower depth range as few sites are perfectly vertical. The Transect and Plot protocols are defined to sample between 0 and 10 m chart datum depth. Since Abalone depth distribution is not uniform in the 0-10 m chart datum depth range (densities typically highest between 0 and 5 m) results from surveys that sample different depth ranges are not comparable.

Extrapolation difficult. Since the depth range sampled is not consistent between sites, extrapolation of density from Breen surveys to estimate total population size is difficult.

***Low repeatability*.** Divers choose the position to start the survey underwater. There is a possibility for between-diver differences in choosing the starting point, which may lead to different depth ranges being sampled at the same location between years.

Transect Survey Method

Transect surveys were initially used in the late 1990s to assess Abalone abundance and distribution over coastline lengths of up to 5-6 km. This method can provide unbiased density estimates over areas of interest since survey locations are chosen randomly. However, it is likely to provide imprecise estimates due to surveying all habitat types regardless of suitability to Abalone. Therefore, it provides mean density estimates for surveyed sections of coastline.

Strengths

Area coverage. Transect surveys are less time consuming than Plot surveys and therefore more locations can be surveyed (for a given number of field days), potentially across a broader geographical area. Consequently, population estimates may apply to larger areas than plot surveys.

Unbiased population estimates. Survey locations can be randomly selected to provide unbiased population estimates.

Covers the full depth range of Northern Abalone habitat. Transects by definition run from shallow to 10 m chart datum so the same depth range is surveyed at all locations each time. This makes data more comparable between locations or for a given location over time.

Surveying of all habitat types in a given area. Survey locations are chosen randomly so all habitat types (i.e., not only Abalone habitat) in an area are likely represented in the survey. Mean population densities will therefore apply to an entire survey area regardless of whether it's suitable habitat.

Extrapolation to determine total population size. Total population size for a survey site can be estimated by multiplying Abalone density by the size of the site defined as mean transect length multiplied by length of the site.

Weaknesses

Imprecise density estimates. Sampling locations are chosen randomly and occur across areas that incorporate a variety of habitat types. Therefore, mean density estimates can be imprecise with large confidence intervals. DFO is working on species and habitat distribution maps for the BC coast but those are not yet available. Once more precise data is available on mapping of Northern Abalone habitat distribution, surveys could be stratified to randomly sample Abalone habitat only, which may improve precision of transect surveys.

Further analyses required to determine the number of transects required for shoreline lengths greater than 2000m. Current estimates of number of transects required and spacing between transects were established for sites up to 2000 m shoreline length. The number of transects required and spacing between transects for surveying sites > 2000 m have not been evaluated.

Plot Survey Method

Plot surveys were designed with the intent of monitoring changes over time in small experimental plots or areas that may be subject to human impacts. Plots typically require periodic resurveying. This method focuses larger survey effort over small areas (in comparisons to other Abalone survey protocols) and is expected to yield higher precision and improve the ability to detect changes in density over time in response to a broad range of factors including disturbance, predator establishment or rebuilding efforts.

Strengths

Consistency in survey location. Plot surveys enable a relatively high degree of control over the effects of habitat variability and patchy distributions on Abalone because the exact same location is surveyed each time.

More precise density estimates. The same location is surveyed each time, which is expected to lower variability between surveys. Surveying is more intensive than Breen or Transect methods which is expected to increase precision around density estimates thus enabling the detection of smaller changes in density. This method can be used to study longer-term responses to management and conservation efforts such as artificial habitat installation or wild stock aggregations of adults to promote successful spawning events.

Covers the full depth range of Abalone habitat. Plots by definition run from shallow to 10 m chart datum so the same depth range is sampled at all locations each time. This makes data more comparable between locations or for a given location over time.

Weaknesses

Resource intensive. Plot surveys are time consuming (1-2 days per plot as there are 18 transects per plot to survey) and can therefore be expensive, particularly if a large number of plots are established. Generally, plots are established and resurveyed periodically and thus survey expenses are contingent on the frequency of resurveying (e.g. annually vs. every 5 years).

Limited spatial extent. Survey plots are small (40 m wide), therefore, population inference is limited to plot areas and population estimates cannot be extrapolated to larger areas.

Additional considerations

Timed Swims

Timed swims provide limited inference on actual Abalone abundance but can be a useful tool for initial scouting of habitats to target with more thorough methodologies (Lessard et al. 2002). Timed swims can provide information on presence/absence of Abalone and relative (not actual) abundances between sites.

Timed swims involve two divers swimming along a compass bearing or swimming in a ‘zigzag’ pattern within a depth zone for a predetermined amount of time (e.g. 20 minutes). Divers can record the number of Abalone observed, their relative sizes, the number of urchins (can use categories), coarse habitat characteristics (substrate, slope etc.), and dominant algal species.

The use of timed swims must be limited to a relative guide of local abundance. Density estimates cannot be derived from timed swims (Lessard et al, 2002). Appropriate applications of timed swims include circumstances where preliminary site/location information is required such as targeting optimal habitat for rebuilding projects or scouting for potential control sites with similar traits to an impacted area.

Cryptic Survey Methods

Cryptic surveying is the surveying of Abalone occupying cryptic habitats (e.g. under rocks) that would otherwise be missed if only visible Abalone were accounted for (referred to as 'exposed' Abalone in DFO literature). Whether or not to conduct cryptic surveying will depend on the specific objectives of a survey. Cryptic surveying adds considerable dive time to a survey. Campbell (1996) estimated that only 8% of adult Abalone (shell ≥ 70 mm) occupy cryptic habitats. As a result, cryptic surveying for adult Abalone may not provide vastly different density estimates. Lessard et al. (2002) suggest interpreting density estimates of exposed adult Abalone as minimum estimates to account for undetected cryptic individuals.

In contrast to adults, a greater proportion of juvenile Abalone occupy cryptic habitats (Sloan et al. 1988). Up to 33% of all Abalone < 70 mm in shell length occupy cryptic habitats (Cripps and Campbell 1998, Campbell and Cripps 1998). Projects interested in estimating density of juvenile Abalone should consider integrating cryptic surveying into survey protocols. Typically, all movable substrate (e.g. cobble and boulders small enough for divers to move) are carefully moved and examined for Abalone in a cryptic quadrat. All Abalone encountered are removed from substrate, measured and placed outside the quadrat in a safe location. Once all crevices and moveable substrate have been thoroughly examined everything is returned to the quadrat. Great care must be taken to minimize damage to habitat and avoid injury to any Abalone within, or adjacent to the quadrat being sampled.

Cryptic surveying can occur to any degree of intensity (i.e. ranging from surveying cryptic habitat in every quadrat to random selection of a subset of quadrats). Full cryptic surveying is not recommended given time requirements and the associated damage to benthic habitat and organisms from moving boulders and rocks.

Practical Considerations for Developing Survey Design

Several steps are necessary in order to develop a survey design.

1. What is the objective of the survey or what question needs answering? This should always be the first and foremost element to decide on.
2. Which survey protocol is best suited to meet the objective or answer the question?
3. Where are suitable general areas for the survey? Need to identify the general area where the survey is to take place before selecting specific survey locations.
4. Is preliminary sampling or scouting required? For some projects, preliminary sampling or scouting to identify Abalone habitat within the area of interest may be necessary.
5. Survey design considerations: Factors such as time available, manpower, budget, equipment, etc. will all affect how much work is logistically feasible. Although these factors should not be the main drivers of survey design, they should be considered to ensure the objective of the project is achievable.
6. Design the survey. Select specific survey locations following selection methods described in the survey protocols (above).
7. Plan the logistics of the survey, i.e., where, when, who, what (boats, equipment) and how (which survey protocol to follow).

8. Conduct the survey. It is important for the person in charge of the survey to keep notes of what work was done where and when, this includes (but is not limited to) recording latitude and longitude of all survey locations and keeping dive logs for all dives.
9. After the survey, ensure data is complete, entered into a database and checked for errors (outliers, missing data, etc.).

The section below provides a coarse overview of the main logistical considerations when planning an Abalone survey regardless of the protocol employed. SCUBA surveys are resource intensive (time, money, number of people, equipment, knowledge, etc.) and require divers with experience conducting scientific surveys to ensure crew safety and efficiency. A successfully executed Abalone survey requires experience operating small boats, planning and conducting scientific underwater surveys, identifying Abalone, and knowledge of the area to be surveyed. Previous survey protocols (Lessard et al. 2002, 2007) required a trained biological monitor to ensure that impact assessment and brood stock surveys were conducted by an experienced survey lead.

1. **Site/location accessibility:** locations to be surveyed will be a major determinant of the amount of work that can be completed per day. Longer boat run times to and from survey locations will reduce the amount of time spent surveying. Location may influence how often dive work can be safely conducted at a site. Locations more exposed to swell and waves, and sometimes current, will be more difficult and take longer to survey and may also restrict when some of the locations can be surveyed.
2. **Time of year:** Since Abalone are generally found in habitats exposed to waves and swell, it is not recommended to attempt surveys in winter months due to inclement weather. Ideally, Abalone surveys should be conducted between May and August to minimize adverse weather conditions. Long-term sites (i.e. sites that will be surveyed repetitively) should be surveyed consistently at the same time of year, as much as possible, to minimize the effect of seasonal variability (e.g. seasonal kelps, variation in Abalone distribution etc.). It should also be noted that periods of highest algal abundance (June-August) can reduce the ability of divers to accurately detect all Abalone.
3. **Crew experience:** Northern Abalone can be camouflaged and difficult to see, especially small individuals; a more experience dive crew will be more likely to locate and identify Abalone, and may produce data of better accuracy and quality. It is beneficial to allocate appropriate time to diver training in underwater survey techniques and protocols; to ensure date is collected properly and consistently (e.g. measuring Abalone, spotting juveniles, algae and substrate identification etc.). At a minimum, an experienced dive biologist should lead the survey.
4. **Equipment:** Boats suitable for diving are required as well as specialized survey equipment.
5. **Safety:** As with any field work, safety of crew is a prime concern. Having crew with the appropriate training, certifications and experience is essential. Refer to Worksafe BC for details of certifications required and regulations.
6. **Time requirements:** Many factors affect how much dive work can be completed in a day such as weather, location, crew experience, equipment and/or boat malfunctions or breakdowns etc. Adequate scheduling is required to allow for weather days, diver availability, and equipment trouble-shooting.
7. **Data recording:** Completed data sheets should be reviewed at the end of each day to ensure data is recorded legibly. At each survey location, dive tenders and boat operators record dive information (e.g. diver, transect, time in, time out, maximum depth) and latitude

and longitude (from a GPS); and ensure divers are completing all required data fields on data sheets (e.g. transect number, location, date, divers etc.). This information is crucial for data entry and error checks.

8. **Data entry:** Prior to data entry, all data sheets must be reviewed to check for errors and legibility, which requires qualified personnel. It is recommended that data be entered into a spreadsheet or database. Extreme care is required during data entry to avoid errors and ensure data accuracy. A key component of the impact assessment and broodstock survey training focuses on data entry (Lessard et al. 2002, 2007); to ensure that data are entered properly, are in a format that is compatible with DFO data, and can be verified and analyzed with existing tools.
9. **Data sharing:** If data is to be shared, establish who will have access to survey data prior to conducting a survey.
10. **Survey impacts:** Minimizing impact on Abalone populations and habitats is paramount during all survey work. This requires responsible dive and boat operations.
11. **Permitting:** Surveying species listed as Threatened or Endangered under the Species at Risk Act, such as Northern Abalone does not require any permitting unless there is a potential for harm, harassment, capture, or take of an individual (e.g. tagging or relocation of individuals). However, it is important to inform a local field office of the DFO Conservation and Protection Unit of any survey activities, including specific areas to be surveyed, well in advance of start dates.

Recommendations for Future Research

- Conduct quantitative analysis of Breen survey data to determine the number of Breens required to obtain an adequate level of precision in density estimates along a given length of shoreline.
- Conduct quantitative analysis of transect survey data to determine the number of transects required to obtain an adequate level of precision in density estimates.

Conclusions

This report provides an overview of three survey protocols used to assess Northern Abalone populations in BC; Breen surveys, random transect surveys and plot surveys. The use of a specific protocol will depend on the objectives of a survey. This report summarizes the strengths and weaknesses of each method, the application for each method and provides an overview of each methodology.

Breen surveys were established to assess densities of Abalone over time but have limited inference in terms of providing accurate density estimates because existing sites were not randomly chosen. Breen survey locations could be chosen randomly for future surveys.

Random transect surveys enable unbiased estimation of Abalone density at the site or area spatial scales over ‘average’ habitat conditions. This approach is suitable for determining Abalone distributions and obtaining unbiased Abalone density estimates.

Lastly, the plot survey offers the ability to focus on small, specific habitat types (e.g. optimal habitat or rebuilding sites) or locations (e.g. culturally significant or impacted areas). It is also the optimal method to monitor population trends over long time frames as the same (permanently marked) plots are sampled each time and high sampling intensity are expected to increase precision of density estimates. Plot surveys are limited to small areas (40m wide) and more constrained habitat conditions. Therefore, data may not reflect average densities within a general area and should not be interpreted to represent larger-area estimates.

Contributors

Contributor	Affiliation
Leslie Barton	DFO Science, Pacific Region
Dominique Bureau	DFO Science, Pacific Region
Joel Harding	InStream Fisheries Research
Nicholas Komick	DFO, Science, Pacific Region
Aleria Ladwig	DFO Species at Risk, Pacific Region
Joanne Lessard	DFO Science, Pacific Region
Sean MacConnachie	DFO Science, Pacific Region
Lesley MacDougall	DFO Science, Pacific Region
Tammy Norgard	DFO Science, Pacific Region
Caroline Wells	DFO Species at Risk, Pacific Region

Approved by

Carmel Lowe
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada

July 26, 2016

Sources of Information

Atkins, M. and Lessard, J. 2004. Survey of northern Abalone, *Haliotis kamtschatkana*, populations along north-west Vancouver Island, British Columbia, May 2003. Can. Manuscr. Rep. Fish. Aquat. Sci. 2690: 12 p.

Breen, P.A. and Adkins, B.E. 1979. A survey of Abalone populations on the east coast of the Queen Charlotte Islands, August 1978. Fish. Mar. Serv. Manuscr. Rep. 1490: 125 p.

Bureau, D., Hand, C.M., Hajas, W. Stock Assessment Framework for the British Columbia Geoduck Fishery, 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/121. viii + 79p

Campbell, A. 1996. An evaluation of Abalone surveys off southeast Queen Charlotte Island. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 111-131.

Campbell, A., and K. Cripps. 1998. Survey of Abalone populations at Stryker Island, Tribal Group and Simonds Group, central coast of British Columbia, May, 1997. Can. Manuscr. Rep. Fish. Aquat. Sci. 2451: 21 p.

Cripps, K., and Campbell, A. 1998. Survey of Abalone populations at Dalain Point and Higgins Pass, Central Coast of British Columbia, 1995-96. Can. MS Rep. Fish. Aquat. Sci. 2445: 31 p.

COSEWIC. 2009. COSEWIC assessment and update status report on the Northern Abalone Haliotis kamtschatkana in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 48 pp. (Accessed July 26, 2016)

Duprey, N.M.T., Hand, C.M., Lochead, J. and Hajas, W. 2011. Assessment Framework for Sea Cucumber (*Parastichopus californicus*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/105. vi + 38 p.

Egli, T. P. and Lessard, J. 2011. Survey of northern Abalone, *Haliotis kamtschatkana*, population in the Strait of Georgia, British Columbia, October 2009. Can. Manuscr. Rep. Fish. Aquat. Sci. 2955: iii + 12 p.

Fisheries and Oceans Canada. 2012. Action Plan for the Northern Abalone (*Haliotis kamtschatkana*) in Canada Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. vii + 65 pp.

Fisheries and Oceans Canada. 2007. Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Vancouver. *vi* + 31 pp.

Farlinger, S. 1990. Review of the biological basis for management of the British Columbia abalone fishery. Can. Manuscr. Rep. Aquat. Sci. 2099: 41-65.

Geiger, D.L. 1999. A total evidence cladistic analysis of the family Haliotidae (Gastropoda: Vetigastropoda). Ph.D. Thesis, University of Southern California, Los Angeles. xix + 423 pp

Hankewich, S., and Lessard, J. 2008. Resurvey of northern Abalone, *Haliotis kamtschatkana,* populations along the central coast of British Columbia, May 2006. Can. Manuscr. Rep. Fish. Aquat. Sci. 2838: vi + 41 p.

Hankewich, S., Lessard, J., and Grebeldinger, E. 2008. Resurvey of northern abalone, Haliotis kamtschatkana, populations in southeast Queen Charlotte Islands, British Columbia, May 2007. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2839: 37p.

Lessard, J., Campbell, A. and Hajas, W. 2002. Survey protocol for the removal of allowable numbers of northern Abalone *Haliotis kamtschatkana*, for use as broodstock in aquaculture in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/126: 41 p.

Lessard, J., Campbell, A., Z. Zhang. L. MacDougall, and Hankewich, S. 2007. Recovery Potential Assessment for northern Abalone, *Haliotis kamtschatkana*, in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/061: 101 p.

Leus, D., Campbell, A., Merner, E., Hajas, W.C., and Barton, L.L. 2014. Framework for Estimating Quota Options for the Red Sea Urchin (*Strongylocentrotus franciscanus*) Fishery in British Columbia Using Shoreline Length and Linear Density Estimates. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/094. vi + 68 p.

McLean, J. 1966. West American prosobranch gastropoda: Superfamilies Patellacae, Pleurotomariacea, and Fissurellacea. Ph.D., Stanford University. 255 pp.

Sloan, N.A., and Breen, P.A. 1988. Northern Abalone, *Haliotis kamtschatkana* in British Columbia: fisheries and synopsis of life history information. Can. Spec. Public. Fish. Aquat. Sci. 103: 46 p.

Waddell, B., Zhang, Z. and Perry, R.I. 2010. Stock assessment and quota options for the green sea urchin, *Strongylocentrotus droebachiensis*, fishery in British Columbia, 2010-2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/027. vi + 36 p.

Appendix

Table A1. Substrate Dive Survey Codes

Code	Substrate
1	Wood or bark
2	Bedrock, smooth
3	Bedrock with crevices
4	Boulders = Larger than basketball
5	Cobble = Fist sized to basketball
6	Gravel = 1cm to Fist sized
7	Pea Gravel = 2mm to 1cm
8	Sand <2mm
9	Mud
10	Crushed Shell, often seen as barnacle shell banks
11	Shell, whole or chunks

Table A2. Breen Survey Data Sheet

Abalone index sites survey - underwater sheet Page ____ of ____

Area: ______________________________ Site #: ______________________ Date: ______________

Measurer: ____________________ Recorder: ______________________________

Comment: ____

Quad #	Depth ft.	Time	Substrate	Abalone Shell Length (mm)	Urchin Count	Predators	Canopy	Understory	Turf	En %

Substrate codes: 1 bedrock smooth; 2 bedrock crevices; 3 boulders; 4 cobble; 5 gravel; 6 pea gravel; 7 sand; 10 crushed shell; 9 mud; 11 whole shell

General Algae codes:
EN encrusting (flat)
AC articulated coralline

Grasses (GR)
PH Phyllospadix
ZO Zostera marina

(Combine 2 codes below)
B brown
R red algae
G green algae
F foliose (leaf-like)
B branched (tree-like)
H filamentous (hair-like)

Specific algae codes:

AG Agarum sp	CF Codium fragile	GI Gigartina sp	EG Egregia
AB A cribosum	CO Costaria	IR Iridea sp	MA Macrosystis
AF A fimbriatum	CY Cymathere	LA Laminaria sp	NT Nereocystis
AL Alaria sp	DE Desmarestia sp	LB L bongardiana	PL Pleurophycus
AM A marginata	DL D ligulata	LS L saccharina	PT Pterygophora
AA A nana	DV D viridis	LT L setchellii	UL Ulva sp

*Note algae codes may vary depending on latest DFO protocols, diver abilities or desired level of detail.

Table A3. Random Transect Survey Data Sheet

Abalone Field Sheet - Transect

Page ____ of ____

Site Name: ____________________ File number: ____________________ Date: ____________________

Measurer: ____________________ Recorder: ____________________ Time in: __________ Out: __________

LAT: ____________________ LONG: ____________________ Direction (bearing in °): __________

Transect Number: __________

Quad #	Depth ft.	Time	Substrate	Abalone Shell Length (mm)	Urchin Count	Predators	Canopy	Understory	Turf	En %

Substrate Codes: 1=Bedrock Smooth, 2=Bedrock w crevices, 3=Boulders, 4=Cobble, 5=Gravel, 6=Pea Gravel, 7=Sand, 9=Mud, 0=Wood/Bark, 10=Crushed Shell, 11=Whole/Chunk Shell

General Algae codes:
Combine 2 codes below
Colour - Morphology
G…green algae
B…brown
R…red algae
B…branched
F…foliose
H…filamentous

Grasses
PH Phyllospadix
ZO Zostera
AC…Articulated Coraline
BH…Diatom Mats
BT…Beggiatoa

Green Algae
AP Acrosiphonia
CL Cladophora
Codium sp:
CF C fragile
CS C setchellii
UL Ulva

Brown Algae
Agarum sp:
AB A clathratum
AF A fimbriatum
Alaria sp:
AA A nana
AM A marginata
CP Colpomenia
CO Costaria
CG Cystoseria
CY Cymathere
DB Dictyota

Desmarestia sp:
DA D aculeata
DF D foliacea
DL D ligulata
DM D munda
DV D viridis
DY Dictyoneurum
EG Egregia
EI…Eisenia
FU Fucus
HE Hedophyllum

Laminaria sp:
LB...L bongardiana
LS…L saccharina
LT L setchelii
LY L yezoensis
LE Leathesia
LO Lessoniopsis
MA Macrocystis
NT Nereocystis
PV Pelvetiopsis
PL Pleurophycus
PT Pterygophora

SL Scytosiphon
SA Sargassum
Red Algae
CN Constantinea
CR Cryptopleura
FA Fauchea
GI…Gigartina sp
GR Gracilaria
HA Haloscaccion
IR…Iridea sp
PO Porphyra
PR Prionitis

*Note algae codes may vary depending on latest DFO protocols, diver abilities or desired level of detail.

Table A4. Plot Survey Data Sheet

Abalone Field Sheet - Plot Page ____ of ____

Site Name: ____________________ File number: ____________________ Date: ____________

Measurer: ____________ Recorder: ________________ Time in: Out: ________

LAT: ______________________________ LONG: ______________________________

Reference Line: **Shallow or Deep** Location: ____________________ Plot Number: ________

Transect start locations: to be determined randomly for each plot Start **Up or Down**

Tide height (height@time): ____

Quad #	Depth ft.	Time	Substrate	Abalone Shell Length (mm)	Urchin Count	Predators	Canopy	Understory	Turf	En %

Substrate Codes: 1=Bedrock Smooth, 2=Bedrock w crevices, 3=Boulders, 4=Cobble, 5=Gravel, 6=Pea Gravel, 7=Sand, 9=Mud, 0=Wood/Bark, 10=Crushed Shell, 11=Whole/Chunk Shell

General Algae codes:
Combine 2 codes below
Colour - Morphology
G…green algae
B…brown
R…red algae
B…branched
F…foliose
H…filamentous

Grasses
PH Phyllospadix
ZO Zostera
AC…Articulated Coraline
BH…Diatom Mats
BT…Beggiatoa

Green Algae
AP Acrosiphonia
CL Cladophora
<u>Codium sp</u>:
CF C fragile
CS C setchellii
UL Ulva

Brown Algae
<u>Agarum sp</u>:
AB A clathratum
AF A fimbriatum
<u>Alaria sp</u>:
AA A nana
AM A marginata
CP Colpomenia
CO Costaria
CG Cystoseria
CY Cymathere
DB Dictyota

<u>Desmarestia sp</u>:
DA D aculeata
DF D foliacea
DL D ligulata
DM D munda
DV D viridis
DY Dictyoneurum
EG Egregia
EI…Eisenia
FU Fucus
HE Hedophyllum

<u>Laminaria sp</u>:
LB...L bongardiana
LS…L saccharina
LT L setchelii
LY L yezoensis
LE Leathesia
LO Lessoniopsis
MA Macrocystis
NT Nereocystis
PV Pelvetiopsis
PL Pleurophycus
PT Pterygophora

SL Scytosiphon
SA Sargassum
Red Algae
CN Constantinea
CR Cryptopleura
FA Fauchea
GI…Gigartina sp
GR Gracilaria
HA Haloscaccion
IR…Iridea sp
PO Porphyra
PR Prionitis

*Note algae codes may vary depending on latest DFO protocols, diver abilities or desired level of detail.

This Report is Available from the

Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2016. Review of Dive Survey Methods for Northern Abalone in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/044.

Aussi disponible en français :

MPO. 2016. Examen des méthodes de relevés d'ormeau nordique par plongée effectués en Colombie-Britannique. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2016/044.